Final Report

India Zero Emission Transportation Program

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NEXANT INC.
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Table of Contents

Executive Summary

Vehicular emissions, particularly two-stroke two and three-wheelers, are one of the primary contributors to deteriorating ambient air quality in the major urban areas of India. There has been remarkable growth in the number of registered vehicles during the last 10 years in India. The consequences of these emissions include increased morbidity and mortality rates and dampened economic productivity. Few technologically advanced vehicles had been available for the consumer in India. The United States Agency for International Development (USAID), working with the Indian and U.S. private sector, put into place a collaborative, multi-pronged alternative transport program to address these issues.

Pursuant to prolonged discussions between USAID and prospective partners lasting over seven years, a collaborative program titled "Indian Zero Emissions Transportation" (IZET) was developed. Program partners included: Bajaj Auto Limited (BAL), New Generation Motors (NGM), Starwood Hotels/WELCOMGROUP, Archeological Survey of India (ASI), TRICON Restaurants International, and Nexant. Partners' roles and responsibilities including design and performance criteria, and the overall schedule were agreed upon during the kick-off meeting in Pune, India on February 1999. Program partners agreed to develop and undertake the following tasks to implement the IZET program:

- Increase public awareness of electric vehicle technology (EV) through various media outlets;
- Cost-share resources among all participants;
- Provide technical assistance in planning, and vehicle design and integration;
- Initiate development of a market-driven technology for EVs by accelerating the commercialization process;
- Provide commercially attractive technology options for reducing vehicular emissions in urban areas; and
- Demonstrate a technology.

Following exhaustive testing in the U.S. and at BAL's facilities in Pune, the electric three-wheeler successfully underwent certification tests for roadworthiness, which is required by the Government of India. Formal demonstration of the electric vehicle technology initially took place in Agra beginning in March 2001where electric three-wheelers are operated by the Mughal Sheraton Hotel to date for transporting guests to points of interest. This was followed by the activation of an additional electric three-wheeler in Agra at the Taj Mahal on September 2001 where ASI operates the vehicle to date, providing transportation within the compound for the elderly and physically challenged. In April 2002 additional electric three-wheelers and two-wheelers were unveiled in Delhi and are awaiting permits to operate on the streets. One electric three-wheeler will be stationed at the U.S. Embassy supporting their mail operations while the majority of the electric three-wheelers are expected to operate as flag-down taxis. The electric two-wheelers will be operated by TRICON to deliver Pizza Hut pizzas. The remaining electric two and three-wheelers will be activated in Pune where BAL's facilities are located. These vehicles will be used under a variety of conditions while allowing BAL technicians the opportunity to closely monitor vehicle performance.

By most measures IZET has been a success. USAID's contribution of catalyzing, brokering, initiating, managing, and leveraging appears to have taken hold. An integral element within

IZET, for example, was to foster the relationship between BAL and NGM to sustain IZET after USAID disengages. This role took on many shapes including: assisting with the inevitable concerns that occur in such an undertaking; facilitating a conditional grant from ICICI to assist NGM assess design changes that would reduce manufacturing costs; and, assisting with an application for additional funds through the Global Environmental Fund to offset the anticipated higher initial cost to the consumer for the electric three-wheeler. The carry-over activities of IZET extended to the Ahmedabad Electricity Corporation where technical assistance was provided in preparation of their launching a pilot EV program and earlier to the joint venture of Maini and Amerigon which became the REVA Corporation, Scooter of India Ltd., and Mahindra & Mahindra for the commercialization of their electric vehicles.

Currently, EVs specifically designed by NGM and BAL for Indian driving and environmental conditions are operating in Pune, Agra, and Delhi for approximately the past 15 months, logging in over 6,000 km. Perhaps more remarkable, the vehicles have, for the most part, performed well, exceeding the majority of the performance characteristics of conventional vehicles, without any tailpipe emissions.

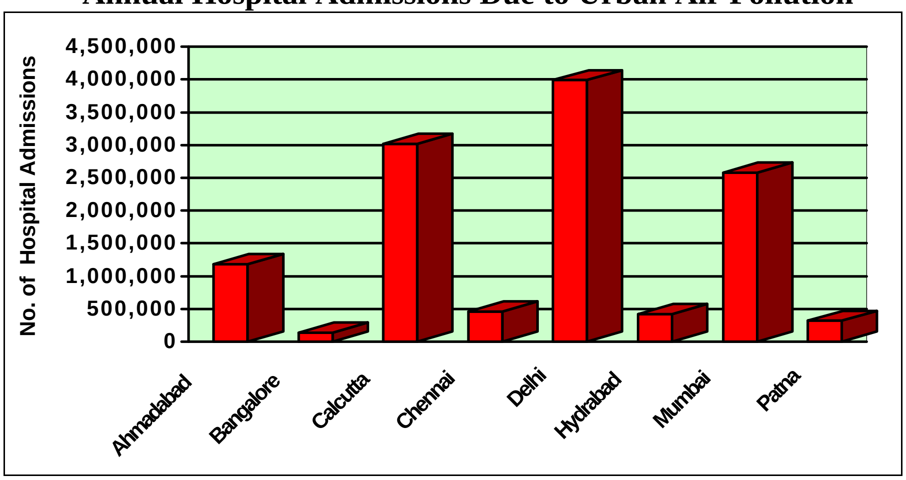
BAL and NGM are building upon this success – the two firms intend to introduce approximately 1,200 additional electric three-wheelers, incorporating the lessons learned from the initial IZET design and demonstration program. Recently the two firms signed a licensing agreement where BAL will manufacture the electric drive systems in India while NGM will provide technical assistance. The various environmental assessments performed have one item in common: under current Indian power supply conditions - there would be a net improvement in urban air quality. It is also estimated that USAID funds have, to date, been leveraged by 1:4.5. And, as the private sector continues down the commercialization path this ratio will significantly increase.

1. Introduction

Economic reforms since 1991 have provided new opportunities for business enterprises in India. India's gross domestic product has increased 2.5 times over the past two decades. An estimated 300-million middle-class consumers, with increasing disposable income, constitute one of the fastest growing markets for vehicles in the world. The top three income groups – middle, upper middle, and upper class families have also grown from 10% in 1986 to 17%. Overall vehicle population increased more than seven-fold between 1981 and 1997 from about 5 million to 38 million vehicles. Among all the vehicles, the growth in 2-wheelers (e.g., motor scooters), predominantly with two-cycle engines, has been the most dramatic, increasing by more than 10-fold between 1980 to1997. The number of 3-wheelers (e.g., autorickshaw) in the same period increased approximately six fold. In the early 1990s, 2- and 3-wheelers accounted for about 70% of all registered vehicles.

There is a price for this growth - vehicular pollution has increased eight times and pollution from industries has quadrupled. Inefficient vehicles and increasingly congested roadways are key factors in the deteriorating ambient urban air in India. Environmental regulations, until very recently, were often rendered ineffective by lax enforcement and consumers have had few options – mass transportation is inadequate and technologically advanced vehicles had not been available. Hospital admissions and deaths resulting from urban air pollution are extremely high (Fig 1).

Fig –1
Annual Hospital Admissions Due to Urban Air Pollution



Source: Financial Times, August 1, 1997

Unhealthy air is producing not only increased rates of sickness and death but also dampened economic productivity. But, unlike other countries in the region, India has a vibrant vehicle manufacturing industry that is becoming increasingly motivated to introduce alternative transport technologies.

The general driving conditions in urban India are conducive to alternative transport technology and are marked by relatively short trip distances and congested roadways creating the basis for a potential market for alternative vehicles. Travel in the three largest Indian cities accounts for 50% of total vehicle distances in the country. Average distance traveled per day within a city is

25-26 km[1], which is significantly less than 50-60 km in Western countries. Several studies also indicate the average speed in larger urban areas to be between 5-12 km per hour.[1]

USAID's Approach

USAID spearheads the U.S. Government's efforts to assist in developing strategies to tap private capital and talent to meet the growing environmental challenges of host countries. At the heart of USAID programs is the recognition that a sustainable economy requires a market-based approach. In pursuit of this strategy, USAID collaborates with the U.S. and host-country private sectors, international financial institutions, and host-country agencies to leverage resources and encourage private sector participation through financing and partnerships.

Recognizing the Economic and Environmental Needs in India. USAID's interest developed in an effort to assist India in balancing economic needs with those of the environment. The goals of mitigating urban air pollution and leveraging linkages with the private sector to remove obstacles for cleaner transport options were clear. Within this broader context, USAID's approach to India began over seven years ago, beginning with observations of the poor air quality in many urban areas and continued with identifying the main sources of urban air pollution. During this timeframe, technologies best suited for mitigating the air pollution, trends with policies, regulations, and public sentiment, and private sector resources and plans were obtained and assessed. The information obtained was challenged, screened, and updated. Although acknowledging this as a high-risk venture, electric vehicle technology emerged as a serious contender to mitigate urban air pollution.

Because USAID has limited funds and programs such as this one have long gestation periods, careful selection of private sector collaborators was required to ensure their technical and financial commitment. An outreach program began with a series of meetings with Indian vehicle manufacturers to better gauge their commitment and resources. Similarly, public opinion was weighed, government policy and regulatory actions were measured, and economic performance on a macro and micro level was assessed. At the same time the resources and interest of the U.S. electric vehicle community were gauged.

USAID/India sponsored the Indo-US Workshop on Electronic/EVs – Technology & Policy Issues in Delhi during 1995 to bring together the Indian and U.S. private and Indian public sectors by providing a forum for the free exchange of thoughts and interests. This workshop was well attended by industry and government and was widely viewed as a success in initiating serious dialogue and action into determining the feasibility of EVs. USAID/India also sponsored two publications, Electric Vehicle Investment Opportunities in India and, A Directory of the U.S. Electric Vehicle Industry. These documents were aimed at providing information to the private sectors of both countries to sustain the interest begun at the workshop and to partially respond to their requests for additional data.

Brokering. Following these activities, USAID worked closely with the several Indian vehicle manufacturers to more fully understand their views. Drawing upon this understanding, USAID

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[1] Impact of Road Transport System on Energy and Environment- an analysis of metro pollution cites of India, A Report, Ministry of Urban Development, Govt of India, 1993

developed a strategy to create more interest in the Indian vehicle manufacturers for electric vehicle technology. A series of focused one-on-one meetings with their senior and mid-level management teams was particularly effective. Selected technological assistance was also provided. For example, the lessons learned from USAID's Thailand experience were shared. Meetings to provide specific technical exchanges were arranged with U.S. organizations. Throughout this process, USAID stood fast to a basic premise - a neutral position with respect to the advantages and/or disadvantages of technologies. Each Indian firm was provided information but the conclusions they reached needed to be based upon their decision process. Through these steps, USAID was able to catalyze several Indian firms into action.

During this period of activity, a convergence of factors began to develop making the timing right for a more hands on action by USAID:

- Growing concern for urban air quality;
- Enactment of more stringent emissions regulations;
- Markets for conventional vehicles are being limited;
- Increasing middle class disposable income; and
- Indian vehicle manufacturers became committed to pursuing alternative transportation technologies.

The parameters of the specific programs to be developed, including prototype EVs, were clear: USAID would provide nominal financial assistance and /or technical assistance to the participants, and the payoff for the participating corporations might be a jump-start into the potentially sizeable alternative transportation market in India.

One company, BAL, emerged as the most committed. Following confirmation of their intentions and resources, programs were developed to:

- Increase public awareness for electric vehicle technology;
- Cost-share resources;
- Provide technical assistance;
- Initiate development of a market-driven technology for EVs;
- Provide commercially attractive technology options for reducing vehicular emissions in urban areas; and
- Demonstrate the technology.

IZET. USAID is interested in accelerating the commercialization path for electric 2- and 3-wheelers. The 2-wheeler is the fastest growing vehicle segment in India and the 3- wheeler is a widely used vehicle throughout Asia. Discussions took place between USAID and prospective partners for about one year. During this time a collaborative program was developed. Responsibilities and the overall schedule were agreed upon for the newly created IZET Program. The program partners ultimately became:

- BAL, which is India's leading manufacturer of conventional two- and three-wheeled vehicles with a large network of dealerships, was actively involved in screening electric drive systems for the Indian marketplace. BAL committed to providing substantial resources: design, testing, certification, operation, maintenance, oversight of data acquisition, and, product evaluation.

- NGM, an innovative electric drive system manufacturer and integrator in the United States, is the technology provider selected by BAL. A popular choice of solar car race teams, NGM holds patents on a highly efficient DC, brushless motor. NGM is committed to cost-share their design and production activities with USAID.

- ASI, has responsibility for managing the Taj Mahal in Agra.

- Two private sector partners are the Starwood Hotel's WELCOMGROUP which operates, among others, the Mughal Sheraton Hotel in Agra and TRICON Restaurants International (Pizza Hut) in New Delhi. During the demonstration phase of IZET, Sheraton used the electric three-wheelers and Pizza Hut will use electric two-wheelers as part of their normal operations. These firms are well managed, willing to provide resources, and committed to use the electric vehicle prototypes in real market applications.

Design Considerations. One of the objectives of IZET is to design safe and reliable electric 2 and 3- wheelers that look, operate, and feel, as much as possible, like conventional units at a production cost that is within reach of the intended markets. Another aspect is to draw upon the brand name and familiarity consumers have with BAL's products. This offered serious challenges to the BAL/NGM design team. That said and knowing the EVs will be heavier, it is encouraging to note that the EVs, with the same payload as the conventional counterparts, meet or exceed most current road performance parameters – top speed, gradeability, and acceleration. The range @ 80% depth of discharge is also greater than expected. The electric three-wheelers have been consistently averaging about 100 km per charge while the electric two-wheelers are averaging about 65 km per charge. Power consumption is in the range of <0.02 kWh/km and <0.06kWh/km for the 2 and 3- wheelers, respectively. A 48-volt system was selected to coincide with Indian safety concerns. Key considerations for the selection of the batteries were availability, cost, and performance. The batteries chosen for the initial demonstration fleet are flooded lead-acid Trojan T-105 and sealed lead-acid Hawker G16-EP for the 3 and 2- wheelers, respectively.

Cost Considerations. Two wheelers in urban areas are generally used for personal transportation. The anticipated market is viewed as being dominated by a more sophisticated consumer; one that recognizes the life cycle costs and is more concerned for the environment. Given these conditions, as long as the electric vehicle is reliable and meets performance expectations, a higher initial cost for an electric vehicle can be rationalized.

Three wheelers are primarily used as taxis and goods carriers. Operating in fleets and individual ownership, these businesses need to be profitable. Market demand for this vehicle is price elastic and operational costs need to be minimized. Since the initial cost for an electric driven 3-wheeler is expected to be more than a conventional unit, alternative marketing approaches will need to be considered such as extended warranties, financing incentives, and or subsidies. This said, the anticipated cost to the consumer for an electric 3- wheeler, without subsidies, is about $2,300 or about twice the price of a gasoline two stroke 3- wheeler, which is about $1,100. The running costs of an electric 3- wheeler are expected to yield an annual savings of about $300.

Given the trend to finance and the high interest rates in India, a simple breakeven point for the consumer is about five years.

Demonstration. Product certification tests for the electric three and two- wheelers took or are taking place at the Automotive Research Association of India in Pune, India.

IZET EVs have been operating in Pune, Delhi, and Agra for the past 15 months, logging in over 5,00 km without any significant incidents and have exceed the majority of the performance characteristics of conventional vehicles.

After thorough training the drivers traveled their customary routes. Periodic checks of the vehicles were performed to assess reliability and safety factors. During this time data was acquired, reduced, analyzed, and the lessons learned will be applied towards the next iteration of vehicles.

The following sections of this report provide the details of this public-private partnership:

- Program Coordination
- Design Of Electric Two and Three-Wheelers
- Equipment and Prototype Testing
- Outreach
- Demonstration of Prototype Vehicles
- Environmental Assessment
- Industry, Policy and Regulatory Assessment
- Economic and Financial Assessment
- Fiscal Report
- Conclusions

2. Program Coordination

The design of vehicles is a challenging effort. Made even more challenging, in the case of a collaborative effort such as IZET, by the distances and roles among the stakeholders. These differences can be broadly categorized as geographic, culture, and perspective. But, in the end, these differences were the key elements in bringing the stakeholders together and, coupled with the shared objectives, also became the basis for successful execution of the IZET program. The period of performance for this effort was November 1998 – July 2002.

Channeling differing views, strengths, and contributions into an effective resolution of issues that are inevitable in such an undertaking was accomplished through various tools including: program schedules, regularly scheduled meetings and conference calls, ad hoc meetings and conference calls and, of course, e-mail.

Key Meetings

During the initial meeting in February 1999, all partners agreed regularly scheduled meetings made up of the active partners would help to ensure the success of the IZET Program (meeting minutes are contained in Appendix 1). The composition of the members, including the programmed steering committee, would be based upon the specifics of the meeting. The timing of these meetings was tied to activities or milestones within the IZET Program. All parties also agreed there would most likely be a need for meetings during the course of IZET that were dependent upon factors that were unforeseen at the time. Additional program discussions at this meeting included: basic performance and operating characteristics of the EVs, quantity of EVs to be provided, roles and responsibilities, communication protocol including software, and overall schedule.

Key members included: USAID/India, USAID/G/ENV/EET, BAL, NGM, and Nexant.

Formal meetings were agreed upon for the following activities:

Preliminary design review
Initial testing of each electric vehicle platform
Initial assembly of each electric vehicle platform
Activation at each location

The preliminary design review was conducted in late 1999 in Pune, India. The purpose of this meeting was to review and agree upon the design concepts and the approach to integrating the two and three-wheeler platforms.

The initial testing of the electric three-wheeler took place in mid 2000 in Ashburn, Virginia. The performance tests of the initial electric vehicle were conducted and plans were finalized for the final design and integration of the remaining electric three-wheelers. Integration of the electric two-wheeler was also discussed.

The initial assembly of the electric three-wheeler was performed in Pune, India in early Fall 2000. Assembly techniques were reviewed and testing was conducted. Further discussions were held on the integration efforts of the electric two-wheeler.

Activation of the electric three-wheeler in Agra, India took place in the spring of 2001. Training was provided to the technicians and operators. The units were driven and minor issues were resolved.

The initial testing of the electric two-wheeler took place in mid 2001 in Ashburn, Virginia. The performance tests of the initial electric vehicle were conducted and plans were finalized for the final design and integration of the remaining electric two-wheelers. Commercialization steps were discussed and a course of action was determined.

The initial assembly of the electric two-wheeler took place in Pune, India in January 2002. Assembly techniques were reviewed and testing was conducted. Further discussions were held on the specific actions need for commercialization.

In addition to the prearranged meetings several meetings on specific issues were held in India and the U.S. during the course of IZET. Topics included schedules, design, component features, integration, tests, and component failures. Regularly scheduled conference calls also took place. Reports providing the details of the meeting and/or conference call were distributed. Monthly reports were also issued to USAID.

Selection of Design Firms

During the initial phase of the program, BAL had identified two US based design firms as having the state-of–the-art technology for this program. First company was NGM and the second was Unique Mobility (UQM) of Colorado. Based on BAL's recommendation USAID agreed to have two different technology partners since the program provided opportunity for both firms to market their products to BAL and India. Tenders were issued to both firms. Unfortunately, UQM chose to include in its bid an extremely high price and took exception with required contract provisions. After several months of negotiations to involve UQM on the project, Nexant was compelled to have NGM as a sole provider of electric drive system technology.

Deliverables

The following final deliverables and the submittal dates for this Task Order are:

1. Work plan	6/00
2. Performance Monitoring Plan	7/02
3. Steering Committee Reports	3/99 thru 4/02
4. Infrastructure and Economic/Financial Assessment	7/00
5. Industry, Policy, and Regulatory Assessment	12/01
6. Data Acquisition System	6/01
7. Prototype Technical Specification	8/99
8. Conventional Operational and Performance Tests	9/00 & 6/01
9. Prototype Vehicles	8/01 thru 6/02

10. Video	9/01
11. Final Report	7/02
12. Miscellaneous (Monthly, Conference Calls, etc.)	4/99 thru 4/02

3. Design Of Electric Two and Three-Wheelers

The design of each platform was carried out under the following criteria:

- Vehicles needed to perform the same or better than the conventional units
- Vehicles needed to be as reliable or better than the conventional units
- Vehicles needed to appear identical to the conventional units
- Design needed to be sensitive to production costs

Beginning with the initial meeting, in February 1999, in Pune, India among the stakeholders, USAID, BAL, NGM, and Nexant, the design parameters were established. The BAL platforms to be used were the rear engine autorickshaw and the Sapphire scooter. Subsequently, BAL changed the scooter platform to their Spirit line. Shortly after this meeting the technical specifications (Appendix 2) for the design and the verification tests were developed, vetted, and agreed upon. As is typical of this type of undertaking modifications occurred to the technical requirements improving the product but not reducing the intent of the original requirements. The first formal key design meeting occurred during the Preliminary Design Review in November 1999 in Pune. During this meeting the basic design approach, platform layout, and anticipated results were discussed and agreed upon. During the course of IZET several other meetings were held in India and the U.S. to review the status, witness performance tests, and resolve design issues and approaches. These meetings were also supplemented with regular conference calls and the exchange of data.

The current configurations of the electric two and three-wheelers are using a modified BAL Spirit and a rear engine autorickshaw chassis, respectively. The electric drive system, excluding the batteries, has been designed specifically to meet the specifications which in turn have been derived from actual Indian environmental, performance, and operating conditions.

The end products to date have functioned well. Overall, the performance is better than specified having only encountered a few problems and is a testament to the perseverance and diligence by NGM and BAL to ensure, before activation, that the vehicles can perform as intended. In particular, the electric two-wheeler has been proven to be difficult in packaging, given the limited space with the Spirit chassis. The electric three-wheelers in Agra, for example, have logged over 5,000 km and have been in testing and then in operation for approximately twelve months. The range of the electric three-wheelers is another example where actual performance far exceeds the specified distance (specification requires 70 km and actual is about 100 km per charge in urban areas). To be sure, there were lessons learned from this demonstration. The reliability and performance characteristics needed for the on-board charger seem to have been underestimated. After one re-design effort the units appear to be more reliable but the re-charge time will require additional modifications to function as needed for the intended market.

A failure analysis report identifying the issue, and remedial and corrective action to resolve the component failure is included in Appendix 3

Tables 1 and 2 provide the performance comparison of the conventional vehicles with the design requirements for the electric versions.

Table –1 Design Performance Comparison of Conventional and Electric Three-Wheelers

Item	**Conventional Rear Engine**	**Electric**
Engine/Motor Type	2-stroke, single cylinder forced air-cooled	DC brushless motor
Vehicle Weight (Kg)		
Shell Weight	276	580
Payload	334	305
Road Performance		
Top Speed (kph)	55	55
Gradeability (%) at 10 kph	16	19.3
Acceleration (sec) 0 to 20 kph 0 to 30 kph 0 to 40 kph	 6 11 16	 3.7 7.4 12.6
Range (km)	208 km (with 8 ltr fuel tank)	72@80% DOD on IDC
Fuel/Power Consumption	24+/- 4 km/ltr	<0.082 kWh/km
Battery Voltage	N/A	48 V
Tire Rolling Radius (mm)	203	203
Turning Circle Radius (mm)	2,880	2,880

Table –2 Design Performance Comparison of Conventional and Electric Two-Wheelers

Item	**Conventional ICE**	**Electric**
Engine/Motor Type	2-stroke, single cylinder forced air-cooled	DC brushless motor
Vehicle Weight (Kg)		
Shell Weight	67	144
Payload	130	75
Road Performance		
Top Speed (kph)	55	60
Gradeability (%) at 10 kph	16	34
Acceleration (sec) 0 to 20 kph 0 to 30 kph 0 to 40 kph	 3.2 6.1 10	 2 3.2 4.9
Range (km)	km (with 3.5 ltr fuel tank)	80@80% DOD
Fuel/Power Consumption	38.4 km/ltr	<0.026 kWh/km
Battery Voltage	N/A	48 V
Tire Rolling Radius (mm)	240	240
Turning Circle Radius (mm)	Not relevant for two-wheeler	

BAL and NGM plan to produce up to 1,200 electric three-wheelers incorporating the lessons learned from the initial IZET design and demonstration effort. Some of the planned changes are:

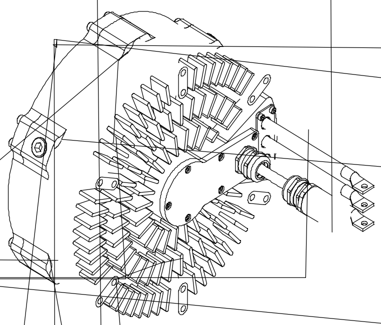
- Removable battery trays (reduces re-charge time)
- Integrate the controller with the motor (improves packaging and lowers costs)
- Radial tires (improves range)

- Use indigenous batteries (reduces cost)

The two key components in the electric drive system are the motor and controller. A brief description of each component follows.

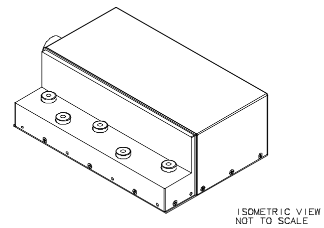
The IZET two and three-wheeler EVs use state of the art *Axial Flux* design. The motor performance, and operating characteristics were designed specifically for the IZET vehicles. The schematic of the motor is shown below in Figure-2. The motor is rugged and very efficient. Design criteria are noted in table 3.

Fig - 2
Motor Schematics



Phase Current Continuous (I_c)	A_rms	148
Peak Torque @ I_max (T_p)	Nm	58.8

The controller performance and operating characteristics for the electric two and three-wheelers were designed specifically for this application. The controller characteristics are noted below, and the specifications are described in table 4.



- Sine-wave or trapezoidal control
- Serial Interface for configuration and data acquisition
- CAN Bus interface to external interface module for maximum flexibility and reduced wiring complexity.
- State-of-Charge (SOC) tracking with programmable battery profile
- Internal 150W, 12.0-14.4V power supply available for vehicle auxiliary loads such as lights, vehicle display and cooling fans.
- Motor Current Limiting (MCL) logic provides a speed governor, limp-home mode based off of SOC, Battery charge and discharge protection and phase current limiting for efficiency.

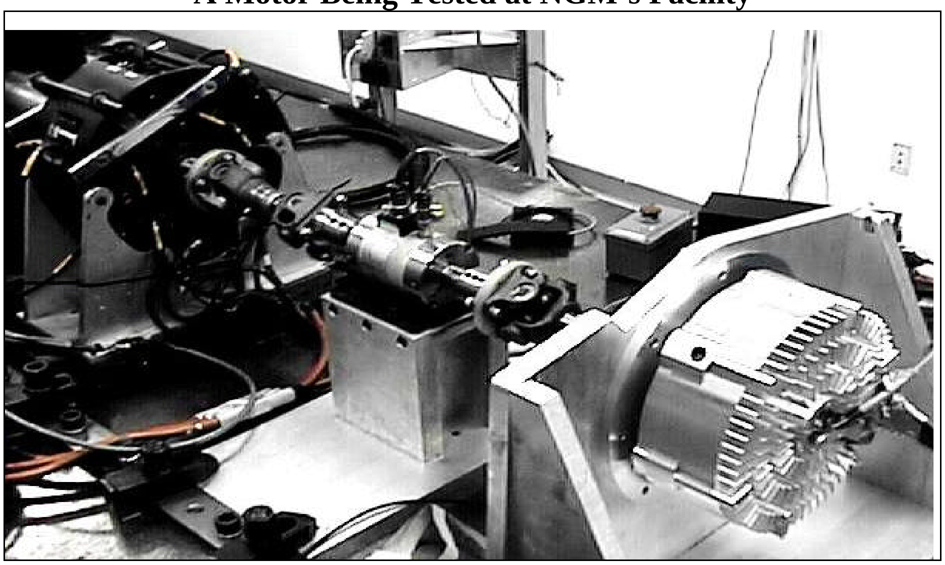
Table - 4 Controller Specifications

Peak RMS Phase Current (Amps)	265
Nominal Bus Voltage (Volts)	48
Min./Max. Operating Voltage (Volts)	36/60
Maximum Withstand Voltage (Volts)	75
Input Capacitance (uF)	15,120
Peak Efficiency %	99
Height (in.)	3.12
Width (in.)	5.95
Length (in.)	8.88
Weight (lbs.)	6

4. Equipment and Prototype Testing

The IZET program objective for the electric two and three-wheelers is to design an all electric powered scooter and autorickshaw using BAL's existing platforms that perform and operate the same or better than the conventional vehicles. Prototype vehicles were placed into monitored demonstration service with IZET partners in Delhi, Agra and Pune in India. Based on the program, electric traction drives were designed, engineered, and manufactured and integrated with a scooter and an autorickshaw. As outlined in the technical specification and agreed upon by all parties, prototype vehicles were instrumented and tested to validate performance and operational requirements and were prepared for the demonstration. The performance tests were first conducted by NGM personnel and then were witnessed by representatives from Nexant and BAL. Figure 3 shows a motor being tested at NGM's facility. The prototypes also underwent rigorous testing to meet GOI requirements before these vehicles were put on the streets.

Fig – 3
A Motor Being Tested at NGM's Facility



Two-wheeler

Performance Test

Vehicle performance evaluation tests were carried out for the prototype electric scooter, which was integrated with an electric drive system based on axial-flux, brushless DC, permanent magnet motor technology.

The results presented are based on testing that took place in April 2001 at the NGM facilities. Each set of tests was performed twice. The purpose of these tests was to evaluate the performance of the electric scooter and to verify compliance with the technical specifications set forth in the IZET Technical Specifications for two-wheelers (Appendix 2). The vehicle performance was evaluated based on the following four criteria:

- Top Speed

Top speed test of the prototype two-wheeler was carried out to determine the maximum vehicle speed that can be sustained continuously on level ground. The average top speed achieved was 60.6 km/h, as specified in the specification. The test results are given in table 5.

Table - 5 Top Speed Test Results

Distance in meters	Speed	
	Required	Achieved
40	60	60.5
100	60	60.6
200	60	60.7

- Acceleration

The purpose of this test is to determine the maximum achievable vehicle acceleration on level ground when the batteries are at 60 % State of Charge (S.O.C.) and to verify compliance with the acceleration requirements set forth in the technical specification. The prototype satisfied all the required acceleration parameters during the testing. The results from the acceleration tests are given in table 6.

Table - 6 Acceleration Tests Results

Speed (KPH)	Time (sec)		
	Req'd by Spec	NGM bench test	Witnessed
0-20	2.0	2.14	1.97
0-30	5.0	3.34	3.08
0-40	9.0	5.05	4.65
0-60	18.0	N/A	11.90

- Gradeability

This test determines the maximum vehicle speed that can be maintained on roads having different grades and to verify compliance with the gradeability requirements set forth in the technical specifications. The results of the gradeability test are summarized in the table 7 and also shown in these figures are the IZET requirements. The results clearly indicate that the prototype two-wheeler passed or exceeded the requirements set forth in the specification.

Table -7 Gradeability Test Results

Speed (KPH)	Type	Gradeability		
		IZET Reqd	NGM	Witnessed
10	Peak	19%*	30%	34%
30	Continuous	10% (continuous)	13%	15%
55	Continuous	1% (continuous)	6%	8%

* 0-10 KPH and maintain 10 KPH for 10 meters

- Range

The purpose of this test is to determine the maximum range or distance of the vehicle with one full battery charge while following repeated IDC cycles and to comply with the range requirement set forth in the technical specification. The target range of two-wheeler while driving the IDC cycle is 55 Km at 25°C as specified in the technical specification. Results from the test demonstrated the vehicle exceeded the 55 Km range requirement after 20% SOC.

Roadworthiness Test

A prototype two-wheeler is undergoing roadworthiness/certification tests at the Vehicle Research and Development Establishment (VRDE) facility and the Automotive Research Institute of India (ARAI). The results of the comprehensive tests are not yet available. However, preliminary tests indicate the prototype two–wheeler met or exceeded all but EMI (Electro-magnetic Induction) test. Both NGM and BAL are investigating the cause of EMI failure and trying to correct the problem.

Components Failure Analysis

There have not been any component failures. The electric two-wheeler units have not been activated yet. The units will not be activated until the prototype passes the certification test.

Three – wheelers

Performance Evaluation Test

Prior to activating vehicles for demonstration, the vehicles underwent performance tests as required by the technical specification. The purpose of these tests is to evaluate the performance of the vehicle, to verify its compliance with the technical specifications. The vehicle performance requirements were evaluated based on the following four criteria, (1) top speed, (2) acceleration, (3) gradeability, and (4) range. Each one of these criteria was tested independently. The tests at NGM's facility were witnessed by Nexant and BAL.

- Top Speed

The purpose of this test was to determine the maximum vehicle speed in each gear that can be sustained continuously on level ground. Table 8 presents a summary of the observed average top speed for each gear.

Table - 8 Measured Average Top Speed

Gear	Top Speed (KPH)	
	Required	Measured
2	N/A	32.2
3	N/A	43.5
4	55.0	56.5

It can be seen from Table 8 that the measured average top speed of the vehicle in 4th gear exceeds the minimum required vehicle top speed of 55kph.

- Acceleration Test

The purpose of this test was to determine the maximum achievable vehicle acceleration on level ground when the batteries at 60 % S.O.C. and to verify compliance with the acceleration requirements set forth in the IZET 3-wheeler technical specification document. Test results in table 9, indicate that the performance of the three-wheeler is acceptable.

Table - 9 Average Acceleration Time

Speed (KPH)	Average Time (sec)	
	Req'd	Measured
0 to 20	3.0	3.6
0 to 30	7.0	6.9
0 to 40	15.0	11.8
0 to 50	30.0	22.5

- Gradeability Test

The purpose of this test was to determine the maximum vehicle speed that can be maintained on roads having different grades and to verify compliance with the gradeability requirements set forth in the 3-wheeler technical specification. The results of the gradeability test are summarized in table 10.

Table - 10 Gradeability Test results

Speed (KPH)	Gear	Gradeability	
		Req'd	Estimated
10	1	19.0%	20.2%
20	2	10.0%	9.9%
30	3	5.0%	6.5%
40	4	3.0%	3.7%
50	4	1.0%	2.9%

Vehicle weight and transmission gear ratios affected the gradeability test. The drive system was originally designed to meet the IZET requirements based on a vehicle test weight of 844kg, as specified in the 3- Wheeler Technical Specifications. The weight of the vehicle as tested was 885kg (and 935kg for 19%). Since the gradeability is inversely proportional to vehicle weight, the increase in weight adversely affects the gradeability performance of the vehicle. The gradeability tests conducted at NGM facilities were performed with a reduced payload to compensate for the increase in curb weight. The results of these tests indicate that with the design curb weight of 510 Kg, all gradeability requirements would have been met. In addition, the drive system was originally designed for custom-built gear ratios for first and second gear. BAL decided to keep the existing gear ratios. At the design review meeting in December 1999, it was agreed the non-compliance with this requirement would not affect the acceptance approval.

- Range Test

The purpose of this test was to determine the maximum range of the vehicle one full battery charge when operated on a dynamometer while following repeated IDC cycles and to verify compliance with the range requirement set forth in the technical specifications. The official measured vehicle range was 10.5% lower than the specified IZET requirement due to 23% increase in vehicle weight. In addition, all but four of the cycles were run in third gear only. The top speed of the vehicle in second gear was found to be 31.5 km/h. The IDC cycle speeds were below 31 km/h for over 68% of the total cycle time and 46% of the total cycle distance. This indicates that the vehicle could be in second gear for nearly ½ of the total traveled distance. Since the drive system is more efficient at higher motor speeds, the overall vehicle range is expected to increase if second and third gears were used throughout the range test. The vehicle range also depends on the battery pack total Amp-Hour capacity and the battery capacity could have lost the charging capacity.

Based on these factors, it was believed that the maximum range potential of the vehicle exceeded the requirement of 80km. Although the IDC could not be replicated as accurately during the NGM range test as it can be on the dynamometer, the road test itself proved to give a good indication of the expected vehicle range. The vehicle during the demonstration period logged close to 100 km per battery charge.

Road Worthiness Tests

In October 2000, the first electric three-wheeler prototype was tested at the facilities of the ARAI and VRDE in Ahmednagar. These tests followed the testing at the NGM facilities in the U.S., which were witnessed by Nexant and BAL representatives in September 2000.

The tests were conducted to obtain a certification for compliance with the Central Motor Vehicles Rules, 1989 of India. The tests included environmental, safety, EMI and operational aspect of the prototype vehicle. The environmental component involved testing the vehicle’s ability to drive in wet weather including flooded roads without impacting electronic components and parts. Safety aspects of the tests included overall integrity of the prototype including the braking capabilities. The prototype was able to meet or exceed all the required parameters.

Component Failure Analysis

During the course of integrating, testing and/or demonstrating of the prototype 3-wheeler and its components, there were instances where components failed or lost their partial functionality. In each of these cases, the hardware was either repaired and/or replaced and the cause for the malfunction was analyzed to determine the need for redesign or other rectification. Failure analysis was conducted on the following components of the prototype electric three-wheeler:

- Controller

During water immersion test in October 2000 at the VRDE facility in Ahmednagar, India, water leaked inside the controller casing by way of one of its connectors. The analysis found that the component was not sealed properly for water tightness and was not assembled per its manufacturers' requirements. The problem was then rectified with proper sealant to prevent future leaks. The controller functioned properly after applying sealant.

- Motor

The motor showed a temperature error during repackaging of the vehicles at Bajaj's facility in November 11, 2000. Bajaj noticed "no motor" status and the temperature reading of -265^0C at that the "Configuration Utility" program. This indicated that either the temperature sensor in the motor was not working or the motor was not properly connected to the program. Yet, preliminary inspection of the motor cable and connector by BAL showed no unusual sign of wear or damage. After a thorough analysis, NGM found that the "motor return" sense loop was not connected properly at the motor end, indicating a loose connection in the internal wiring. The problem was traced back to loose fitting of the rubber compression during assembly of the motor. The rubber compression grommet on the motor was tightened to prevent future failures. A slightly smaller grommet was used in the remainder of the motors to rectify the problem. The three-wheeler motors haven't reported any problem since this occurrence.

- Charger

Bajaj reported malfunctions of two prototype 480W chargers in October 2000. After several troubleshooting attempts at both Bajaj's and NGM's facilities, it was discovered that there were some errors in the connections of the harness. The failure occurred due to combination of things including documentation errors and miscommunication between Bajaj and NGM. The damaged units were returned to the manufacturer and it was confirmed that components on the logic board were permanently damaged because of the voltage input. The damaged prototype chargers have been sent back to the manufacturer for detailed analysis. The analysis confirmed that the existing design did not have any preventative measures against hardware damage that should be instituted to prevent this type of mistake.

Recognizing that the existing charger is troublesome and recharging time is too long (8 – 10 hrs) for commercial vehicles, Bajaj and NGM decided to redesign the charger. NGM have since redesigned the charger and the new design is being provided by BAL.

5. Outreach

Indian urban centers suffering from congested streets and significant tailpipe emissions are among the most polluted in the world. During the program design phase few technology options were available in India. The majority of two & three – wheelers are driven by inefficient two stroke engines. Therefore, it is USAID's intent to generate greater awareness of alternative transportation technologies among the general public. Consequently, the IZET team organized activities and participated in several forums to promote electric vehicle technology.

Conferences and Seminars

In order to increase public awareness on the benefits of alternative transportation technology, the IZET team participated and presented technical papers at various seminars and conferences in the US and abroad.

International Symposium on Automotive Electronics and Alternative Energy Vehicles - '99 and '01, Kanpur, India

Indian Institute of Technology- Kanpur hosts a bi-annual symposium on alternative energy vehicles and automotive electronics. The symposiums are well attended by auto industries, policy makers, scientists and engineers. Some of the larger manufacturers of conventional vehicles and EVs provided sponsorship of the symposium. In 1999 and 2001, USAID India co-sponsored the symposiums. The IZET team also assisted the organizing committee in identifying and locating keynote speakers for the symposium. Considered an excellent platform to promote USAID programs, IZET team submitted a paper titled *"Innovations in the Development and Marketing of EVs - The United States Agency for International Development Experience"* for '99 symposium. USAID was also invited to provide a keynote speech at the symposium.

Similarly, in 2001 the IZET team presented a paper titled "IZET- *A Driving Force for Change*" and showcased an IZET electric three-wheeler for a show and ride at the symposium. Both papers are included in Appendices 4 & 5.

EVs -17, Montreal, Canada

IZET team presented a paper at the 17th annual International EVs Symposium held in Montreal, Canada. This symposium is the largest venue for alternative fuel vehicles. The symposium was well attended by automotive industries, policy makers, engineers and interested individuals from around the world. IZET team presented two papers with different themes. The first paper was based on collaborative aspects of the IZET program, which was titled "Electric Vehicle Technology – Moving to Commercial Reality: *Lessons Learned from a U.S. Government Agency's Initiatives with the Private Sector In South Asia*." The second paper focused on the design and production aspects of the program, which was titled "Indian Zero Emission Transportation Project (IZET): *an International Collaborative Electric Vehicle Initiative*." Both papers were well received by the audience. Both papers are included in Appendices 6 & 7.

Media Presentation

The IZET team also used various media outlets and showcased EVs at various functions to promote the program.

IZET Video

A video titled " *IZET - A Driving Force for Change*" was produced to inform the private and public sectors about the IZET program. The video captures various stages of IZET- from a concept to the possibility of EVs in India. The video features interviews of key stakeholders of IZET.

The video has been widely circulated to various entities to promote the concept of this collaborative effort. The videos have been provided to EV Industry association in the US and India, ranking members of the US Senate and House, USAID missions around world, the multilateral agencies and Indian policy makers. Good reviews were received from the recipients.

The video won bronze and silver medals at the 2001 Catalyst Award for 2001 on documentary and employee communications categories. The IZET video was selected among 300 entries. The Catalyst Award recognizes corporations and small businesses for their accomplishments.

Print Media

Fact Sheets

Brief description of the IZET project including its objectives and goals were printed and circulated within the Agency. The objective of the fact sheet was to inform USAID officers about the collaborative program. A copy of the fact sheet is included in the Appendix 8.

Project Profiles

Several two pager project profiles were created to promote and publicized the IZET program to general public. The two-pager profiles were also distributed to the guests at the three-wheeler ceremony in Agra. Copy of the project profile is included in the Appendix 9.

Press Coverage

Press coverage of IZET activities included: local, regional, and national newspapers and TV stations in India.

Inaugural Ceremonies

Electric three- and two- wheelers were unveiled in Agra and Delhi.

Two & Three – wheeler Inaugural Ceremony in Delhi

A low-level ceremony was held on April 20, 2002 to mark the launch of the electric two and three -wheelers in Delhi (Fig –4). The inaugural event was organized by Baggalink, BAL's local dealership facility. The electric two & three - wheelers were displayed at the ceremony. During the ceremony, a key to an electric three-wheeler was presented to Mr. J. Bever of USAID/India to be used within the US Embassy compound (Fig –5).

The ceremony was attended by following individuals from representative organizations:

USAID/India:	Mr. J. Bever, Ms. B. Bever, Mr. R. Edwards, Mr. R. Berry, Ms. U. Kumar and Ms. S. Kripalani
Tricon:	Mr. R. Paraskar
BAL:	Mr. T. Basu
BaggaLink:	Mr. P. Bagga and Mr. G. Bagga
NGM:	Dr. N. Bedewi and Mr. E. Takamura
Nexant:	Mr. D. Vincent

After the ceremony, the guests took demonstration rides on electric two & three -wheelers.

Fig–4 Guests Riding the IZET Electric Two-wheeler	**Fig –5 Handing of a Key of an Electric Three-wheeler to US Embassy**
	

Three-Wheeler Inaugural Ceremony in Agra

As outlined in the MOU between USAID and Mughal Sheraton Hotel, three assembled electric three-wheelers were delivered to the hotel for transporting their guests to points of interest in and around Agra. Prior to engaging the IZET vehicles for actual use, an inaugural ceremony was held on March 14, 2001 at the Taj Khema in Agra (Fig–6). Various dignitaries from the US and Indian government and representatives of non-government organizations were invited to witness the ceremony. A copy of the invitation is attached in the Appendix 10. The ceremony was well attended by local civic leaders, teachers, judicial authority, law enforcement, tourism industry and representatives from transport industry in Agra and surrounding areas. Symbolic of this collaborative effort, USAID Mission Director to India Mr. Walter North represented the US, while Principal Secretary of Environment for State of Uttar Pradesh, Mr. Pradeep Kumar, represented India.

Director of the Energy, Environment and Enterprise Program at USAID/India, Mr. Richard Edwards, provided the opening remarks, which were followed by presentations from the following speakers.

- Mr. Pradeep Kumar, Principal Secretary, State of Uttar Pradesh
- Mr. Walter North, Mission Director USIAD/India
- Dr. Samuel Schweitzer, USAID/Global
- Mr. Tapan Basu, Deputy General Manager, BAL Ltd.
- Dr. Nabih Bedewi, Chairman, New Generation Motors
- Mr. SS Dhawan, Vice President, ITC Hotels Ltd.
- Mr. D.V. Sharma, Superintendent, Archeological Survey of India (ASI)

The speakers stressed the US – India collaboration and highlighted the importance of alternative vehicles in the Indian transport sector:

Fig – 6
Inaugural Event in Agra

During the ceremony, Mr. North handed over a symbolic key for an electric three-wheeler to Mr. D. V. Sharma of Archeological Survey of India (ASI) (Fig-7) for the EV donated to ASI for the use of older and physically challenged visitors to the Taj Mahal. Ms. Christine Lyons, USAID Regional Contracting Officer, made the actual delivery of the EV to ASI in an event held at the inner lawns of the Taj Mahal on September 14, 2001.

After handing over an electric three-wheeler key to ASI, Mr. Kumar and Mr. North were invited to cut a ribbon to mark a symbol of unveiling of the IZET electric three-wheeler in Agra (Fig-8).

Fig – 7 Mission Director is Handing a Key of an Electric Three-wheeler to ASI	**Fig – 8 Mission Director and the Guest Speaker are Cutting a Ribbon of an IZET Three-wheeler**
	

Following the ceremony, Sheraton hosted a lunch for all the guests. The ceremony was well covered by the local and regional media.

Display of Vehicles

Display of IZET ECORICK for Former President Clinton's Visit to Agra March 2000

In March of 2000 former US president William Jefferson Clinton, traveled to Agra during his official visit to India. In Agra, site of the Taj Mahal, President Clinton announced several new initiatives to strengthen Indo-American efforts to protect the environment, develop clean energy resources, and combat global climate change. Various alternative fuel vehicles from India were displayed for the President at the Taj Mahal compound as a part of his initiative to protect and combat global warming. The IZET electric three –wheeler was one of the vehicles that were displayed (Fig –9).

Fig –9
IZET ECORICK Displayed During President Clinton's Visit to Agra

EPA Visit:

In January 2002, an EPA delegation led by Administrator, Christine Todd Whitman, visited India. The delegation also visited Agra and the IZET EVs were showcased to the delegation during their visit to the Taj Mahal.

6. Demonstration of Prototype Vehicles

An element of the IZET program is to operate the EVs in real-life applications. The lessons learned would provide valuable information for the commercialization phase. In order to obtain field data from the vehicles, USAID signed Memorandum of Understandings (MOU) with the IZET program partners, ASI, WELCOMGROUP, and TRICON Restaurants International to field-test two and three –wheeled EVs at their premises for 6 to 12 months. The electric three-wheelers are operating in Agra at the Taj Mahal transporting the elderly and physically challenged, and at WELCOMGROUP's Mughal Sheraton Hotel where guests are transported to local points of interest. Up to seven electric two- wheelers will be deployed at a Pizza Hut franchise in Delhi in support of regular food delivery operation. In addition, electric- three-wheelers have been deployed in Delhi as taxis and one electric three-wheeler has been provided to the US Embassy, New Delhi for their local use, especially for the delivery of mail.

Prior to deploying the EVs thorough training was provided to the operators. Detailed operations and maintenance manuals were also provided to the operators.

Two -Wheeler

TRICON/Delhi

TRICON, Pizza Hut Restaurants, will deploy up to seven electric two-wheelers at their franchises in Delhi. The vehicles will be used in regular routes to deliver food to customers. BAL and NGM will thoroughly train TRICON's drivers on the specifics of the EVs including safety procedures. The vehicles will operate during their normal business hours. TRICON's food delivery service usually runs from 10 am until midnight. TRICON will provide a night watchman and a secure place to house the vehicles during non-business hours.

The vehicles are expected to travel up to 40 km per day during normal operation. The delivery locations are within 12 km radius of the restaurant. The average daily distance for each vehicle is well below the average range of 55 km per single charge.

BAL/Pune

BAL is planning to field test the remaining two-wheelers close to its manufacturing facility in Pune. This arrangement will allow BAL to obtain first hand knowledge of the EVs while making it easier to monitor daily activities. Currently, BAL is in the process of identifying a reliable partner who would use these vehicles in their regular operations.

Three Wheeler

Archeological Survey of India (ASI)/Agra

The ASI agreed to field-test an electric three-wheeler at the Taj Mahal compound. The vehicle is being used to assist senior and physically handicapped tourists inside Taj Mahal

Compound. Shiel Auto, a local BAL dealership in Agra, is responsible for maintaining the vehicle during the demonstration phase.

Mughal Sheraton Hotel/Agra

As one of the IZET partners, Mughal Sheraton hotel has been field-testing three electric three-wheelers in Agra since March 2001. The vehicles are being used as a taxi service for its hotel guests. The vehicles provide transport services to its guests to and from various points of interest in and around Agra including the Taj Mahal. The Sheraton has received positive feedback from its guests.

Mughal Sheraton has built a canopy and charging stations to house and charge the vehicles during off hours. It is also promoting the use of EVs to its guests. The drivers at the hotel are well trained on operating the vehicles and are keeping daily operating logs. Sheraton is providing BAL and NGM with valuable operational data.

Data received from Sheraton suggests that the vehicles are operating without any major problems. The vehicles are traveling between 15 to 45 km/day. Table 11 below provides sample data for one of the vehicles.

Table -11 Data Log from Vehicle # 5647 Recorded on 05-02-02

Time		Km Reading		Kms. Traveled	State of Charge (%)		Charge Used (%)	Charging Start	Charging End	Comments Eg. Route, Charger used, Down time, if any	Driver
Out	In	Start	End		Start	End		Time/ SOC	Time/ SOC		
1025	1120	12277	12292	15	100%	90%	10%	1130 / 90%	1420 / 99%	NA	Purna Bahadur
1420	1445	12292	12299	07	99%	92%	07%			NA	-do-
1510	1605	12299	12308	09	92%	83%	09%	1605 / 83%	1730 / 90%	NA	- do-
1730	1825	12308	12323	15	90%	75%	15%	1830 / 75%	1000 / 100%	NA	-do-

Data Acquisition

IZET was designed to include systems to acquire and store performance data from the electric vehicles during the day-to-day operations. Parameters to be measured and the sample frequency were agreed upon by all partners. Appendix 11 contains the equipment lists and characteristics of the data acquisition system developed for IZET. In addition, operators of the EVs at each site are maintaining logs, recording various information that is being submitted on a regular basis.

7. Environmental Assessment

Urban air pollution in India is among the worst in the world and vehicular emissions, primarily from two -stroke two and three-wheeled vehicles, are the major contributors. Due to rapid population growth and urbanization, the number of two and three-wheelers continues to grow in India. A recent study by the Central Pollution Control Board has shown that transportation is the single greatest cause of air pollution in Delhi, accounting for 67% of total air pollution[2].

Considering the environmental and human health impact of urban air pollution and future growth of conventional two–stroke two and three-wheel vehicles in Delhi, for example, there is significant pressure within the Indian government to reduce air emissions and introduce alternative fuel vehicles. Capitalizing on the government's decision, USAID, working with the private sector in the US and India, embarked on a technology transfer and commercialization project that has helped to determine the possibility of replacing these vehicles with electric driven vehicles. Electric vehicle technology has the potential of reducing significant vehicular pollution in urban areas. Therefore, it was USAID's desire to examine the net environmental benefit of replacing two-stroke two and three-wheelers with electric motors of near-equivalent function.

Two studies were performed to assess the change in air emissions and health impact on local population due to introduction of EVs in Delhi:

> The first study was primarily a desk study, which focused on an assessment of CO_2 and other pollutants such as CO, PM, NOx and SO_2 to determine how replacing conventional vehicles with electric driven vehicles will change the overall emissions level and associated health impacts in Delhi.
>
> The second study focused on lifecycle assessment of Greenhouse Gases (GHG) emission associated with the entire energy chains.

A third study was carried out to estimate the change in emission of GHGs and other pollutants from an electric utility in Ahemadabad due to different penetration scenarios of electric two & three - wheel vehicles. The emissions resulting from EVs are compared with the emissions from conventional two and three-wheel vehicles throughout the energy chain to determine the net change.

Objective

The objective of these studies was to perform an initial, integrated assessment of environmental impacts resulting from the introduction of EVs into the population of conventional two and three-wheeled vehicles in Delhi and Ahmedabad, India. Results from these studies further support the determination of the feasibility and desirability of assessing alternative technology for these vehicles.

[2] Source: White Paper on Pollution in Delhi with Action Plan, GOI.

Determine the net impact on local environment and human health in Delhi

This study was carried out to determine the net impact on local environment and human health in Delhi due to: a) tailpipe emissions from conventional two-stroke two and three-wheelers; b) change in emissions at power plants from replacing conventional vehicles with EVs. This study assumed varying degrees of introduction of electric two- and three-wheeled EVs in Delhi such as 10, 50 and 100%.

Boundaries for this study included tailpipe emissions from conventional vehicles and air emissions from the power sector. Tailpipe emissions are measured and analyzed for estimating emissions from conventional vehicles and emissions at power plants were analyzed to estimate emissions related to EVs.

This study primarily relied on existing and available data from Delhi since specific data on the impact of urban air pollution on human health are scarce. The study was carried out in various steps starting from data collection to impact analysis.

Mass balance calculations were carried out to estimate net change pollutants such as PM-10, SO_2, NO_X and CO based on rate of introduction of EVs. Table 12 illustrates the net changes in overall emissions from conversion of two and 3- wheeled conventional vehicles to EVs at three different scenarios.

Table-12 Projected Net Change in Emissions of PM, NO_X, CO, SO_2 and CO_2 as a Result of Conversion of 2 and 3-Wheeled Vehicles to Electric Power in Delhi. India (1)

% Conversion to Electric, by Type	PM (metric tpy)	NOx (metric tpy)	CO (metric tpy)	SO_2 (metric tpy)	CO_2 (metric tpy)
2-Wheeler					
10% Conversion	-661	87	-3,277	534	-68,970
50% Conversion	-3,306	436	-16,385	2,672	-344,851
100% Conversion	-6,611	873	-32,770	5,344	-689,702
3-Wheeler					
10% Conversion	-45	49	-931	248	19,821
50% Conversion	-225	246	-4,654	1,238	99,104
100% Conversion	-450	492	-9,308	2,477	198,207
Total					
10% Conversion	-706	136	-4,208	782	-49,149
50% Conversion	-3,530	682	-21,039	3,910	-245,747
100% Conversion	-7,061	1,365	-42,078	7,821	-491,495

(1) Negative numbers indicate net decrease, positive numbers indicate net increase

There is significant decrease in PM and CO as conventional vehicles are replaced with electric motors, as conventional vehicles are a major source of these pollutants. Similarly, there is a net increase in SO_2 and NOx since there is additional load at the power plants from charging EVs. The detail study including the assessment of health impact is included in Appendix 12.

Estimation of GHG (CO_2 Equivalent) emissions from two and three –wheelers in Delhi using World Bank's EM model

This study compares the lifecycle assessment of air emissions from conventional two and three-wheel vehicles with air emissions from power plants and other process due to EVs. The emissions resulting from conventional vehicles and EVs are analyzed using the EM Model[3]. There are approximately 1.8 million scooters and 80 thousand rickshaws in Delhi. Unlike the previous study, which assumes 10, 50 and 100% replacement scenarios, this study is based on an assumption that the entire fleet of conventional two & three wheelers in Delhi is converted to EVs.

At each possible step, during this analysis, the EM model has been altered to reflect actual Indian conditions. Table 12 below illustrates operating characteristics of conventional vehicles and EVs, which are inputs into the model. The operating characteristics of conventional vehicles are drawn from Bajaj built two and three-wheelers of the same size while the characteristics of EVs are direct input from the IZET vehicles. The figures in Table 13 are the primary basis for determining the emissions from each fuel chain.

Table -13 Vehicle Operating Characteristics in Delhi

	2-Wheeler	3-Wheeler
No. of vehicles	1,800,000	80,000
No. of days per year of driving	330	300
Travel (km/day)	25	80*
Electricity consumption for an EV (KWh/km)	0.026	0.065
Energy consumption for 2-stroke vehicles (mj/km)	0.906	1.39
Average annual distance traveled per vehicle (km)	8,250	24,000
Total distance traveled for all vehicles per year (million km)	14,850	1,920
Total Electricity required to operate all vehicles per year ('000 MWh)	386.1	124.8
Total petrol consumption for all vehicles (million liters)	386.72	76.8

Note * Daly range of conventional three-wheeler is fixed at 80 km/day to be consistent with actual range of electric three-wheeler.

Table 14 provides the overall CO_2 emissions avoided each year by replacing conventional two & three -wheelers with EVs. The table also provides total CO_2 equivalent emissions avoided for the next 10 years from Delhi's transport sector. However, the table does not assume growth in number of vehicles or technology/efficiency improvement over the years on either side of the fuel chain. The detail study is provided in Appendix 13.

[3] The 'Environmental Manual for Power Development' (EM in short) is a WINDOWS-based computerized tool for the inclusion of environmental and cost data into the decision-making process of Development Agencies regarding energy projects. The software was developed by GTZ with scientific support from Oeko-Institut. It is part of a multilateral project on environmental management, coordinated by the World Bank with contribution from BMZ, BAWI, DGIS, GTZ, ODA, World Bank.

Table 14 - CO_2 Emissions Equivalent/Platform/Energy Source (Tons)

	Emissions from Petrol		Emissions from Coal		Difference due to EVs	
	2-W [(a)]	3-W [(b)]	2-W [(c)]	3-W [(d)]	2-W [(a-c)]	3-W [(b-d)]
From Vehicles	1,205,000	218,800	444,900	123,400	760,100	95,400
From Other Processes	187,600	3,736	67,555	18,817	120,045	(15,018)
Total	1,392,600	222,536	512,455	142,200	880,145	80,336
Total CO_2 equivalent emissions avoided each year by converting all the conventional two and three-wheelers to electric powered ones in Delhi						**960,481**
Total /CO_2 emission avoided in next ten years (x10) (The model does not assume growth in number of vehicles and technology improvement over the years on either side of the fuel chain)						**9,604,810**

The results indicate that converting all of Delhi's conventional two and three – wheelers will avoid approximately 1 million tons of CO_2 equivalent each year. In order to validate the above findings, the results (g/km) have been compared with similar studies recently carried out by various entities. Table 15 compares the results of this effort with a study carried out by the Pew Center[4] and BAL for two & three wheelers.

Table – 15. Emissions of CO_2 Equivalent in g/km

	Pew Center [1]	Bajaj[1]	USAID/IZET
Petrol Scooter	118	N/A	85
Electric Scooter	51	N/A	32
Petrol Rickshaw	N/A	118	105
Electric Rickshaw	N/A	90	67

[1] Pew Center assumes average driving distance of 9,438 km/vehicle for 1,568,000 2-wheelers in Delhi. Pew Center results are based on the Lifecycle Environmental Model (LEM) developed by Dr. Mark Delluchi of University of California, Davis. Bajaj numbers are calculated using the GREET model developed by US DOE. Bajaj assumes an average driving distance of 42,000 km/year/vehicle for Delhi's 80,000 3-wheelers.

[4] Transportation in Developing Countries -Greenhouse Gas Scenario for Delhi, India, Pew Center on Global Climate Change, May 2001

Air Emissions Impact from EVs in Ahemadabad

Ahmedabad Electric Corporation (AEC) and USAID/India agreed to collaborate on assessing the lifecycle air emissions of replacing conventional two and three wheelers with electric driven vehicles in AEC's service area.[5] The collaboration resulted in a study of air pollution impact on Ahmedabad's ambient air quality by replacing conventional vehicles with electric driven units. This study served USAID's desire to determine the net impact on air quality of EVs using real data from a utility. The study also provided AEC with valuable information on air emissions impact at their generating unit as they operate a small fleet of electric three-wheelers for their internal use.

AEC provided the operational characteristics of their generation system and the conventional two and three-wheeler use profile in Ahmedabad. Remaining inputs to the study were obtained from the earlier Delhi study. Based on information provided by AEC, baselines for air emissions from conventional vehicles and AEC's generation system have been developed. The baseline represents what would occur in the absence of EVs. To quantify EV impacts, two scenarios of EV market penetration are modeled, with market shares of 10% and 40% for the electric three and two-wheel vehicles. As a result, there is a net emissions reduction in per unit of electricity generation from AEC's generating unit (Table 16). A detail copy of the study is provided in Appendix 14.

Table 16 - Emissions Per Unit of MWh and Percentage Change at AEC

	SO_2		NOx		PM		CO		CO_2 Equivalent	
	Tons	% Change	Tons	% Change	Tons	% Change	Tons	% Change	Tons	% Change
Baseline	0.0056	N/A	0.0062	N/A	0.0052	N/A	0.0016	N/A	0.0327	N/A
Additional load of 10% EVs	0.0050	10.6327	0.0056	10.6301	0.0046	10.6349	0.0015	10.4173	0.0294	9.9838
Additional load of 40% EVs	0.0048	15.1570	0.0053	15.1595	0.0044	15.1548	0.0014	15.3711	0.0275	15.7986

[5] The lifecycle emissions associated with each vehicles are calculated using the World Bank's Environmental Manual (EM) Model

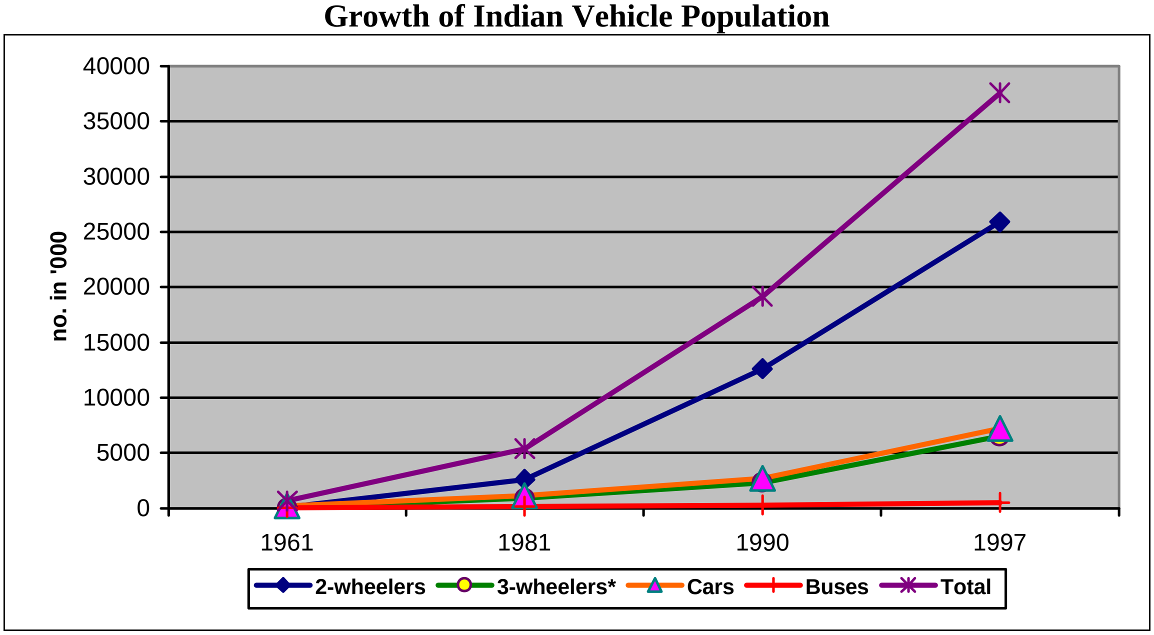
8. Industry, Policy and Regulatory Assessment

There has been a convergence of factors in India favorably affecting the industry's outlook towards alternative transportation technologies. These factors include:

- growing consumer disposable income
- growing traffic congestion
- increasing air pollution in large urban areas
- increasing grassroots concern for improved ambient urban air
- increasing regulatory constraints for conventional vehicles
- sophisticated auto manufacturing sector
- benign user profile
- shrinking traditional scooter and autorickshaw markets.

Since 1991, production, trade, and investment reform have yielded new opportunities for business in India. As a result there is an estimated 300 million-middle class consumers and a growing disposable income. This large and growing middle class has made India one of the fastest growing markets for vehicles. Overall vehicle population increased more than seven-fold between 1981 and 1997 from about 5 million to 38 million vehicles. Among all the vehicles, the growth in 2-wheelers, predominantly with two-cycle engines, has been the most dramatic, increasing by more than 10-fold between 1980 to1997. The number of 3-wheelers (e.g., autorickshaw) in the same period increased approximately six fold. In the early 1990s, 2- and 3-wheelers accounted for about 70% of all registered vehicles. The growth of the Indian vehicle population is illustrated in figure 10.

Figure -10
Growth of Indian Vehicle Population



Source: Society of Indian Automobile Manufacturers, India Auto Statistics, 1999

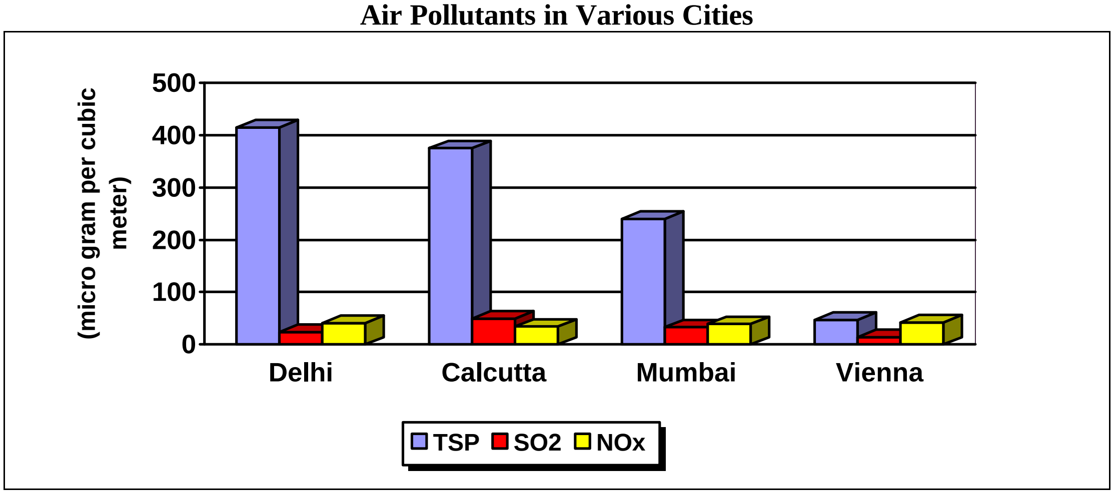
The recent growth in sales of vehicles, however, has been mixed. The two-wheeler market has been flat or declining except for motorcycles and sales of conventional petrol or diesel autorickshaws are being hurt by increasing regulation in the urban areas.

Moreover, the Indian road system has not kept up with the growing number of vehicles resulting in severe congestion in urban areas – among the worst in the world. A majority of the vehicles in major cites, for example, stay idle in traffic for 20 to 25 percent of the time exacerbating the poor air quality.

User Profile and Market. Relatively short trip distances, growing disposable income, congested roadways, and increased concerns for air quality together are creating a market for alternative vehicles in urban India. Driving distances are relatively short compared to Western nations. Moreover, travel in the three largest Indian cities accounts for 50% of total vehicle distances in the country. Average distance traveled per day within a city is 25-26 km[1], which is significantly less than 50-60 km in Western countries. Several studies also indicate the average speed in larger urban areas to be between 5-12 km per hour.[6] The top three income groups – middle, upper middle and upper class families have also grown from 10% in 1986 to 17% of the total Indian population.[7]

Worsening Urban Environment. Industrialization and urbanization in India have resulted in deteriorating air quality. India's gross domestic product has increased 2.5 times over the past two decades. There is a price for this growth - vehicular pollution has increased eight times and pollution from industries has quadrupled. Growing urban air pollution has become an issue of public and political concern throughout urban India. A comparison of air pollution in various cities is given in figure 11.

Figure -11.
Air Pollutants in Various Cities



Source: World Development Indicators, The World Bank, 1998; TSP = total suspended particles

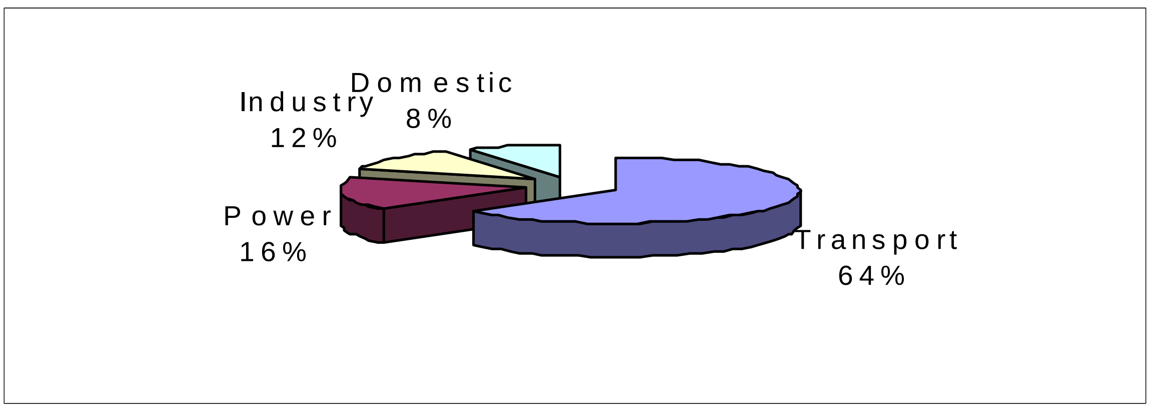
[6] Impact of Road Transport System on Energy and Environment- an analysis of metro pollution cites of India, A Report, Ministry of Urban Development, Govt of India, 1993

[7] Automobile Industry Association of India, Report to GoI, 1999

Environmental Conditions in India

The Indian government and judiciary have made significant efforts in the field of environmental protection. The government, particularly for 3-wheelers, has issued a series of more stringent directives and regulations. In 1999, for example, the Indian Supreme Court prohibited registration of new vehicles in the National Capital Region surrounding New Delhi if they fail to meet EURO II emissions norms after April 1, 2000. Figure 13 provides the rationale for the government's decision for issuing new directives on transport emissions. In Mumbai, autorickshaws are banned within the central part of the city. Moreover, a directive was issued to retire older autorickshaws in Delhi supplemented with financing incentives for replacement with more efficient 3- wheelers. Leaded gasoline is also being phased out. Vehicle manufacturers are developing new products to maintain volume and market share, and there is an increased interest in alternative transport technologies. Other significant policies and regulations are contained in Appendix 15.

Figure -12
Contribution of Transport Sector to Total Pollution In Delhi[8]
(CO+HC+NO2+PM)



Source: N.V. Iyer, BAL Ltd., Pune, India, "Workshop on Pollution From Motorcycles: Issues and Options", The World Bank March 9, 2000

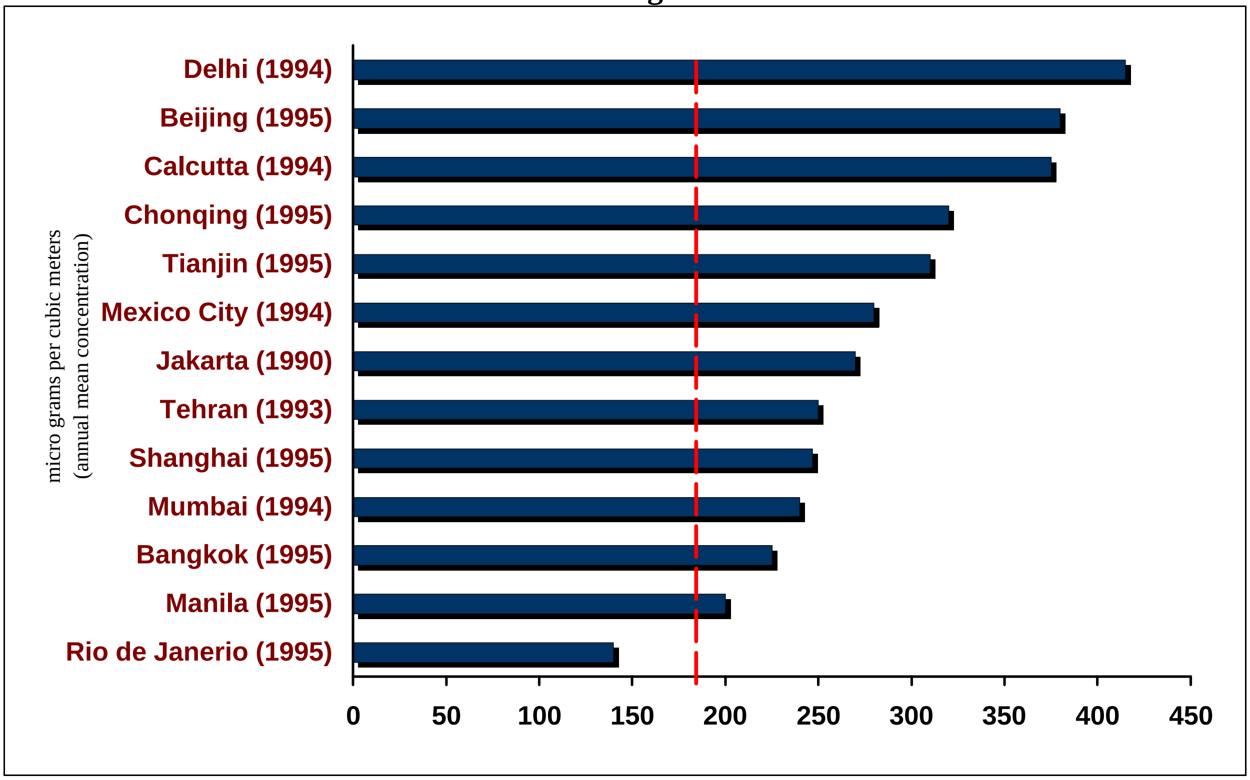
Health Risk. The primary and most pressing reason for controlling emissions and reducing ambient loadings of air pollutants is their effect on human health. Inhalation of, or exposure to, fine particles (PM-2.5 microns), oxides of nitrogen (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), hydrocarbons (HC), ozone (O_3), and heavy metals are the primary causes of adverse health effects. Such effects result from both chronic and acute exposures; the chronic exposures have a cumulative effect, while acute exposures typically take a heavier toll among the young, old, and ill. Adverse health effects include premature or sudden death, as well as an increased incidence of chronic respiratory, coronary, and neurological disorders.

According to the World Health Organization (WHO), three major Indian cites, Delhi, Calcutta, and Mumbai, are among the most polluted cities in the world (Figure 13). The majority of this

[8] N.V. Iyer, BAL Ltd., Pune, India, "Workshop on Pollution From Motorcycles: Issues and Options", The World Bank March 9, 2000

pollution comes from the Indian transport sector - primarily from two-stroke 2 & 3-wheelers. In Delhi alone almost seventy percent of the city pollution is attributed to transport sector. Moreover, forty percent of these emissions are attributed to 2 & 3 –wheelers.

Figure 13
Ambient Concentration of TSP Exceeding WHO Guidelines in Different Cities



Source: World Resources, 1998-99
Note: ------ Represents WHO Guidelines for TSP at 180 µg/m^3

9. Economic and Financial Assessment

The basic premise of the IZET stakeholders for the 3-wheeler continues to be that the owner of the vehicle will be more receptive to alternative technologies if their net income is the equivalent to a conventional 3-wheeler or more.

Three wheelers are primarily used as taxis and goods carriers. Operating in fleets and individual ownership, these businesses need to be profitable. Market demand for this vehicle is price elastic and operational costs need to be minimized. Since the initial cost for an electric driven 3-wheeler is expected to be more than a conventional unit, alternative-marketing approaches will need to be considered such as extended warranties or financing incentives. This said, the anticipated cost to the consumer for an electric 3- wheeler, without subsidies, is about $2,300 or about twice the price of a gasoline two stroke 3- wheeler, which is about $1,100 (Table-15). The running costs of an electric 3- wheeler are expected to yield an annual savings of about $300. Given the trend to finance and the high interest rates in India, a simple breakeven point for the consumer is about five years.

Table-15 Economics of Electric 3- Wheeler Operation - Sample Calculation (all numbers are in Indian currency (Rs.) except where noted)

ITEM		I.C.ENGINE	NO GOVERNMENT INCENTIVES		WITH GOVERNMENT INCENTIVES		COMMENTS
			ELECTRIC (CASE 1)	Assump's	ELECTRIC (CASE 2)	Assump's	
1	Net Manufacturing Cost	38,000	84,375		69,863	Concession/ Waived Customs, Excise and Sales duties	US$750 for Motor, Controller. etc.
2	Government Levies	9,950	21,259		3,493		
3	Other Costs	4,932	5,860		5,346	Concession Road Tax	
4	On Road Price	52,882	111,494		78,702		(1)+(2)+(3)
5	Less Govt. Cash Subsidy				(-)15,740	@20%	
6	***Net Cost to customer***	***52,882***	***111,494***		***62,962***		(4)-(5)
7	Loan	47,594	100,344		56,666		Margin=10%; Term=5yrs.
8	Interest on Loan	21%	21%	21%	12%	*Soft loan for EVs*	
9	Net fixed cost	60,177	126,874		53,413		Cost of capital, resale value etc
10	***Fixed cost / Year***	***8,597***	***12,687***		***5,341***		Assumed life (yrs.) - Petrol=7 // EV=10
11	Distance travelled/yr. (Kms.)	24,000	24,000		24,000		300 days usage/ yr.
12	Running cost (Rs/ Km)	*1.20*	0.64		0.48		-Petrol = Rs.30/l -Electricity= Rs3/kWh - Battery change every $2^1/_2$ yrs.
13	Running cost / year	28,880	15,303		11,489		(10)*(11)

14	Maintenance cost / year	5,500	2,750		2,750		Assumed
15	Operating cost / year	34,300	18,053		14,239		(13)+(14)
16	Cost / year (Total)	42,897	30,740		19,580		*(15)+(10)*
17	Cost / Km (Total)	1.79	1.24		0.82		
18	Saving – Rs./ Km		0.51		0.97		
19	***Saving – Rs. per year***	**–**	***12,157***		***23,386***		**Earnings (ICEV) = Rs.*66,300 pa***

Note: US$ 1= Rs. 49

Two wheelers in urban areas are generally used for personal transportation. The anticipated market is viewed as being dominated by a more sophisticated consumer; one that recognizes the life cycle costs and is more concerned for the environment. Given these conditions, as long as the electric vehicle is reliable and meets performance expectations, a higher initial cost for an electric vehicle should be able to be rationalized by the consumer.

It should be noted this information is preliminary and one of the next major activities by BAL and NGM is to look at ways to maintain quality and performance but reduce manufacturing costs. The Government of India's view towards incentives for the industry is also still unfolding.

10. Fiscal Report

Original Contract					Revision 1 (Modification #3)			Revision 2 (Modification #4)			Revision 3 (Modification #5)			Revision 4 (Modification #6)				Invoiced As of 6/28/02		Variance
																				Budget
	Level	Work Days	FBDR	Total	Work Days	FBDR	Total	Work Days	FBDR	Total	Work Days	FBDR	Total	Work Days	FBDR	Total	Work Days	FBDR	Total	Actuals
Labor		**3030**		**$ 2,687,717**	**2318**		**$ 1,855,856**	**2021**		**$ 1,608,273**	**1704**		**$ 1,338,578**	***1656***		**$ 1,338,496**	**1416.8**		**$ 1,195,188**	**143,390**
Other Direct Costs				$ 1,235,150			$ 2,066,403			$ 2,313,986			$ 2,583,666			$ 2,583,748			$ 2,418,170	$ 165,496
Total Contract				**$ 3,922,867**			**$ 3,922,259**			**$ 3,922,259**			**$ 3,922,244**			**$ 3,922,244**			**$ 3,613,358**	$ 308,886

Notes:

Modifications were as follows

Mod 1 Change in CTO

Mod 2 Funding

Mod 3 Change in Geographic code

Mod 4 Budget re-alignment, Revise SOW, Subcontract approval

Mod 5 Budget re-alignment

Mod 6 Budget re-alignment

Mod 7 Change in End date

*$82,000 paid to NGM in May 2002, included in figures above.

11. Conclusions

The objectives of the IZET program have been met and perhaps exceeded. Electric prototype 2 and 3-wheelers have been designed, manufactured, assembled, tested, and deployed successfully. The results of the design, assembly, and testing indicates the technical feasibility is positive. These results also indicate the economic feasibility is within reach to be viable. The environmental assessments performed by Nexant and others also point to significant reductions in air emissions with electric vehicle technology. The outreach for IZET has purposely been low-key, in deference to BAL, but yet has made marks within the industry and, perhaps more importantly, with consumers that have had first hand experience with the EVs. And, the publicity should grow as more vehicles are placed in the market. The interpersonal dynamics between BAL and NGM personnel are improved and a seemingly collegial relationship focused on commercialization efforts has emerged. USAID’s investment has been leveraged by about 1:4.5. Moreover, BAL and NGM have entered into an agreement to produce an additional 1,200 electric 3-wheelers by early 2003, incorporating the lessons learned from IZET into the next step of the commercialization path. These vehicles will be used to test consumer preferences and overall reliability. As BAL and NGM continue their efforts, the ratio of USAID’s leverage will widen considerably and hopefully, ambient air quality will improve as the products move from prototype to the market.

Appendices

IZET KICK-OFF MEETING
FINAL MEETING MINUTES
February 23 – March 4, 1999

AGENDA ITEM			MINUTES
1	23/2/99	**ARRIVAL OF ALL PARTICIPANTS AT PUNE** dinner + introductions	**GENERAL** *Informal meet + briefing on local travel arrangements, overall plan of work and any other requirements*
2	24/2/99	Introductory and general meeting	**GENERAL** *Introduction of personnel, sharing of expectations in this program, and laying the groundwork for this meeting and program*
2.1		Welcoming Remarks	N. Iyer opened the meeting by welcoming all. Particular appreciation was expressed for Dr. Schweitzer's, USAID, perseverance in catalyzing Bajaj's interest and acceptance of electric vehicle technology. Mr. Iyer posed the question to USAID about their strategy/interests after the completion of this demonstration program. Dr. Schweitzer indicated an integral part of this program is to assess current Indian policies and regulations to effect positive change conducive to the EV market. Examples were given: current study of Indian import duty regulations for the purpose of providing an approach where reductions might occur; involving the IFC to provide financing for the purchase of EVs and/or investing in a joint venture with US firms/Bajaj for the purpose of producing EVs; and, coordinating with USAID/India's programs to possibly provide favorable financing for the purchase of EVs. N. Iyer closed in saying he hopes for open and candid involvement by all participants throughout this program.
2.2		USAID Perspective and Expectations	S. Schweitzer expressed his gratitude to all participants (Bajaj, NGM, and UQM) for being involved in this program. An overview of USAID activities to catalyze action to develop EV products in India for the past 4 years was provided. Leveraging the resources of all participants for publicizing this program was discussed and all agreed this program has significant potential.

IZET KICK-OFF MEETING *FINAL MEETING MINUTES* *February 23 – March 4, 1999*			
AGENDA ITEM			MINUTES
			The overall schedule was brought up and all were advised that the program target completion date is December 2000.
2.3		Program Objectives, Description & Role (Bechtel)	D. Vincent expressed his appreciation for: • Bajaj in hosting this meeting, assisting in travel arrangements, upfront work in preparation, and their commitment of substantial resources in implementing this program. • USAID in their perseverance in catalyzing Indian and US private sector firms to develop EV transport products, and funding to reduce the front-end risk associated with product development. • NGM and UQM for traveling such distances and their commitment to cost share in this program. An overview of past support to USAID was provided, particularly in a similar EV demonstration program. Program objectives were discussed and the components of the entire program were briefly reviewed. Regarding the urban demonstration component, Bechtel's responsibility to USAID is overall management and coordination. This meeting represents an opportunity for all participants to identify all actions needed and the schedule for implementing this phase of the program. A pamphlet providing an overview of the EV program, prime contact list, preliminary schedule, and driving profile of TRICON delivery operations was handed out. S. Ravikumar, Bajaj senior manager, questioned what contingencies are in place in the event the schedule slips past December 2000 (Bechtel contract expires). A general discussion ensued on this topic. It was left that the schedule would be continually monitored in the hope that corrections could be made in sufficient time to mitigate any delays.
2.4		Bajaj Perspective, Markets &	T. Basu expressed his appreciation, particularly to USAID, for attending this meeting.

IZET KICK-OFF MEETING *FINAL MEETING MINUTES* *February 23 – March 4, 1999*	
AGENDA ITEM	MINUTES
Expectations	An overview of Bajaj's interest in EVs was provided. For example, their initial strategy was to obtain the rights of a complete, developed technology. It became clear to Bajaj that no satisfactory product existed and that they would have to work with selected firms to integrate their technology with Bajaj's strengths to develop suitable electric scooters and autorikshaws. A discussion on presentations to the Indian Government was provided and Bajaj's market assessments as it relates to market dynamics for their products. Bajaj is hopeful of governments' or perhaps a multilateral's intervention on associated aspects of an EV industry. Examples given included support for the necessary infrastructure, policies and regulations that are catalytic, particularly in the early phase of product entry into the marketplace. They feel the auto industry is the best position to effect change on issues they can control, e.g., product quality and meeting market needs. N. Iyer suggested Bajaj would prefer USAID to be involved in the relations with the Indian Government. He stated industry anticipates the Indian Supreme Court to mandate 2% of all vehicles to be zero emissions. Bajaj produces about 1.5 million vehicles per year. The impact to Bajaj's market would be approximately 30,000 electric vehicles per year. K. Barnes questioned what Bajaj sees as its path to commercialization for EVs. T. Basu indicated this demonstration program is a step towards providing the right product. The lessons learned will be significant and valuable towards moving to commercial production. It is fully expected that refinements will be needed to move towards production of EVs – when the market requires. N. Iyer indicated there is a convergence of factors affecting the need to develop a suitable EV for the

IZET KICK-OFF MEETING *FINAL MEETING MINUTES* *February 23 – March 4, 1999*			
AGENDA ITEM			MINUTES
			marketplace. Their assessment leads them to believe the emissions from the transport sector will increase in spite of continuing more stringent emissions standards. Example given is a poor public transportation system that relies upon primarily buses for the movement of people in urban centers. One of the consequences of a lack of an effective mass transport system is that more vehicles will be needed and consequently more emissions. Bajaj is involved in a current assessment with the industry sponsored Association of Indian Automotive Manufacturers to provide recommendations to the Indian government to mitigate the effects of growing transport emissions. For example, current law requires owners to have the emissions of their vehicles checked every 6 months. The stations performing this inspection are privately owned and the implementation could be significantly more effective. T. Basu discussed Bajaj's experience with their current electric autorickshaws prototype (eco-rick). They feel they have learned a great deal but also realize the current configuration is far from their needs. Nonetheless, the eco-rick represents a baseline for comparison with the EV prototypes to be provided under this program and also serves as Bajaj's initial answer to supplying EV vehicles should the Supreme Court issue the mandate for zero emissions vehicles. T. Basu discussed the target markets for the electric scooters and autorickshaws. Bajaj believes they can provide electric vehicles that are more cost effective over the life cycle of ownership. T. Basu closed in saying that for EVs to be viable in India, manufacturing of all significant components needs to be ultimately located in India. Otherwise the product will be too expensive.
2.5		NGM's Perspective and Expectations	N. Bedewi expressed his appreciation for the opportunity to participate in this program and looks forward to a lasting relationship with Bajaj. They are excited about the prospects and feel the publicity of being involved in this program will strengthen their

IZET KICK-OFF MEETING *FINAL MEETING MINUTES* *February 23 – March 4, 1999*			
AGENDA ITEM			MINUTES
			firm. A key element in their growth is to develop strategic partners and Bajaj is key to their growth.
2.6		UQM's Perspective and Expectations	K. Barnes expressed his pleasure and appreciation for the opportunity to participate in this program. They see this program as a way to develop a product that meets the needs of Bajaj.
3	24/2/99	**INPUT AND CONSENSUS ON SUPPORTING EFFORTS** Operational requirements – including registration, stabling, geographical area of use, permits for 3 wheelers (use as Taxi or hotel ferry?).	**COMMERCIAL** *Obtain input and reach consensus on peripheral efforts in support of the overall program* D. Vincent provided an overview of interest points for this topic. T. Basu gave a general description of the registration and permitting processes in India. He does not foresee any obstacles in obtaining registration and permits for the EV demo fleets. Bajaj will obtain from ARAI and other government organizations, as appropriate, all requirements and expects to have definitive direction from ARAI within 2-3 weeks. Partial basis for this position is that Bajaj will be using previously certified platforms. T. Basu requested information from SAE working committees on current thinking of total product safety issues for EVs. **ACTIONS: S. Schweitzer agreed to obtain SAE working papers.** **T. Basu to identify any registration requirements needed to be considered in the design of the electric drive systems and with the first EV autorickshaw and scooter prototypes within 2 – 3 weeks (31/3/99).** D. Vincent requested a copy of TERI's report for the Ministry of Urban Development on the impact of road transportation systems.

IZET KICK-OFF MEETING *FINAL MEETING MINUTES* *February 23 – March 4, 1999*			
AGENDA ITEM			MINUTES
			ACTION: T. Basu agreed to provide a photocopy of the TERI report – completed. T. Basu provided general weather and driving conditions expected at both demo sites. In particular there is a concern for the effects of dust, heat and water on the motor and electrical components of the demo fleet. A fair amount of discussion ensued by all parties. Possible solutions will be discussed in more detail during the technical portions of these meetings. One potential solution is to impose a conservative design standard. Permits for operation on the streets of Delhi and Agra were discussed. T. Basu indicated this would not be an issue since their local dealers are well aware of all necessary filings.
		Public Relations approach	There was a general discussion on this topic but all parties agreed that it is premature to begin a campaign at this point. It is recognized that the planning for publicity, however, needs to begin and coordinated with all participants. Coordination and review dates will be established in overall PR approach. S. Schweitzer requested the participants to identify their focal point for the coordination. Some general ideas are coordinating the colors, logos, providing brochures for Sheraton guests riding electric autorickshaws, labels or newly designed boxes for the pizzas, display in the lobby at the Sheraton, painting driver helmets for the electric scooters. Bajaj stated they do not want the EVs to look like "formula racing" vehicles. **ACTION: Bajaj, NGM, & UQM to identify contact point for publicity. Bajaj, NGM & UQM provided contact points. Completed.** **ACTION: D.Vincent to provide a "short list" of project titles for consideration and selection by all**

IZET KICK-OFF MEETING ***FINAL MEETING MINUTES*** ***February 23 – March 4, 1999***			
AGENDA ITEM			MINUTES
			parties for decision by tomorrow. (Completed, project title: "IZET" for Indian Zero Emission Transportation Project)
		Economic data	This topic was postponed and will be discussed separately with S. Schweitzer, T. Basu, & D. Vincent.
		Policy/Regulatory data	This topic was postponed and will be discussed separately with S. Schweitzer, T. Basu, & D. Vincent.
		Steering Committee	After a discussion by all parties, it was agreed to abandon the idea for this program.
		Title/Commercial risk	This topic elicited considerable discussion among all parties. In the end all agreed it is best the title for the EVs is with Bajaj. Current thinking is to lease the EVs to TRICON & WELCOMGROUP with a clause to indemnify Bajaj. Bajaj believes Indian laws preclude anyone involved in an accident or in the event of product failure resulting in injury/damage from claiming compensation from a third party. NGM requested to be named as additional insured under Bajaj's insurance policy. **ACTION: D.Vincent/T. Basu to confirm commercial arrangements with TRICON & WELCOMGROUP during upcoming visits. Discussed with both organizations will be finalized before urban test.** USAID and Bajaj will determine final disposition of equipment near the end of the demonstration phase at each respective test sites (Delhi & Agra). NGM and UQM may request one of the vehicles be returned. NOTE: NGM recalls the discussions on this issue to be that NGM would be involved in the decision to disposition their equipment. They have expressed concern about their equipment remaining in India if

IZET KICK-OFF MEETING ***FINAL MEETING MINUTES*** ***February 23 – March 4, 1999***			
AGENDA ITEM			MINUTES
		Detailed Summary of Discussions	the commercialization path is eliminated. RESPONSE: While there was various conversations on this issue. In the end, it was agreed by all that USAID and Bajaj will make final disposition. Additionally, it was also agreed that if NGM and/or UQM would request their equipment to be returned at the end of this program, then arrangements would be made - subject to agreeable terms with USAID. Considerable discussion ensued about a suitable non-disclosure statement between Bajaj and NGM & Bajaj and UQM. A draft version was negotiated and Bajaj is to provide the next iteration by tomorrow for another "round". K. Barnes needed to consult with UQM's home office for approval of today's discussions. Bajaj & UQM and Bajaj & NGM signed the non-disclosure statements on February 28. **ACTIONS: 1) Bajaj is to explore Indian laws to determine liability exposure, if any, for US firms supplying electric drive trains; 2) Bajaj is to send to Bechtel a copy of pertinent information on their insurance coverage.** Given the lateness of the day (approx. 7:00 PM) and the need for Bajaj personnel to attend another meeting, this issue was not discussed.
4	25/2/99	**TECHNICAL ORIENTATION TO PRODUCT PLATFORMS OF BAJAJ** 2 Wheeler/ 3Wheeler models	**TECHNICAL** *General presentation by Bajaj Product Platform engineers on the characteristics of vehicles, design and evaluation methodologies, steps to productionalising and after-sales service support.* Bajaj presented an overview of their 3 wheeler and 2 wheeler vehicles. There are two versions of the 3-wheeler

IZET KICK-OFF MEETING ***FINAL MEETING MINUTES*** ***February 23 – March 4, 1999***			
AGENDA ITEM			MINUTES
			autorickshaw, a front engine and a rear engine model. The autorickshaw being used for this program is a rear-engine model. Bajaj's target market for electric autorikshaws are owner-operated. Their daily running is 70 – 80 km per day. If the autorickshaw is leased, the daily running is 130 – 140 km. Maximum speed is 55 – 60 kph; front to rear weight ratio is one third front, two thirds rear; gear box is 91% - 92% efficient (third and fourth gear); the gear ratio of 5.63:1 (third gear) is the most comfortable, a vehicle can climb a 30% grade with a top speed of 48 kph; vehicle curb weight is 750 kg; diesel engine weighs 55 kg, the transmission weight is 28 kg. Daily earnings for an autorickshaw owner are about Rs 200 – 250; for a driver it is about Rs 150 – 175. The existing autorickshaw gearbox costs approximately \$90; diesel engine costs approximately \$350. The 2 wheeler, the Saffire, weighs approximately 75 kg. It has drum brakes on a 10-inch wheel. Bajaj is ISO 9001 certified. **ACTION: T. Basu to provide NGM and UQM with costs of engine and ICE components for the three wheelers by March 10th. Bajaj has requested a revised date of 28/3/99.** **ACTION: T. Basu to provide a list of tests and testing procedures used by Bajaj for the 2 & 3 wheel vehicles. (Completed)** **ACTION: T. Basu to provide a copy of overview charts used in 2 & 3-wheeler overview**

IZET KICK-OFF MEETING *FINAL MEETING MINUTES* *February 23 – March 4, 1999*			
AGENDA ITEM			MINUTES
5-10	26-28/2/99	Concepts, Design steps, Prototyping, Evaluation, Batch & Series Production, Service Functions	**presentation. Copy provided to USAID. D. Vincent to obtain and distribute copies to UQM & NGM. Completed 23/3/99.** **1.** ACTION: T. Basu to provide electronic files of Saffire drawings in multiple forms per the attached schedule; i.e.: one version detailing complete vehicle, one version with ICE components removed. ***Bajaj has reconsidered and does not believe the Saffire is the best platform for conversion. Bajaj is reinvestigating modifying the chassis of the Spirit and reducing the range requirements. Bajaj expects to resolve this issue by 5/4/99.*** **ACTION: T. Basu offered to provide UQM, NGM and Bechtel with any dynamic information --- Required by March 20th. Completed 16/3/99.** Bajaj gave an overview of the steps involved in vehicle production. All range numbers reflect an 80% depth of discharge. Originally Bajaj wanted to use their model, Spirit, for the scooter conversion. After much discussion, it was agreed to use the Saffire model for conversion. This model allows for greater flexibility in integration of the electrical drive system. The electric Saffire should have a range of about 75 km. **ACTION: T. Basu to provide NGM & UQM with parameter settings for dyno testing by March 20th. Bajaj advises this will be completed 22/3/99. Bechtel needs to confirm.** **ACTION: T. Basu to provide NGM, UQM and Bechtel with performance curves for vehicle acceleration by March 20th. Completed 16/3/99.**

IZET KICK-OFF MEETING *FINAL MEETING MINUTES* *February 23 – March 4, 1999*			
AGENDA ITEM			MINUTES
			Originally Bajaj planned a 45-day testing period for the vehicle in India before placing the EVs at the urban demo sites. In light of the accelerated schedule, this will be reduced. After seven days Bajaj will provide NGM/UQM with initial test data. Bajaj provided guidelines for selection of vehicle tests. It incorporated what Bajaj considers the more relevant tests from their standard testing procedures. **ACTION: T. Basu to provide the acceptance criteria by March 15th. (Completed)** The 3-wheeler that Bajaj converted to an EV has a range of 85km at 80% depth of discharge (DOD). The vehicle is equipped with Trojan flooded lead acid batteries. Performance specifications for the electric vehicles to be provided by NGM & UQM: The existing configurations such as frame, body, and ground clearance must be retained. Electric autorickshaw is to include these features: 1) Battery voltage 48 volts 2) Throttle to incorporate potentiometer (Bajaj to send 3-wheeler with throttle cable and twist handle). 3) Regenerative braking 4) Compression braking 5) Limp-home mode at 80% DOD. 6) Battery state of charge monitor 7) On-board charger. 8) DC to DC converter. 9) Top speed of 55kph at 60% DOD. 10) Gradability 10 kph – 19% (0-10 kph and maintain 10 kph for 10 meters) 20 kph – 10% (Continuous)

IZET KICK-OFF MEETING *FINAL MEETING MINUTES* *February 23 – March 4, 1999*			
AGENDA ITEM			MINUTES
			30 kph - 5% “ 40 kph - 3% “ 50 kph - 1% “ 11) Acceleration 0 to 20 kph - 3 sec 0 to 30 kph - 7 sec 0 to 40 kph - 15 sec 0 to 50 kph – 25 sec 12) Range should be 80 km. The electric scooter is to include these features: 1) Battery voltage 48 volts 2) Throttle to incorporate potentiometer (Bajaj to send 2-wheeler with throttle cable and twist handle). 3) Regenerative braking 4) Compression braking 5) Limp-home mode at 80% DOD. 6) Battery state of charge monitor 7) On-board charger. 8) DC to DC converter. 9) Top speed of 60kph at 60% DOD. 10) Gradability 10 kph – 19% (0-10 kph and maintain 10 kph for 10 meters) 30 kph – 10% (Continuous) 55 kph - 1% “ 11) Acceleration 0 to 20 kph - 2 sec 0 to 30 kph - 5 sec 0 to 40 kph - 9 sec 0 to 60 kph – 18 sec 12) Range to be 50 km minimum, 65 km desired. Ambient temperatures at Agra are 0 to 48 degrees Centigrade. Spares – NGM recommends one motor and two controllers for each platform. UQM recommends two complete systems for each platform. It was agreed that USAID would procure two motors and

IZET KICK-OFF MEETING *FINAL MEETING MINUTES* *February 23 – March 4, 1999*			
AGENDA ITEM			MINUTES
			controllers from NGM & UQM for each platform provided there is sufficient funds. Bajaj has subsequently requested 2 complete systems from UQM & NGM for each platform. Chargers – UQM/NGM to investigate and agree upon a common manufacturer. Batteries – Trojan flooded lead-acid for autorickshaw. Hawker sealed lead-acid for scooter. Note: It was subsequently agreed that NGM/UQM would investigate and present their findings to Bechtel. Bechtel to determine battery type. **ACTION: T. Basu to contact Trojan and Hawker to enlist their buy-in into the program. T. Basu to advise Bechtel of discussions. Bajaj will complete by 30/4/99.** Data Collection. It was agreed sensors be installed on the vehicles to collect the following data: 1) Leg current 2) Battery V, I 3) Hours of use 4) Temperatures – motor, battery, controller, ambient 5) Speed (motor, vehicle) 6) Throttle command level & brake command 7) Strain gauges (vehicle payload, chassis) 8) DC/DC voltage 9) DC/DC current 10) Brake on/off 11) Lights on/off 12) Horn on/off 13) Accessory on/off 14) Acceleration Both NGM and UQM have standard data collection packages that they use in-house and will provide the

IZET KICK-OFF MEETING *FINAL MEETING MINUTES* *February 23 – March 4, 1999*			
AGENDA ITEM			MINUTES
		Environ. Considerations, Driver preferences etc	data necessary for development and prototype testing. Bajaj to instrument the vehicles for more extensive testing in India. **ACTION: NGM/UQM to provide Bechtel/Bajaj with listing of data collected by their in-house systems by March 12th. UQM provided information on 11/3/99. Need information from NGM.** The "feel" of the electric vehicles should closely mimic the existing 2 & 3 wheelers.
5-10	26-28/2/99	Performance/Operating expectations	An overriding concern is that the driver does not have a different "feel." Ancillary devices (connectors, potentiometers, etc.) to be provided by NGM & UQM. Indicators, signals or controls that will be used by the operator should be consistent with conventional vehicles. System commands to be provided by UQM and NGM: accelerator command – signal form throttle (0-5 volts); key-on command – system indicator; key-off command – ties into the DC – DC converter; charger LED to indicate status; battery meter and state-of-charge; emergency off switch; forward/reverse switch on 3 wheeler. A safeguard should be included to prevent the electrical from being powered up until the diagnostics are complete. UQM/NGM requested that they be provided with a conventional 3 wheeler to assist their design efforts. Bajaj agreed. **ACTION: T. Basu to provide two Saffires (scooters) and two autorickshaws to both UQM**

IZET KICK-OFF MEETING *FINAL MEETING MINUTES* *February 23 – March 4, 1999*			
AGENDA ITEM			MINUTES
			and NGM as noted in the attached schedule. Refer to earlier comment on scooter platform. The motor, batteries, converter, chargers, special connectors are USA-supplied. Bechtel and Bajaj requested the battery packages to be consistent with each US firm. Bechtel to be copied on meaningful correspondence between Bajaj/UQM/NGM. Microsoft Office 97 software, Project/Word/Excel to be used for the project. Formal bi-monthly status reports by UQM, NGM, & Bajaj to be provided to Bechtel by the first of the month due. All agreed to notify Bechtel as soon as possible with any problems that affect scope of supply and/or schedule delays. **ACTION: D. Vincent to provide format for status report for comment by Bajaj, UQM & NGM by April 30 1999.**
6.0	26/2/99	Meeting Bajaj Management (Rahul Bajaj and Senior Managers)	Mr. Bajaj welcomed everyone. He provided Bajaj's view of EV technology and potential market applications and size. The current and projected market for two and three wheelers in India was characterized and quantified. Mr. Bajaj stated that the two US firms are free to pursue any market opportunities they wish but he must insist on exclusivity for India if there is to be a viable partnership. While there is growing pressure for controlling vehicle emissions, particularly in the larger urban areas, he does not feel there is an immediate market for EVs. Notwithstanding this, he is firmly committed to looking forward. Moreover, he has personally taken charge of Bajaj's strategy and course of actions for EVs. While he feels there is a

IZET KICK-OFF MEETING *FINAL MEETING MINUTES* *February 23 – March 4, 1999*			
AGENDA ITEM			MINUTES
			role for the public sector and endorses government involvement, he stressed the transport industry is in the best position to provide products that meet market needs. Government, on the other hand, is better positioned to handle issues like infrastructure and perhaps some creativity towards taxes and/or financing – particularly to facilitate the market in the early stages. He closed by wishing this program success but cautioned against high expectations from the participants, stating that this is part of the commercialization process. Dr. Schweitzer expressed his appreciation to Mr. Bajaj for moving forward on EV technology and for hosting our meetings in Pune this week. He believes conditions in India make EV technology particularly attractive, unlike other regions. This program has been in discussions for considerable time with Bajaj and it is gratifying to finally see movement. While he recognizes there are going to be difficulties, as in any similar program, it is reassuring to know Mr. Bajaj is personally behind this program. R. Edwards, USAID/India, expressed his appreciation to Mr. Bajaj for this meeting. He indicated USAID/India is firmly committed to this project and the potential environmental benefits EV technology provides. He stated the US Ambassador and Mission Director have taken a particularly keen interest in the program and other similar efforts. USAID/India is active on a number of initiatives to reduce urban air pollution. One of the examples sited is a study they are commissioning to investigate current import duties and restrictions with respect to the EV industry. He closed in stating he wishes this program success and will be working closely with Dr. Schweitzer to ensure success. R. Piacesi expressed his appreciation to Mr. Bajaj and indicated NGM is firmly committed to this program and beyond.

IZET KICK-OFF MEETING *FINAL MEETING MINUTES* *February 23 – March 4, 1999*			
AGENDA ITEM			MINUTES
			G. Geddes expressed his appreciation to Mr. Bajaj and also indicated UQM is fully committed to this program and looks forward to the opportunity of working with Bajaj beyond this program. D. Vincent indicated Bechtel is pleased to be supporting USAID in this program and appreciates the hospitality, commitment and support from Bajaj. He provided an overview of USAID's program. He stated the supply and testing of prototype EV scooters and autorikshaws in high profile locations is the most critical component. The objective of this component of USAID's program is to determine the feasibility of replacing conventional scooters and autorickshaws with EV drive systems. More importantly is the hope that Bajaj and one or both of the US firms will continue their efforts to bring these products to the marketplace.
11	27 & 28/2/99	Schedule	Considerable discussion ensued on the overall schedule for both platforms. All parties reached agreement on the schedules. NGM requested the dates for providing the electric autorikshaws to Sheraton be discussed during our scheduled visit. Given the timeframes, shipment by airfreight is needed to accommodate the schedule. Both UQM & NGM, at their own risk, agreed to begin work to meet the agreed upon schedules. See attached schedules. NOTE: Schedules not attached due to file size. **ACTIONS: T. Basu to provide estimated costs for air shipments. R. Piacesi, NGM, and K. Barnes, UQM, to provide shipping coordinates to Bajaj. T. Basu to provide NGM & UQM with preferred freight forwarder.** **ACTIONS (key milestones from agreed upon schedule):** **Bajaj to provide:** **1) Drawings for scooter and autorickshaw**

IZET KICK-OFF MEETING *FINAL MEETING MINUTES* *February 23 – March 4, 1999*			
AGENDA ITEM			MINUTES
			(electronic and/or 2-D DWG's) to UQM/NGM by March 1st. ***Bajaj sent the following drawings on the autorickshaw to UQM & NGM on 13/3/99: EVSK0001, General Layout; 0002, Transmission Assembly; 0003, Motor Clutch Assembly; 0004, Traction Motor; and 0005, Clutch Carrier. UQM acknowledged receipt without "redline" comments. NGM sent an email to Bajaj on 24/3/99 indicating more detail information is needed. Drawings for the scooter are delayed until a platform is decided upon – refer to earlier comment.*** **2) T. Basu will ship by March 8th via airfreight a differential unit and interface information to NGM/UQM. Bajaj advised the equipment has been shipped on 16/3/99. UQM & NGM have not received.** **3) 3 wheelers to UQM/NGM by June 9th, 2 wheelers by August 1st.** **4) Preliminary test results to UQM/NGM by September 15th.** **5) Accelerometer data – endurance test data (Excel files) to NGM/UQM by March 15th. Completed 15/3/99.** **ACTION: NGM/UQM to provide 3 wheeler drawings to Bajaj by December 1, 1999; 2 wheeler drawings by May 15, 2000.** Currently scheduled visits (refer to Project Schedules – Gantt Charts): Bajaj to visit NGM – task 18, proto EV test in U.S. NGM to visit Bajaj – task 50, assembly of 3 wheeler in India; task 56, test at Agra. Bajaj to visit UQM – task 19, proto EV test in U.S. UQM to visit Bajaj – task 51, assembly of 3 wheeler in India; task 57, test at Agra. Witness points:

IZET KICK-OFF MEETING *FINAL MEETING MINUTES* *February 23 – March 4, 1999*			
AGENDA ITEM			MINUTES
			Bechtel/Bajaj to witness at UQM/NGM: 1) Preliminary design review 2) Critical design review 3) Prototype testing Bechtel/UQM/NGM to witness at Bajaj 1) 15 day testing period 2) Final testing and introduction of vehicles to customer
12	29/2/99	Travel to Delhi	No minutes.
13	1/3/99	Travel to Agra	No minutes.
14	1/3/99	Meet with Bajaj Dealership Personnel. Ascertain travel conditions in Agra.	Traveled expected route of EV autorickshaws. Distance is about 40-km roundtrip from Sheraton Hotel to points of interest for tourists. Road conditions vary from satisfactory to extremely uneven. The areas in poor condition are due to street repairs and potholes. We were advised temperatures during the year range from 0° C to 56° C. Dealership personnel appear to be committed and have adequate resources. There was a general discussion about expectations and the characteristics of the EVs – how to charge, troubleshoot, repair, & collect data.
15	2/3/99	Meet Sheraton Personnel	Discussion with Sheraton GM, S. Schweitzer, T. Basu, & D.Vincent preceded formal meeting. The schedule was discussed and the GM reiterated his position that a delivery by October 1999 is preferred. GM also expressed concerns about liability during urban demo and his need to obtain clearance through corporate headquarters in Delhi. Potential solutions discussed for liability included Bajaj or Sheraton or Bechtel procuring additional insurance to protect all parties. Regarding schedule, GM was advised the best that could be done is late December 1999 or January 2000. All agreed to work together. The entire team met the GM and the chief engineer to assess Sheraton operations and to discuss expectations and handling methods for the EV urban demo. Found the hotel to be well organized and staff

IZET KICK-OFF MEETING ***FINAL MEETING MINUTES*** ***February 23 – March 4, 1999***			
AGENDA ITEM			MINUTES
			to be quite competent. GM agreed to have a questionnaire on autorickshaw driving profile translated and completed. Bajaj reassured Sheraton the local dealer would handle maintenance in an efficient manner. Sheraton is very interested in working with USAID to publicize the EV program. Memorandum of Understanding between USAID and Sheraton was signed. **ACTION: D. Vincent to prepare autorickshaw driving profile questionnaire and send to GM by April 28.**
16	2/3/99	Meet Local Authorities	Due to a local holiday a meeting with the local authorities could not be arranged.
17	3/3/99	Return to Delhi	No minutes.
18 & 19	3/3/99	Meet TRICON Personnel. Ascertain travel conditions in Delhi.	The team met with TRICON executive to discuss the overall program and the details of the EV urban demo program. A pamphlet providing a general description of the overall program and prime contact list for all participants was given to TRICON. Schedule was discussed. It is anticipated the EVs will be delivered to TRICON by late 1st quarter 2000 or early 2nd quarter. TRICON is very interested in working with USAID to publicize the EV program. Bajaj provided reassurance of timely repairs and maintenance. TRICON arranged for the team to visit one of the restaurants where the EV urban demo will take place. Team was able to see operations and capabilities at this location. Restaurant Manager provided an overview of operations. Problems with current conventional scooters were discussed. The driving profile and charging requirements were discussed in detail. Memorandum of Understanding between USAID and TRICON was signed. Team visited local Bajaj dealership, Bagga Link, and

IZET KICK-OFF MEETING *FINAL MEETING MINUTES* *February 23 – March 4, 1999*			
AGENDA ITEM			MINUTES
			toured facilities to assess operations. Discussed expectations and handling methods for the EV urban demo. Found the dealership to be well organized and staff to be quite competent. Dealership is very interested in working with USAID to publicize this program.
20	4/3/99	Wrap-up meeting with USAID	R. Berry opened the meeting providing the purpose and welcoming all to the Mission. Following introductions, S. Schweitzer provided an overview of activities and accomplishments these past two weeks. T. Basu provided Bajaj's perspective on this program and EV markets in India. K. Barnes, UQM, & B. Piacesi, NGM, expressed their appreciation to USAID and their commitment to this program. R. Goldman indicated the Ambassador and Mission are solidly behind this program. He expressed a need to work together and encouraged open communication. Memorandum of Understanding between USAID and Bajaj was signed.

Indian Zero Emission Transportation Program (IZET)

Technical Specification

23865-E-107S-EV-NGM Rev.4

Electric Scooter

Table of Contents

1. General

The Indian Zero Emission Transportation Program (IZET) is a collaborative effort among USAID, Nexant, Bajaj Auto, and New Generation Motors (NGM) to provide a commercially attractive mode of transportation that reduces urban ambient air and noise pollution. The IZET program objective for the electric two-wheeler is to design an all electric powered scooter using Bajaj's platform. Prototype vehicles will be placed into monitored demonstration service with TRICON Restaurants International in Delhi, India and elsewhere. NGM will concept, design, engineer, and manufacture an electric traction drive to be integrated with the scooter and integrate one prototype vehicle. This prototype vehicle will be instrumented and tested. Additional vehicles will be converted to electric drive and operated over a period consistent with the IZET program schedule to provide data concerning the day-to-day operational characteristics/requirements of the vehicles. The data collected will be analyzed to provide an assessment of the requirements and operational/commercial feasibility of an electric scooter in India. Spares for the electric drive train will also be provided to support the urban demonstration effort.

2. Scope of Work

This section describes the scope of work. The schedule for the scope of work can be found in Attachment B.

2.1 NGM shall design and prototype an electric drive system for the two-wheeled scooter. Equipment supplied by NGM shall include:

a) Traction Motor
b) Traction Inverter/Controller
c) Batteries. Nexant/Bajaj shall investigate the potential relationship with the major battery manufacture and their willingness to participate in this demonstration program. If a suitable partnership cannot be arranged with a battery supplier, then NGM will purchase batteries for the program as described in Attachment D.
d) DC/DC Converter
e) Charger
f) Interface components between electric drive system and vehicle platforms not provided by Bajaj on the vehicle supplied for the initial conversion
g) Ancillary components as specified in Attachment C of this document

2.2. NGM, at its facility in Ashburn, Virginia, shall prototype the drive system and integrate one prototype two-wheeler.

2.3. NGM shall be provided two scooters. One vehicle shall serve as a “baseline” while designing and testing the electric vehicle for qualitative attributes. The second vehicle shall be converted to an electric-powered vehicle using NGM's Brushless

Permanent Magnet Motor and Controller/Inverter traction drive technology. At the end of the IZET program, NGM will be provided with disposition instructions for the conventional vehicle.

2.4. NGM shall be provided adequate drawings and CAD files necessary for the design and integration of the electric drive systems.

2.6. NGM shall submit a written test plan to Nexant for approval for bench testing of the motors and controllers and for full vehicle performance testing.

2.7. NGM shall submit documentation on internal sensors/data to Nexant that are available from the motor/controller system for data acquisition and instrumentation purposes. This information shall be made available to Nexant prior to award.

2.8. NGM shall test the motors/controllers and the fully integrated vehicle according to the approved test plan and submit the test results to Nexant.

2.9. NGM shall provide electric drive trains as follows:

- 1 Integrated Prototype
- 18 Electric Drive Train Sets (15 Sets for vehicles and 3 sets for spares)

2.10. NGM shall ship the initial integrated two-wheeler to Bajaj Auto, F.O.B. Mumbai, India, upon acceptance in the U.S. by Nexant. Acceptance criteria are defined in Section 5 of this document.

2.11. NGM shall participate and provide technical support for the preliminary design review at Bajaj's offices in Pune, India of up to 5 working days, excluding travel.

2.12. NGM shall participate and provide technical support for initial prototype testing in India for a period of up to 10 working days, excluding travel.

2.13. NGM shall prototype fifteen additional electric drive systems for the scooter platform and ship those components to Bajaj Auto, F.O.B. Mumbai, India, for integration. The equipment provided shall include:

a) Traction Motor
b) Traction Inverter/Controller
c) Batteries
d) DC/DC Converter
e) Charger
f) Ancillary hardware designed by NGM (Attachment C) for the integration of the electric drive systems with the autorickshaw
g) Interface components between the electric drive system and vehicle platform not provided by Bajaj on the vehicle for the initial conversion.

2.14. NGM shall provide adequate package and interface drawings, installation instructions and user manuals to be used for the integration of the electric drive systems.

2.15. NGM shall provide on-site training and support to Bajaj Auto on the integration, operation, and maintenance of the electric drive systems for a period of up to 10 working days in India, excluding travel.

2.16. NGM shall provide on-site training to the demonstration users on the operation and maintenance of the electric drive systems for a period of five working days in India, excluding travel.

2.17. NGM shall provide onsite review of vehicle performance and user operation for a period of five working days in India, excluding travel.

2.18. NGM shall provide and ship to Bajaj Auto, F.O.B. Mumbai, India, three additional electric drive systems as spares. Spare systems shall include:

a) Traction Motor
b) Traction Inverter/Controller
c) DC/DC Converter
d) Charger
e) Batteries
f) Ancillary hardware designed by NGM for the integration of the electric drive systems with the autorickshaw.
h) Interface components between electric drive system and vehicle platforms not provided by Bajaj on the vehicle supplied for the initial conversion.

2.19. NGM shall provide ongoing technical support from the U.S. during the demonstration phase of the IZET program.

3. Codes and Standards

3.1. The following references are provided for guidance in the design and selection of components for the electric drive system:

ANSI	American National Standards Institute
BAS	Bajaj Auto Standards
IEEE	Institute of Electrical and Electronic Engineers
NEC	National Electrical Code
NSC	National Electrical Safety Code
UL	Underwriter’s Laboratories
JIS	Japanese Industrial Standards
IEC	International Electrotechnic Commission
ISO	International Standards Organization

3.2. Metric hardware shall be used wherever possible/practical.

4. Drawings and Documents

4.1. Industry standard symbols and nomenclature shall be used on all drawings.

4.2. Electronic format is recommended when exchanging drawings. The following formats are preferred:

TYPE	FORMAT
2d & 3d models	IGES or STEP
2d sketch & drawings	DXF

4.3. Microsoft's family of Office 97 and Microsoft Project 98 software shall be used for project documents.

4.4. NGM shall provide one electronic and four hard copies of the documents identified in Attachment D.

5. Technical Specification

The following technical specification for the two-wheeled vehicle is intended to provide operational characteristics that closely mimic the conventionally powered scooter. It is important that the qualitative operator "feel" and interface with the vehicles remains as consistent as possible with that of the conventional vehicles.

5.1. Two-Wheeled Electric Scooter specifications.

5.1.1 At a minimum, the vehicle shall include the following features:

a) Throttle input
b) Regenerative braking
c) Compression braking "feel"
d) Battery state-of-charge
e) On-board charger (220vac, 50Hz)
f) DC/DC converter to 14 volts, 80W DC for auxiliaries
g) Emergency off switch
h) Limp-home mode at 80 percent depth of discharge

5.1.2 Two-wheeler vehicle performance requirements, based upon Hawker Battery model G16EP and its published data, are as follows:

a) At 60 percent, depth of discharge the top speed shall be at least 60 kph.

b) The following shall be the gradeability performance for the vehicle at 60 percent depth of discharge:

Speed	Gradeability
10 kph	19 percent (0-10 kph and maintain 10 kph for 10 meters)
30 kph	10 percent (continuous)
55 kph	1 percent (continuous)

c) The following shall be vehicle accelerations at 60% state of charge, on level ground. (Surface is to be concrete, asphalt, or chassis dynamometer rollers):

Acceleration	Time
0 to 20 kph	2 sec
0 to 30 kph	5 sec
0 to 40 kph	9 sec
0 to 60 kph	18 sec

d) The targeted range for the NGM powered two-wheeler vehicle at 80 percent depth of discharge is > 55 km at 25°C, while driving the Indian Driving Cycle (IDC), as given in Attachment A, on a chassis dynamometer. NGM shall however demonstrate a range of at least 45 km under these conditions. At 80% DOD, the ranges of 37 km at 0°C and 51 km at 48°C are predicted.

Note: All testing conducted to confirm the performance described under Section 5 (5.1.2. a, b, c, and d) should be conducted with payload as 75 kg., and tire pressures as recommended by Bajaj. Curb weight shall be assumed to be 125 kg and tire rolling radius at 199 mm at maximum Gross Vehicle Weight, for the purposes of preliminary design. Vehicle losses are to be assumed as 0.18 N/kg + 0.025 N/kph^2.

5.1.3 Batteries for the two-wheeler shall be Lead Acid, Hawker Battery Model G16EP (or buyer approved alternate), with nominal battery pack voltage not to exceed 60 volts.

5.1.4 In addition to vehicle performance requirements described in Items 5.1.2. a, b, c, and d, all items supplied by NGM shall be designed to operate in the following environmental conditions.

a) Operating temperature: 0 - 48° C
b) Operating humidity: 95 percent @ 40°C non-condensing
c) Water immersion and high pressure washing jets, as appropriate
d) High dust environment

5.1.5 NGM shall use good engineering practices for the design of the electric drive system. The following standards and criteria are provided as guidance:

a)	Endurance test	BAS 08-037, Rev 0
b)	Serviceability test	BAS 08-139, Rev 0
c)	Drive-ability test	BAS 08-084, Rev 1
d)	Hot start-ability test	BAS 08-154, Rev 0
e)	Cold start-ability test	BAS 08-155, Rev 0
f)	Water ingress/splash test	BAS 08-077, Rev 1
g)	Subjective postural/ergonomic test	BAS 08-147, Rev 2
h)	Handling & maneuverability test	BAS 08-072, Rev 1
i)	Subjective headlamp illumination test	BAS 08-162, Rev 0
j)	Ride comfort test	BAS 08-148, Rev 0

k) For the final vehicle configuration, items supplied by NGM shall be designed for operational endurance test criteria as per Attachment F. Applicability of these criteria regarding a specific component and in a particular vehicle platform is outlined by Attachment H. For the purposes of configuring the prototype, these criteria are to be incorporated where practical.

l) Additionally, complete vehicles shall be designed by NGM to meet the environmental, handling, and driveability test criteria as given in Appendix G. Applicability of these criteria regarding a particular vehicle platform is outlined by Attachment H.

m) NGM shall design the electric drive system to meet the India road worthiness certification process as currently required (Attachment I).

5.1.6 NGM shall serialize all electric motors and controllers.

6. Acceptance

6.1. Specification Validation

NGM will provide a Brushless Permanent Magnet Motor and Inverter/Controller traction drive system integrated into the Bajaj scooter. The vehicle will be modified for electric operation. Because this type of vehicle has not been previously tested, NGM shall deliver a tested prototype vehicle that meets the performance stated in Section 5. NGM shall provide the initial prototype vehicle with integrated drive system and eighteen additional drive systems (15 systems and three spare sets) to USAID/Nexant. The NGM powered electric two-wheeler is to be tested dynamically on a certified chassis dynamometer or suitable facility capable of simulating performance criteria in Section 5.

6.2. Qualitative/Subjective

The qualitative performance attributes of the Bajaj scooter will be integrated into the NGM powered electric two-wheeler in an effort to maintain as much of the "driveability" feeling as possible.

6.3 During the scheduled preliminary design review the concepts and design shall be assessed for compliance with this technical specification. In the event of noncompliance design options shall be discussed in good faith. If suitable resolutions cannot be reached, this program may be terminated.

6.4 Witness Points

Nexant to witness NGM's:

1) preliminary design review
2) critical design review
3) initial integrated vehicle testing prior to shipment
4) traction drive tests prior to shipment
5) data collection and reduction

Nexant and/or NGM shall witness in India:

1) Bajaj prototype testing
2) Initial assembly and testing of the five drive systems
3) Introduction and training at demonstration site
4) Operations at the demonstration site
5) Data collection and reduction

7. Schedule

NGM shall meet the schedule in Attachment B.

8. Deliverables

Attachment D details a list of deliverables for this drive development, vehicle integration, and testing program.

9. Communication

9.1 It is expected that there will be frequent exchanges of information between NGM and other IZET participants. Nexant shall be notified in writing on information that affects the scope of work, technical specifications, budget, or schedule as listed in the procurement documents. No changes shall be permitted without Nexant's approval.

9.2 Status reports shall be submitted to Nexant each month on the first workday of the month. Format for this report is Attachment A.

9.3 E-mail shall be the preferred method for routine communications.

10. Attachments:

A Indian Driving Cycle
B. Bi-Monthly Report Status
C. Two-wheeler schedule
D. Ancillary Components
E Program Deliverables
F Environmental Tests for Components
G Environmental Tests for Vehicles
H Applicability Table for Environmental Tests
I Conformity of Production Procedure

ATTACHMENT A – Indian Driving Cycle

Sr No.	Operation	Acceleration (m/s^2)	Speed (kph)	Duration of each operation (sec)	Cumulative time (sec)
1.	Idling	–	–	16	16
2.	Acceleration	0.65	0 – 14	6	22
3.	Acceleration	0.56	14 – 22	4	26
4.	Deceleration	-0.63	22 – 13	4	30
5.	Steady speed	–	13	2	32
6.	Acceleration	0.56	13 – 23	5	37
7.	Acceleration	0.44	23 – 31	5	42
8.	Deceleration	-0.56	31 – 25	3	45
9.	Steady speed	–	25	4	49
10.	Deceleration	-0.56	25 – 21	2	51
11.	Acceleration	0.45	21 – 34	8	59
12.	Acceleration	0.32	34 – 42	7	66
13.	Deceleration	-0.46	42 – 37	3	69
14.	Steady speed	–	37	7	76
15.	Deceleration	-0.42	37 – 34	2	78
16.	Acceleration	0.32	34 – 42	7	85
17.	Deceleration	-0.46	42 – 27	9	94
18.	Deceleration	-0.52	27 – 14	7	101
19.	Deceleration	-0.56	14 – 0	7	108

ATTACHMENT B -- Monthly Report

Monthly status reports shall contain the following:

1. Summarize Activities Completed this Report Period.
2. Summarize Problem Areas/Concerns this Report Period and Resolution
3. Summarize Planned Activities During the Next Report Period.
4. Provide Recommendations

ATTACHMENT C – Two-wheeler schedule

Preliminary Design Review – December 10, 1999

Delivery of Initial Prototype to Mumbai, India – April 13, 2001

Delivery of all (18) electric drive trains to Mumbai, India – August 24, 2001

Final Report – November 11, 2001

ATTACHMENT D – Ancillary Components

1. Twist Grip Throttle Pot
2. Brake Pot
3. Wiring Harness Material
4. Disconnect Switch
5. Battery SOC Indicator
6. Mounting Brackets
7. High Voltage Relay
8. Fuses

Quantities of ancillaries to be consistent with drive systems.

ATTACHMENT E – Program Deliverables

Documents

1	**Motor Electro-Magnetic Design Report ***
2	**Motor - Preliminary Package Drawings ***
3	**Controller – Preliminary Design Report ***
4	**Controller –Preliminary Package Drawings ***
5	**Motor/Controller System - Predicted Drive Performance Sheet ***
6	**Motor/Controller System - Dynamometer Test Plan**
7	**Prototype Electric Two-Wheeler Test Plan**
8	**Motor - Final Package/Interface Drawings ****
9	**Controller - Final Package/Interface Drawings ****
10	**Hardware Photos – Prototype Drive System for Vehicle Integration**
11	**Motor/Controller System-Dynamometer Test Data**
12	**Prototype Electric Two-Wheeler Test Data**
13	**Drive System Installation and Operating Instructions**
14	**User Manual**
15	**Progress Reports**
16	**Final Report**

*** Documents to be submitted at scheduled preliminary design review.**

**** Documents to be submitted at scheduled critical design review.**

Equipment

1	**Completed Prototype Electric Two-Wheeler w/o Batteries**
2	**18-Prototype Drive Systems (15 installs, 3 spares) and Test Data**
3	**18-Ancillary Packages (15 installs, 3 spares)**
4	**160-Hawker Battery Model G16EP, 12 Vdc (or buyer approved alternate), Sealed Lead Acid Batteries** ▪ **8 batteries to be delivered to NGM for Testing.** ▪ **152 batteries to be delivered F.O.B. Mumbai, India for vehicle installations.**

Appendix 2-A

ATTACHMENT F – Environmental and Endurance Tests for Components

Note**: See Attachment H for Applicability Table**

SR. NO	TEST	TEST DESCRIPTION	SAMPLE SIZE	ACCEPTANCE CRITERION	SPECIAL REMARKS
COMPONENT TESTS					
1.	Shock Test	1. Acceleration 100g 2. Pulse duration 11msec 3. Direction X, Y, Z 4. No of Cycles 2 in each direction		1. No cracks, chips etc. 2. Item to function normally after test	
2.	Vibration Test	1. Acceleration 30g 2. Frequency 50 to 500Hz 3. Sweep 6 min. logarithmic 4. Duration 20 hrs. each plane		1. No mechanical damage 2. Item to function normally after test	
3.	Thermal Shock Test (Liq. to Liq.)	1. Medium Water 2. Lower temp. 0ºC 3. Upper temp. 100ºC ± 5 4. Duration at each temp.10min. 5. Transfer time 10 sec. (max) 6. No of Cycles 25		1. No visible cracks, delamination etc. 2. Item to function normally after test	
4.	Thermal Shock Test. (Air to Air)	1. Lower temp. – 40ºC ± 5 2. Upper temp. 100ºC ± 5 3. Duration at each temp.1hr. 4. Transfer time 2 min. (max) 5. No of Cycles 50		1. No visible cracks, delamination etc. 2. Item to function normally after test	

SR. NO	TEST	TEST DESCRIPTION	SAMPLE SIZE	ACCEPTANCE CRITERION	SPECIAL REMARKS
5.	Moisture Test	1. Test Std. JIS D-0203-1976 2. Type of test M2 3. Mode Functional operating 4. Set up (Standard) As per Fig.1 5. Test time 8hrs.		Item to function normally after test	Generally for all items mounted inside the passenger compartment of a vehicle and not subjected to rain/ spray/ power wash and immersion
6.	Water Spray Test	1. Test Std. JIS D-0203-1976 2. Type of test S2 3. Spray ON time 10 min. (Non Functioning) 4. Spray OFF time 20 min. (Functional operating) 5. Set up As per Fig.1 of Standard 6. No of Cycles 50		Item to function normally after test	For all items mounted on the body of the vehicle and subjected to rain/ spray/ occasional power wash but not to immersion at any point of its operational life (generally over 350mm from the ground level))
7.	Water Immersion Test	1. Test Std. JIS D-0203-1976 2. Type of test D3 3. Depth of immersion 300mm 4. Mode (Non Functioning) 5. Test time 1hr. 6. Drain Time 10min.		Item to function normally after test	For all items mounted on the body of the vehicle and subjected to rain/ spray/ occasional power wash and immersion at some point of its operational life (generally below 350mm from the ground level)
8.	Dust Test (Floating)	1. Test Std. JIS D-0207-1977 2. Type of test F2 3. Stirring time 5sec 4. Suspension time 10min. 5. Mode (Non Functioning) 6. Test time 8hr.		Item to function normally after test	Generally for all items mounted inside the passenger compartment of a vehicle at a height of 100mm above floor level

SR. NO	TEST	TEST DESCRIPTION	SAMPLE SIZE	ACCEPTANCE CRITERION	SPECIAL REMARKS
9.	Dust Test (Driven)	1. Test Std. JIS D-0207-1977 2. Type of test C1 3. Mode (Non Functioning) 4. Test time 6hr.			For all items mounted on the body of the vehicle and subjected to driven dust
10.	Corrosion Test	TBD			
11.	Endurance Test	1. Operating Condition: Rated Voltage/ Current/ Load/ Speed as applicable 2. Ambient Temp. 70ºC ± 5 3. Duration 500hrs.			

ATTACHMENT G – Environmental and Endurance Tests for Vehicles

Note**: See Attachment H for Applicability Table**

SR. NO	TEST	TEST DESCRIPTION	SAMPLE SIZE	ACCEPTANCE CRITERION	SPECIAL REMARKS
VEHICLE TESTS					
1.	Drivability test	As per BAS 08-084		1. Rating of 7.0 and above as per para. 2 of the Standard 2. Vehicle and components to function normally after test	1. Substitute all references to carburetor, air/fuel mixture etc and with appropriate references to EV parameters. 2. Flat Spot /hesitation is to be considered as related to delayed start-up, cogging/ torque ripples, throttle response curve etc.
2.	Handling and Maneuverability Test	A per BAS 08-072		1. Rating of 7.0 and above as per para. 4 of the Standard 2. Vehicle and components to function normally after test	
3.	Vehicle Endurance Test	As per BAS 08 037		Vehicle and components to function normally after test	1. Item 3.3.1.2 (a) – Clause to be deleted 2. Item 3.3.31.2 (b) to be amended to 12 days instead of 3 days. 3. Item 3.3.3 to be deferred until performance at low temperatures is established.

SR. NO	TEST	TEST DESCRIPTION	SAMPLE SIZE	ACCEPTANCE CRITERION	SPECIAL REMARKS
					4. Relevant corrections for EVs in relation to “fuel” etc to be made.
4.	Quick Acceleration/ Deceleration Test	As per BAS 08-081		1. As per para. 7 of the Standard 2. Vehicle and components to function normally after test	Annexure 1 and 2 to be revised for deletion of ICE components and addition of EV components for each vehicle platform.
5.	Gear Change Test	As per BAS 08-074		1. As per para. 7 of the Standard 2. Vehicle and components to function normally after test	Annex 1 and 2 – deletion of ICE and addition of EV components for each vehicle platform.
6.	Water Ingress/ Splash Test	1. Generally as per — BAS 08-077 2. Situs of the test track — VRDE test 3. Depth of water — 150±20mm 4. Length of track — 100m 5. Distance to be covered — 5km		1. Vehicle and components to function normally after test 2. Water ingress in designated components to be checked	
7.	Water Immersion Test	TBD			
8.	Dust Test	1. Generally as per — BAS 08-163 2. Distance to be covered — 50km		Vehicle and components to function normally after test	Substitute all references to carburetor, air/fuel mixture etc and with appropriate references to EV parameters

ATTACHMENT H – Applicability Table for Environmental Tests

Sr. No	COMPONENT	Shock Test	Vibration Test	Thermal Shock Test (Liq. to Liq.)	Thermal Shock Test. (Air to Air)	Moisture Test	Water Spray Test	Water Immersion Test	Dust Test (Floating)	Dust Test (Driven)	Corrosion Test	Endurance Test	Drivability Test	Vehicle Endurance Test	Quick Acceleration/ Deceleration Test	Gear Change Test	Water Ingress/ Splash Test	Water Immersion Test	Dust Test
1.	Speedometer	π	π		π	π	π		π		π	π	π	π	π		π	θ	π
2.	Throttle Control Electricals	π	π	π	π	π	π	θ		π	π	π	π	π	π	π	π	θ	π
3.	Brake Control Electricals	π	π	π	π	π	π	θ		π	π	π	π	π	π	π	π	θ	π
4.	Tell Tales/ Fault Indicators	π	π	π	π	π	π	θ	π		π	π	π	π	π	π	π	θ	π
5.	Battery Gauge	π	π		π	π	π		π		π	π	π	π	π		π	θ	π
6.	Emergency OFF Switch	π	π	π	π	π	π	θ		π	π	π	π	π	π	π	π	θ	π
7.	Forward-Reverse Switch	π	π	π	π	π	π	θ		π	π	π	π	π	π	π	π	θ	π
8.	Key switch	π	π	π	π	π	π	θ		π	π	π	π	π	π	π	π	θ	π
9.	Motor	π	π	π	π	π		θ		π	π	π	π	π	π	π		π	π
10.	Motor Controller	π	π	π	π	π		π		π	π	π	π	π	π	π		π	π
11.	Battery Charger	π	π	π	π	π	π	π		π	π	π	π	π	π	π	π	θ	π
12.	Junction Box	π	π	π	π	π	π	θ		π	π	π	π	π	π	π	π	θ	π
13.	Power Connectors	π	π	π	π	π		π		π	π	π	π	π	π	π		π	π
14.																			
15.																			
16.																			
17.																			

KEY: π Generally for all vehicles and for 3 Wheelers if components are mounted 350mm above the ground

θ Generally for 2 Wheelers only, and, for 3 Wheelers if components are mounted lower than 350mm from ground

Indian Zero Emission Transportation Program (IZET)

Technical Specification

23865-E-107A-EV-NGM Rev.3

Electric Autorickshaw

Table of Contents

1. General

The Indian Zero Emission Transportation Program (IZET) is a collaborative effort among USAID, Bechtel, Bajaj Auto, and New Generation Motors (NGM) to provide a commercially attractive mode of transportation that reduces urban ambient air and noise pollution. The IZET program objective for the electric three-wheeler is to design an all-electric powered autorickshaw using Bajaj's rear-engine diesel model. Prototype vehicles will be placed into monitored demonstration service at several sites, including the Mughal Sheraton in Agra, India, where traditional internal combustion powered vehicles have been banned within a five-km radius around the Taj Mahal. NGM will concept, design, engineer, and manufacture an electric traction drive for the autorickshaw and integrate one prototype vehicle. This prototype vehicle will be instrumented and tested. The additional prototype vehicles will be converted to electric drive and operated over a period consistent with the IZET program schedule to provide data concerning the day-to-day operational characteristics/requirements of the vehicles. The data collected will be analyzed to provide an assessment of the requirements and operational/commercial feasibility of an electric autorickshaw in India. Spares for the electric drive train will also be provided to support the urban demonstration efforts.

2. Scope of Work

This section describes the scope of work. The schedule for the scope of work can be found in Attachment B.

2.1 NGM shall design and prototype an electric drive system for the three-wheeled rear-engine autorickshaw. Equipment supplied by NGM shall include:

a) Traction Motor
b) Traction Inverter/Controller
c) Batteries. Bechtel/Bajaj shall investigate the potential relationship with the major battery manufacture and their willingness to participate in this demonstration program. If a suitable partnership cannot be arranged with a battery supplier, then NGM will purchase batteries for the program as described in Attachment D.
d) DC/DC Converter
e) Charger
f) Interface components between electric drive system and vehicle platforms not provided by Bajaj on the vehicle supplied for the initial conversion
g) Ancillary components as specified in Attachment C of this document

2.2. NGM, at its facility in Ashburn, Virginia, shall prototype the drive system and integrate one prototype three-wheeler.

2.3. NGM shall be provided two conventional three-wheeled Bajaj rear-engine model autorickshaws. One vehicle shall be a complete petrol conventional vehicle. This vehicle can be used by NGM as a “baseline” while designing and testing the electric vehicle for qualitative attributes. The second shall be a conventional vehicle without the engine but will include battery supports and battery boxes. This vehicle shall be converted to an electric-powered vehicle using NGM's Brushless Permanent Magnet Motor and Controller/Inverter traction drive technology driving through the existing transmission/differential assembly. At the end of the IZET program, NGM will be provided with disposition instructions for the conventional vehicles.

2.4. NGM shall be provided one transmission/differential assembly presently used on a diesel three-wheeled Bajaj autorickshaw. This assembly shall be used for the initial prototype three-wheeler.

2.5. NGM shall be provided adequate drawings and CAD files necessary for the design and integration of the electric drive systems.

2.6. NGM shall submit a written test plan to Bechtel for approval for bench testing of the motors and controllers and for full vehicle performance testing.

2.7. NGM shall submit documentation on internal sensors/data to Bechtel that are available from the motor/controller system for data acquisition and instrumentation purposes. This information shall be made available to Bechtel prior to award.

2.8. NGM shall test the motors/controllers and the fully integrated vehicle according to the approved test plan and submit the test results to Bechtel.

2.9. NGM shall provide nineteen electric drive trains as follows:

- 1 Integrated Prototype
- 18 Electric Drive Train Sets (15 sets for vehicles and 3 sets for spares)

2.10. NGM shall ship the initial integrated three-wheeler to Bajaj Auto, F.O.B. Mumbai, India, upon acceptance in the U.S. by Bechtel. Acceptance criteria are defined in Section 5 of this document.

2.11. NGM shall participate and provide technical support for initial prototype testing in India for a period of up to 10 working days, excluding travel.

2.12. NGM shall prototype fifteen additional electric drive systems for the autorickshaw platform and ship those components to Bajaj Auto, F.O.B. Mumbai, India, for integration. The equipment provided shall include:

a) Traction Motor

b) Traction Inverter/Controller
c) Batteries
d) DC/DC Converter
e) Charger
f) Ancillary hardware designed by NGM (Attachment C) for the integration of the electric drive systems with the autorickshaw
g) Interface components between the electric drive system and vehicle platform not provided by Bajaj on the vehicle for the initial conversion.

2.13. NGM shall provide adequate package and interface drawings, installation instructions and user manuals to be used for the integration of the electric drive systems.

2.14. NGM shall provide on-site training and support to Bajaj Auto on the integration, operation, and maintenance of the electric drive systems for a period of up to 10 working days in India, excluding travel.

2.15. NGM shall provide on-site training to the demonstration users on the operation and maintenance of the electric drive systems for a period of five working days in India, excluding travel.

2.16. NGM shall provide onsite review of vehicle performance and user operation for a period of five working days in India, excluding travel.

2.17. NGM shall provide and ship to Bajaj Auto, F.O.B. Mumbai, India, three additional electric drive systems as spares. Spare systems shall include:

a) Traction Motor
b) Traction Inverter/Controller
c) DC/DC Converter
d) Charger
e) Batteries
f) Ancillary hardware designed by NGM for the integration of the electric drive systems with the autorickshaw.
g) Interface components between electric drive system and vehicle platforms not provided by Bajaj on the vehicle supplied for the initial conversion.

2.18. NGM shall provide ongoing technical support from the U.S. during the demonstration phase of the IZET program.

3. Codes and Standards

3.1. The following references are provided for guidance in the design and selection of components for the electric drive system:

ANSI	American National Standards Institute
BAS	Bajaj Auto Standards
IEEE	Institute of Electrical and Electronic Engineers
NEC	National Electrical Code
NSC	National Electrical Safety Code
UL	Underwriter's Laboratories
JIS	Japanese Industrial Standards
IEC	International Electrotechnic Commission
ISO	International Standards Organization

3.2. Metric hardware shall be used wherever possible/practical.

4. Drawings and Documents

4.1. Industry standard symbols and nomenclature shall be used on all drawings.

4.2. Electronic format is recommended when exchanging drawings. The following formats are preferred:

TYPE	FORMAT
2d & 3d models	IGES or STEP
2d sketch & drawings	DXF

4.3. Microsoft's family of Office 97 and Microsoft Project 98 software shall be used for project documents.

4.4. NGM shall provide one electronic and four hard copies of the documents identified in Attachment D.

5. Technical Specification

The following technical specification for the three-wheeled vehicle is intended to provide operational characteristics that closely mimic the conventionally powered autorickshaw. It is important that the qualitative operator "feel" and interface with the vehicles remains as consistent as possible with that of the conventional vehicles.

5.1. Three-Wheeled Electric Autorickshaw specifications.

5.1.1 At a minimum, the vehicle shall include the following features:

a) Throttle input
b) Regenerative braking
c) Compression braking "feel"
d) Battery state-of-charge

e) On-board charger (220vac, 50Hz)
f) DC/DC converter to 14 volts, 110W DC for auxiliaries
g) Emergency off switch
h) Limp-home mode at 80 percent depth of discharge

5.1.2 Three-wheeler vehicle performance requirements, based upon Trojan Battery T105 and its published data, are as follows:

a) At 60% depth of discharge (DOD) the top speed shall be at least 55 kph.

b) The following shall be the gradeability performance for the vehicle at 60% DOD:

Speed	Grade
10 kph	19 percent (0-10 kph and maintain 10 kph for 10 meters)
20 kph	10 percent (continuous)
30 kph	5 percent (continuous)
40 kph	3 percent (continuous)
50 kph	1 percent (continuous)

c) The following shall be vehicle accelerations at 40% DOD, on level ground. (Surface is to be concrete, asphalt, or chassis dynamometer rollers):

Acceleration	Time
0 to 20 kph	3 sec
0 to 30 kph	7 sec
0 to 40 kph	15 sec
0 to 50 kph	30 sec

d) The targeted range for the NGM powered three-wheeler vehicle at 80 percent depth of discharge is > 80 km at 25°C, while driving the Indian Driving Cycle (IDC), as given in Attachment A, on a chassis dynamometer. NGM shall however demonstrate a range of at least 75 km under these conditions. At 80% DOD, the ranges of 55 km at 0°C and 90 km at 48°C are predicted.

Note: Testing conducted to confirm the performance described under Section 5 should be with a payload of 334kg for tests 5.1.2. a, b, & c, and 150 kg for test 5.1.2 d. Tire pressures should be as recommended by Bajaj. Curb weight shall be assumed to be 510 kg and tire rolling radius at 211 mm at maximum Gross Vehicle Weight, for the purposes of preliminary design. Vehicle losses are to be assumed as 0.19 N/kg + 0.05 N/kph^2.

5.1.3 Batteries for the three-wheeler shall be Lead Acid, flooded-type, Trojan model T105 (or buyer approved alternate), with a nominal battery pack voltage not to exceed 60 volts.

5.1.4 In addition to vehicle performance requirements described in Items 5.1.2. a, b, c, and d, all items supplied by NGM shall be designed to operate in the following environmental conditions.

a) Operating temperature: 0 - 48° C
b) Humidity: 95 percent @ 40°C non-condensing
c) Water immersion and high pressure washing jets, as appropriate
d) High dust environment

5.1.5 NGM shall use good engineering practices for the design of the electric drive system. The following standards and criteria are provided as guidance:

a) Endurance test	BAS 08-037, Rev 0
b) Serviceability test	BAS 08-139, Rev 0
c) Drive-ability test	BAS 08-084, Rev 1
d) Hot start-ability test	BAS 08-154, Rev 0
e) Cold start-ability test	BAS 08-155, Rev 0
f) Water ingress/splash test	BAS 08-077, Rev 1
g) Subjective postural/ergonomic test	BAS 08-147, Rev 2
h) Handling & maneuverability test	BAS 08-072, Rev 1
i) Subjective headlamp illumination test	BAS 08-162, Rev 0
j) Ride comfort test	BAS 08-148, Rev 0

k) For the final vehicle configuration, items supplied by NGM shall be designed for operational endurance test criteria as per Attachment F. Applicability of these criteria regarding a specific component and in a particular vehicle platform is outlined by Attachment H. For the purposes of configuring the prototype, these criteria are to be incorporated where practical.

l) Additionally, complete vehicles shall be designed by NGM to meet the environmental, handling, and drivability test criteria as given in Appendix G. Applicability of these criteria regarding a particular vehicle platform is outlined by Attachment H.

5.1.6 NGM shall serialize all electric motors and controllers.

6. Acceptance

6.1. Specification Validation

NGM will provide a Brushless Permanent Magnet Motor and Inverter/Controller traction drive system integrated into the Bajaj three-wheeled rear-engine autorickshaw. The vehicle will be modified for electric operation and the motor will drive through the existing transmission/differential assembly presently used on a diesel three-wheeled Bajaj autorickshaw. Because this type of vehicle has not been previously tested, NGM shall deliver a tested prototype vehicle that will meet the performance stated in Section 5. NGM shall provide the initial prototype vehicle with integrated drive system and eighteen additional drive systems (fifteen systems and three spare sets) to USAID/Bechtel. The NGM powered electric three-wheeler is to be tested dynamically on a certified chassis dynamometer or suitable facility capable of simulating performance criteria in Section 5.

6.2. Qualitative/Subjective

The qualitative performance attributes of the Bajaj rear engine autorickshaw will be integrated into the NGM powered electric three-wheeler in an effort to maintain as much of the "drivability" feeling as possible.

6.3 During the Preliminary Design Review stage the concepts and design shall be assessed for compliance with this technical specification. In the event of noncompliance design options shall be discussed in good faith. If suitable resolutions cannot be reached, this program may be terminated.

6.4 Witness Points

Bechtel to witness NGM’s:

1) Preliminary design review
2) Critical design review
3) Prototype vehicle testing prior to shipment
4) Traction drive tests prior to shipment
5) Data collection and reduction

Bechtel and/or NGM shall witness in India:

1) Bajaj prototype testing
2) Initial assembly and testing of the five drive systems
3) Introduction and training at demonstration site
4) Operations at the demonstration site
5) Data collection and reduction

7. Schedule

NGM shall meet the schedule in Attachment B.

8. Deliverables

Attachment D details a list of deliverables for this drive development, vehicle integration, and testing program.

9. Communication

9.1 It is expected that there will be frequent exchanges of information between NGM and other IZET participants. Bechtel shall be notified in writing on information that affects the scope of work, technical specifications, budget, or schedule as listed in the procurement documents. No changes shall be permitted without Bechtel's approval.

9.2 Status reports shall be submitted to Bechtel each month on the first workday of the month. Format for this report is Attachment A.

9.3 E-mail shall be the preferred method for routine communications.

10. Attachments

A. Indian Driving Cycle
B. Monthly Report Status Format
C. Three-wheeler schedule
D. Ancillary Components
E. Program Deliverables
F. Environmental Tests for Components
G. Environmental Tests for Vehicles
H. Applicability Table for Environmental Tests

ATTACHMENT A - Indian Driving Cycle

Sr No.	Operation	Acceleration (m/s^2)	Speed (kph)	Duration of each operation (sec)	Cumulative time (sec)
1.	Idling	–	–	16	16
2.	Acceleration	0.65	0 – 14	6	22
3.	Acceleration	0.56	14 – 22	4	26
4.	Deceleration	-0.63	22 – 13	4	30
5.	Steady speed	–	13	2	32
6.	Acceleration	0.56	13 – 23	5	37
7.	Acceleration	0.44	23 – 31	5	42
8.	Deceleration	-0.56	31 – 25	3	45
9.	Steady speed	–	25	4	49
10.	Deceleration	-0.56	25 – 21	2	51
11.	Acceleration	0.45	21 – 34	8	59
12.	Acceleration	0.32	34 – 42	7	66
13.	Deceleration	-0.46	42 – 37	3	69
14.	Steady speed	–	37	7	76
15.	Deceleration	-0.42	37 – 34	2	78
16.	Acceleration	0.32	34 – 42	7	85
17.	Deceleration	-0.46	42 – 27	9	94
18.	Deceleration	-0.52	27 – 14	7	101
19.	Deceleration	-0.56	14 – 0	7	108

ATTACHMENT B - Monthly Report

Monthly status reports shall contain the following information:

1) Summarize Activities Completed this Report Period.

2) Summarize Problem Areas/Concerns this Report Period and Resolution

3) Summarize Planned Activities During the Next Report Period.

4) Provide Recommendations

ATTACHMENT C - Three-Wheeler Schedule

Preliminary Design Review meeting – December 10, 1999

Delivery of Initial Prototype to Mumbai, India – September 22, 2000

Delivery of 7 Electric Drive Trains to Mumbai, India – September 29, 2000

Delivery of 11 Electric Drive Trains to Mumbai, India – October 29, 2000

Final Report – December 13, 2000

ATTACHMENT D - Ancillary Components

1 Twist Grip Throttle Pot
2 Brake Pot
3 Wiring Harness Material
4 Battery Watering System
5 Disconnect Switch
6 Battery SOC Indicator
7 Mounting Brackets
8 High Voltage Relay
9 Fuses

Quantities of ancillaries to be consistent with drive systems.

ATTACHMENT E - Program Deliverables

Documents

1	Motor Electro-Magnetic Design Report *
2	Motor - Preliminary Package Drawings *
3	Controller – Preliminary Design Report *
4	Controller -Preliminary Package Drawings *
5	Motor/Controller System - Predicted Drive Performance Sheet *
6	Motor/Controller System - Dynamometer Test Plan
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9	Controller - Final Package/Interface Drawings **
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12	Prototype Electric Three-Wheeler Test Data
13	Drive System Installation and Operating Instructions
14	User Manual
15	Progress Reports
16	Final Report

*** Documents to be submitted at scheduled preliminary design review.**
**** Documents to be submitted at scheduled critical design review.**

Equipment

1	Completed Prototype Electric Three-Wheeler w/o Batteries
2	7-Prototype Drive Systems (5 installs, 2 spares) and Test Data
3	7-Ancillary Packages (5 installs, 2 spares)
4	72-Trojan Model T-105, 6 Vdc (or buyer approved alternate), Flooded Lead Acid Batteries ▪ 8 batteries to be delivered to NGM for Testing. ▪ 64 batteries to be delivered F.O.B. Mumbai, India for vehicle installations.

ATTACHMENT F - Environmental and Endurance Tests for Components

Note**: See Attachment h for Applicability Table**

SR. NO	TEST	TEST DESCRIPTION	SAMPLE SIZE	ACCEPTANCE CRITERION	SPECIAL REMARKS
COMPONENT TESTS					
1.	Shock Test	1. Acceleration 100g 2. Pulse duration 11msec 3. Direction X, Y, Z 4. No of Cycles 2 in each direction		1. No cracks, chips etc. 2. Item to function normally after test	
2.	Vibration Test	1. Acceleration 30g 2. Frequency 50 to 500Hz 3. Sweep 6 min. logarithmic 4. Duration 20 hrs. each plane		1. No mechanical damage 2. Item to function normally after test	
3.	Thermal Shock Test (Liq. to Liq.)	1. Medium Water 2. Lower temp. 0ºC 3. Upper temp. 100ºC ± 5 4. Duration at each temp.10min. 5. Transfer time 10 sec. (max) 6. No of Cycles 25		1. No visible cracks, delamination etc. 2. Item to function normally after test	
4.	Thermal Shock Test. (Air to Air)	1. Lower temp. – 40ºC ± 5 2. Upper temp. 100ºC ± 5 3. Duration at each temp.1hr. 4. Transfer time 2 min. (max) 5. No of Cycles 50		1. No visible cracks, delamination etc. 2. Item to function normally after test	

SR. NO	TEST	TEST DESCRIPTION	SAMPLE SIZE	ACCEPTANCE CRITERION	SPECIAL REMARKS
5.	Moisture Test	1. Test Std. JIS D-0203-1976 2. Type of test M2 3. Mode Functional operating 4. Set up (Standard) As per Fig.1 5. Test time 8hrs.		Item to function normally after test	Generally for all items mounted inside the passenger compartment of a vehicle and not subjected to rain/ spray/ power wash and immersion
6.	Water Spray Test	1. Test Std. JIS D-0203-1976 2. Type of test S2 3. Spray ON time 10 min. (Non Functioning) 4. Spray OFF time 20 min. (Functional operating) 5. Set up Standard As per Fig.1 of 6. No of Cycles 50		Item to function normally after test	For all items mounted on the body of the vehicle and subjected to rain/ spray/ occasional power wash but not to immersion at any point of its operational life (generally over 350mm from the ground level))
7.	Water Immersion Test	1. Test Std. JIS D-0203-1976 2. Type of test D3 3. Depth of immersion 300mm 4. Mode (Non Functioning) 5. Test time 1hr. 6. Drain Time 10min.		Item to function normally after test	For all items mounted on the body of the vehicle and subjected to rain/ spray/ occasional power wash and immersion at some point of its operational life (generally below 350mm from the ground level)
8.	Dust Test (Floating)	1. Test Std. JIS D-0207-1977 2. Type of test F2 3. Stirring time 5sec 4. Suspension time 10min. 5. Mode (Non Functioning) 6. Test time 8hr.		Item to function normally after test	Generally for all items mounted inside the passenger compartment of a vehicle at a height of 100mm above floor level

SR. NO	TEST	TEST DESCRIPTION	SAMPLE SIZE	ACCEPTANCE CRITERION	SPECIAL REMARKS
9.	Dust Test (Driven)	1. Test Std. JIS D-0207-1977 2. Type of test C1 3. Mode (Non Functioning) 4. Test time 6hr.			For all items mounted on the body of the vehicle and subjected to driven dust
10.	Corrosion Test	TBD			
11.	Endurance Test	1. Operating Condition: Rated Voltage/ Current/ Load/ Speed as applicable 2. Ambient Temp. 70ºC ± 5 3. Duration 500hrs.			

ATTACHMENT G - Environmental and Endurance Tests for Vehicles

Note**: See Attachment H for Applicability Table**

SR. NO	TEST	TEST DESCRIPTION	SAMPLE SIZE	ACCEPTANCE CRITERION	SPECIAL REMARKS
VEHICLE TESTS					
1.	Drivability test	As per BAS 08-084		1. Rating of 7.0 and above as per para. 2 of the Standard 2. Vehicle and components to function normally after test	1. Substitute all references to carburetor, air/fuel mixture etc and with appropriate references to EV parameters. 2. Flat Spot /hesitation is to be considered as related to delayed start-up, cogging/ torque ripples, throttle response curve etc.
2.	Handling and Maneuverability Test	A per BAS 08-072		1. Rating of 7.0 and above as per para. 4 of the Standard 2. Vehicle and components to function normally after test	
3.	Vehicle Endurance Test	As per BAS 08 037		Vehicle and components to function normally after test	1. Item 3.3.1.2 (a) – Clause to be deleted 2. Item 3.3.31.2 (b) to be amended to 12 days instead of 3 days. 3. Item 3.3.3 to be deferred till performance at low temperatures is established. 4. Relevant corrections

SR. NO	TEST	TEST DESCRIPTION	SAMPLE SIZE	ACCEPTANCE CRITERION	SPECIAL REMARKS
					for EVs in relation to "fuel" etc to be made.
4.	Quick Acceleration/ Deceleration Test	As per BAS 08-081		1. As per para. 7 of the Standard 2. Vehicle and components to function normally after test	Annexure 1 and 2 to be revised for deletion of ICE components and addition of EV components for each vehicle platform.
5.	Gear Change Test	As per BAS 08-074		1. As per para. 7 of the Standard 2. Vehicle and components to function normally after test	Annex 1 and 2 – deletion of ICE and addition of EV components for each vehicle platform.
6.	Water Ingress/ Splash Test	1. Generally as per BAS 08-077 2. Site of the test track VRDE test 3. Depth of water 150±20mm 4. Length of track 100m 5. Distance to be covered 5km		1. Vehicle and components to function normally after test 2. Water ingress in designated components to be checked	
7.	Water Immersion Test	TBD			
8.	Dust Test	1. Generally as per BAS 08-163 2. Distance to be covered 50km		Vehicle and components to function normally after test	Substitute all references to carburetor, air/fuel mixture etc and with appropriate references to EV parameters

ATTACHMENT H - Applicability Table for Environmental Tests

Sr. No	COMPONENT	Shock Test	Vibration Test	Thermal Shock Test (Liq. to Liq.)	Thermal Shock Test. (Air to Air)	Moisture Test	Water Spray Test	Water Immersion Test	Dust Test (Floating)	Dust Test (Driven)	Corrosion Test	Endurance Test	Drivability Test	Vehicle Endurance Test	Quick Acceleration/ Deceleration Test	Gear Change Test	Water Ingress/ Splash Test	Water Immersion Test	Dust Test
1.	Speedometer	π	π		π	π	π		π		π	π	π	π	π		π	θ	π
2.	Throttle Control Electricals	π	π	π	π	π	π	θ		π	π	π	π	π	π	π	π	θ	π
3.	Brake Control Electricals	π	π	π	π	π	π	θ		π	π	π	π	π	π	π	π	θ	π
4.	Tell Tales/ Fault Indicators	π	π	π	π	π	π	θ	π		π	π	π	π	π	π	π	θ	π
5.	Battery Gauge	π	π		π	π	π		π		π	π	π	π	π		π	θ	π
6.	Emergency OFF Switch	π	π	π	π	π	π	θ		π	π	π	π	π	π	π	π	θ	π
7.	Forward-Reverse Switch	π	π	π	π	π	π	θ		π	π	π	π	π	π	π	π	θ	π
8.	Key switch	π	π	π	π	π	π	θ		π	π	π	π	π	π	π	π	θ	π
9.	Motor	π	π	π	π	π		θ		π	π	π	π	π	π	π		π	π
10.	Motor Controller	π	π	π	π	π		π		π	π	π	π	π	π	π		π	π
11.	Battery Charger	π	π	π	π	π	π	π		π	π	π	π	π	π	π	π	θ	π
12.	Junction Box	π	π	π	π	π	π	θ		π	π	π	π	π	π	π	π	θ	π
13.	Power Connectors	π	π	π	π	π		π		π	π	π	π	π	π	π		π	π
14.																			
15.																			
16.																			
17.																			

KEY: π Generally for all vehicles and for 3 Wheelers if components are mounted 350mm above the ground

θ Generally for 2 Wheelers only, and, for 3 Wheelers if components are mounted lower than 350mm from ground

Component Failure Analysis Report

<u>Failure Report Memo for Three- Wheeler from NGM</u>

During the course of integrating and testing the prototype 3wheeler autorickshaw and its components there were 3 particular instances where main hardware either failed completely or lost partial functionality. In each of these cases the hardware was either repaired and/or replaced and the cause for the malfunction was analyzed to determine the need for redesign or other rectification.

The purpose of this memo is to summarize the events and findings from our analysis of the malfunctions, note the changes, if any, required and bring closure to these issues.

Prototype Controller

Event:
During vehicle testing in October 2000 at the VRDE facility in Ahmednagar, India, the prototype 3W was subjected to a 300mm water immersion test in which it was left, unpowered, in 300mm of standing water for approximately 30minutes. The primary factor for passing the test is that after a period of drying out, the vehicle should start up and behave normally. After a “drying time” of less than 5minutes the vehicle would not power up successfully. Through visual inspection of the systems, it was determined that water had crept into the controller by way of one of its connectors.

Analysis:
Water was observed inside a connector that is designed specifically to provide a watertight connection. NGM personnel present in India identified that the “dummy pins” designed to be inserted into unused pin sockets for the purpose of completing the seal, were not used. Second, the harness of this particular connection had a multiple cable exit from the shrink tube strain relief and the areas between the exiting cables were not sealed to prevent water into the connector chamber.

The controller was removed from the vehicle to assess the damage. When it was opened up, an estimated 1/4cup of water was drained from inside the unit. It was left open and using a heat gun, was manually dried out. Upon reassembling the unit, the offending connector was resealed from the inside and the overall cover seal was replaced. The unit was replaced into the vehicle and the vehicle was powered up and operated. There did appear to be some internal damage that caused some irregularities with auxiliary functions, however, the core vehicle functions operated normally and range testing was able to take place at ARAI.

The connector type in question was later assembled per its manufacturer’s specification and it performed as required in maintaining a watertight connection.

Rectifications and Conclusion:
It needs to be noted that the prototype vehicle was not initially integrated with the requirement of passing the 300mm water immersion test. Testing to this specification was discussed only after the vehicle had started testing at BAL. At this time NGM and BAL personnel discussed it and decided that if there was an opportunity, and the known items on the vehicle that were left unsealed were taken care of, the vehicle should be able to undergo the test. Therefore, many of the other vehicle harness connectors were potted and protected accordingly, however, the controller connector was missed. Additionally, it was not thought of to check and verify that the "dummy plugs" had been used where necessary.

Given the fact that the prototype vehicle harness was not sealed to common practice and the controller connector was not assembled per its manufacturers requirements it has been determined that when these are done properly, a watertight connection will result. Neither of these assembly issues is out of the ordinary and there should be no problem ensuring consistency throughout all of the units. Lastly, some packaging changes were made for the demonstration vehicles and they included moving the controller from between the floorboard to a location to the right side of motor. The controller is now completely above the 300mm water line.

The prototype controller was returned to NGM for inspection and a "production" unit was provided as a permanent replacement.

Prototype Motor

Event:
During the months of October and November, BAL decided to repackage some of the components on the prototype vehicle. In order to do this many of the major system components were removed from the vehicle, including the controller and motor. On November 11 th , after reassembling the vehicle to its repackaged form, BAL notified NGM that the vehicle would not operate. BAL observed that the "Configuration Utility" program was indicating a "no motor" status and the motor temperature was reading –265Cwith a motor error fault code indicating that the temperature sensor was not working and the motor was not connected. Preliminary inspection of the motor cable and connector by BAL showed no unusual sign of wear or damage.

Analysis:
Based on BAL's observations, we were relatively certain that the problem was related only to the motor harness, either in the cabling itself or in the external or internal connector. NGM's first chance to look at the motor occurred during the January 2001 meeting at BAL. After verifying that there were no damaged or loose pins in the external connector, a continuity check validated that the "motor return" sense loop was not connected at the motor end, indicating a loose connection in the internal wiring. The encoder cover was then opened and it was verified that

the internal connector that connects the harness to the motor electronics board was not fully engaged.

There are 2 strain relief devices that are used to provide the necessary strain relief for this end of the motor harness. The first is a sealed compression grommet that retains the cable to the cover and the second is a "wire tie" mount (w/ wire tie) that retains the cable to the bottom of the encoder electronics cavity. The main cause of the connector coming loose appeared to be that the wire tie strain relief was installed in a manner that actually put stress on the connector to pull it from its socket. Looking back at the assembly history of the prototype motor, it was noted that the encoder cavity had been removed when the motor was installed in the vehicle to perform some motor/controller troubleshooting while the prototype was at NGM. As the motor was never again removed from the vehicle, the final installation of both strain relief devices was done while the motor was in the vehicle where there is very little space to the assembly work properly.

Therefore, we are very certain that the reason this was not strain relieved correctly was directly related to the improper assembly of this system.

Rectifications and Conclusion:
Although it was relatively straightforward that improper assembly was again the cause of the malfunction, there was a minor change that was implemented in the strain relief scenario. The diameter of the rubber compression grommet was slightly large for the cable and needed to be tightened considerable to be effective. Therefore, motors for the additional motors will either use shrink-wrap to increase the local O.D. of the cable or a slightly smaller I.D. grommet. The prototype motor was reassembled and checked out by NGM personnel while at BAL during the January 2001 trip.

Prototype Chargers

Event:
The two prototype 480W chargers, along with mounting hardware and harnessing, were sent to BAL around the end of October 2000, for their integration into the prototype 3W vehicle. Prior to their integration, BAL planned to run some initial tests on the charger units. BAL proceeded to add connectors to the unterminated ends of the harness and hook up the test. NGM was notified that the chargers were not behaving correctly and after several discussions back and forth, and troubleshooting of items at BAL's and NGM's respective locations, it was discovered that there were some errors in the connections of the harness.

Analysis:
The basic cause of failure was that, in setting this test up, the 48VDC output lines were switched with the "charger-on" lines and as a result, 48Volts of DC output was put into the chargers directly through their logic boards. Cause for the miswired harness was a combination of documentation errors, miscommunication, and simply over rushing the work by NGM and BAL's for the purpose of expediting the certification testing. Basically, the colors of wires sent

to BAL on the prototype harness did not match the documentation, however they were close enough (3 of 4 of the same colors were used) that BAL assumed only one color was replaced and connected the charger up accordingly. Unfortunately, the colors on the prototype harness were completely random and as this was not pointed out by NGM, the simple mistake took place. The damaged units were returned to the manufacturer and it was confirmed that components on the logic board were permanently damaged as a result of the voltage input.

Rectifications and Conclusion:
There are no hardware preventative measures that should be instituted to prevent this type of mistake. It is simply of a matter of using the documentation where necessary and communicating appropriately if something is not in accordance to the documentation. The damaged prototype chargers have been sent back to the manufacturer for detailed analysis and will be repaired if possible.

Innovations in the Development and Marketing of Electric Vehicles
The United States Agency for International Development Experience

September 30, 1999

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Washington, D.C.
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Abstract

Zero emission two- and three-wheeled electric vehicles (EVs) are being promoted in India through partnerships between the U.S. Agency for International Development (USAID) and major corporations. Through these partnerships, USAID hopes to transform the limited reach of the demonstration project into widespread EV usage. India is home to three of the world's ten most polluted cities, and a leading cause is the debilitating levels of pollutants emitted from some of the heaviest traffic in the world. Not only will replacing conventional vehicles with EVs make a significant impact on pollution in India, it also will lessen India's dependence on imported oil and support continued growth of the nation's automobile industry. USAID and its private partners believe India – with its relatively short driving distances and its heavily congested streets – is an ideal ground for re-introducing EVs to the world. Although rare in today's world, EV use was once widespread. In the United States, more than a third of all vehicles on the road were electrically powered before World War I.

Introduction

Electric-driven motors power more than half the vehicles on the road. Delivery personnel driving electric-powered trucks drop off morning newspapers and milk. The streets are free of smog belching from automobile tailpipes. The future? Perhaps, but ironically this is a scene from the distant past. While we struggle today to find alternatives to inefficient and heavily polluting Internal Combustion Engines (ICE) vehicles, we need look no further than turn-of-the-century United States – an era when the electric vehicle (EV) was king of the road. Before World War I, more than a third of all vehicles on the road in the United States were EVs. The United States Agency for International Development (USAID), the foreign development arm of the U.S. Government, believes India – with its relatively short driving distances and its heavily congested streets – is an ideal ground for re-introducing EVs to the world. To facilitate this resurgence, the USAID Global Environmental Center in Washington, DC, and the USAID Mission to India have initiated the India Zero Emissions Transportation (IZET) Program that will create an EV market through partnerships with the private sector.

USAID is teaming with private partners to transform the limited reach of the demonstration project into widespread EV usage throughout India and to fulfill its commitment to help developing countries combat pollution through public-private partnerships and free-market solutions. Under the IZET demonstration project, Sheraton Hotels will be loaned up to six three-wheeler EVs to transport guests of the Mughal Sheraton in Agra to and from the Taj Mahal and other important local sites where urban air pollution has had adverse and damaging effects. Pizza Hut restaurants will be loaned up to six two-wheeler EVs to deliver pizza in New Delhi. This demonstration project is intended to showcase the utility and reliability of the EVs and provide "real road condition" testing data that will benefit manufacturers who need thorough testing before making EVs commercially available.

One of the largest vehicle manufacturers in India, if not the world – Bajaj Auto – and one of the most innovative electric motor/vehicle companies in the United States - New Generation Motors – is USAID's IZET manufacturer partners. Already in the prototype design stage, the Indian EVs – nicknamed "Zipp-shaws," combining "rickshaw" with the acronym "ZIPP" for Zero-emission, Indian Pollution Prevention – are expected to be in place next year.

The Technology Behind EVs

EVs are vehicles using efficient electric motors that drive wheels and extract energy from the car's motion when it slows down – producing little or no fumes or emissions. This is in contrast to the polluting ICE-powered vehicle that uses a constantly running engine whose power is diverted through a series of gears and clutches to drive the wheels and propel it. The intrinsic efficiency of the EV is clear; while the ICE-powered vehicle must keep its motor running, whether moving or not, the EV efficiently conserves its power by running only when needed to propel it. Conservation of power alone increases a vehicle's effective efficiency by roughly one fifth. EVs also capitalize on other efficiencies, such as regenerative breaking systems that use the motor as a generator when the car is slowing down to return as much as half an EV's kinetic energy to the vehicle's storage cells. Energy savings also comes from the inherent efficiency of the electric motor, which converts more than 90 percent of the energy in its storage cells to motive force compared to the ICE using less than 25 percent of the energy from a given quantity of gasoline.[1]

The two- and three-wheeled EVs being produced through the IZET Program are being especially designed for the Indian market – where two- and three-wheeled vehicles make up 75 percent of the traffic. Besides reducing auto emissions and increasing energy efficiency, they will provide Indian motorists other benefits over conventional vehicles, further enhancing their attractiveness as a viable alternative. They are designed to contain just a few moving parts – less than 35 compared with more than 1,500 for an ICE-powered vehicle. Fewer parts mean less maintenance and simpler service. No oils, filters, or coolants will need to be changed, and the EVs will never need tuning-up. The simplicity of design and low maintenance also contributes to greater durability of the vehicles.

Why USAID is Promoting EV Use for India

Decrease Urban Air Pollution. The IZET Program is chief among USAID's urban pollution prevention programs for India, where vehicle emissions are a leading cause of the country being home to three of the world's ten most polluted cities.[2] For example, a recent World Bank study suggests emissions from the transport sector produce up to 70 percent of air pollutants in urban India (refer to the Figure-1 on the following page for annual total suspended particulates in various cities), and two- and three-wheeled vehicles account for 50 percent of India's air pollution. These vehicles are almost always powered by inefficient, and hence more polluting, two-stroke engines requiring a gasoline and oil fuel mix. The common practice of using spent, dirty oil over and over again further increases the amount of pollution and smog this fuel mix generates.

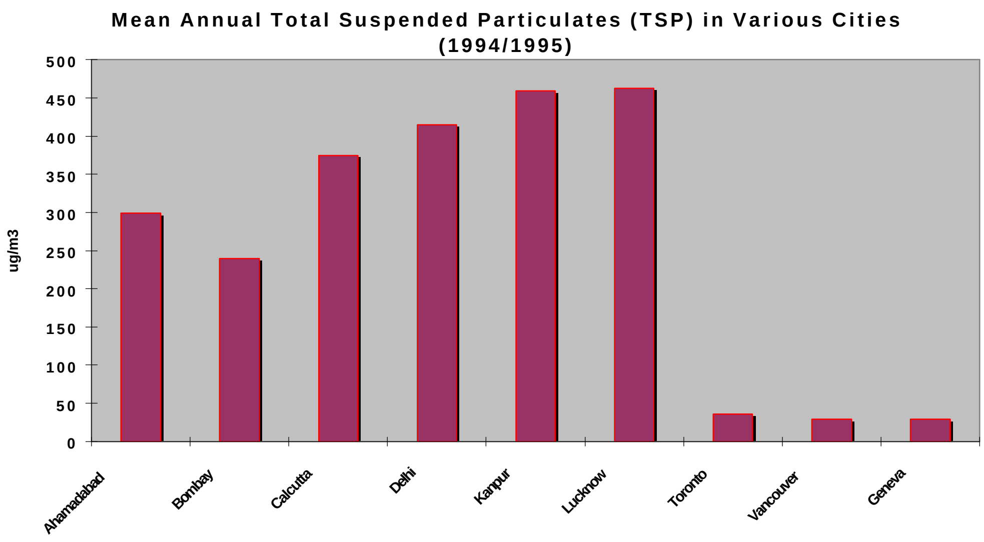
[1] Although the storage cells are typically charged by an electricity-generating system, the efficiency of which averages only 33 percent, an electric drive still has a significant 5 percent net advantage over an ICE. Obviously, the more efficient the power plant, the more savings the electric motor would have over the ICE.
[2] *USAID/New Delhi Environment Team Annual Report*, 1999.

Vehicle emissions are also contributing to India being the sixth largest and second fastest growing emitter of greenhouse gases (GHGs),[3] a leading contributor to global climate change. Since EVs emit little or no fumes or emissions, every conventional car, truck, or scooter that is taken off of the road and replaced with an EV will help reduce GHG emissions and India's debilitating urban smog.

This smog contains potentially fatal levels of lead and other hazardous pollutants and is causing premature deaths and chronic respiratory disease.[4] An estimated 40 percent of New Delhi's emergency hospital admissions of patients with breathing and heart problems is attributed to air pollution.[5] The health costs of ambient air pollution in New Delhi alone are approximately US$250 million per year.[6] Given that vehicle registrations have increased by more than 500 percent over the last 10 years, the future will only bring more severe air pollution and related health problems. If the goals of USAID's IZET program are realized, however, India's urban air quality will be improved in a number of ways:

- Decreasing emissions of nonmethane organic gases (NMOG) and nitrogen oxides (NO_x), which combine to form smog and carbon monoxide
- Decreasing emissions of carbon dioxide (CO_2), the principle GHG linked with global climate change
- Concentrating the energy source (power plants) – and hence pollution point source – away from bulk of population

Figure 1



Introduce a New Product to a Huge Potential Market. Driving distances are relatively short in India compared to Western countries, particularly the United States, creating an ideal market for EVs. Even a very basic EV technology using lead-acid batteries can now let a small four-wheeler go about 80 kms at a single charge at the speed of 40 km/hr.[7] Typical travel data for three of the largest Indian cities – which together account for more than 50 percent of the total number of vehicles in the country – shows that the average distance traveled daily by two-wheelers and passenger cars is 25-26 km, which is well within the range of commercially available EV technology. Unlike in Western nations, all forms of personal transport (passenger

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[3] *USAID India Congressional Presentation 1999.*
[4] *USAID India Congressional Presentation 1999.*
[5] "Dirty New Delhi air makes you breathless," *Times of India,* July 22, 1999.
[6] *Human Development Report, United Nations, New York, pp 67,* 1998
[7] USAID/India, REVA project

cars, motorbikes, and scooters) in India are mostly driven within a single urban area (refer to the Table-1 below).

Table-1

Occupancy and Distance Traveled Daily in the Metro Areas						
Cities	Average Occupancy (persons)			Average Distance Traveled Daily (km)		
	Two Wheelers	**Three Wheelers**	**Cars**	**Two Wheelers**	**Three Wheelers**	**Cars**
Mumbai	1.6	1.8	2.4	25	68	26
Calcutta	1.6	1.6	2.6	25	68	26
New Delhi	1.7	1.8	2.4	25	68	26
Source: Tata Energy Research Institute (TERI), 1995						

Another factor enhancing the market potential for EVs in India is the nation's low average vehicle speed. Due to narrow roads congested with both traffic and pedestrians, average travel speed in most Indian cities is 15-40 km/h – also well within the range of commercially available EV technology.

Boost India's Economy. EV use also would help India, which imports the majority of its oil, curb its dependence on foreign oil[8] and reduce the billions of dollars the country is spending each year on foreign oil as well as environmental pollution. This would help its economy, thereby expanding trade and investment. In addition, EV use would support India's vibrant vehicle-manufacturing sector and sophisticated testing facilities. In 1995, more than 3.5 million vehicles were produced in the country and the annual growth rate of vehicle production was 25 percent. The largest segment within the transport-manufacturing sector has been the two-wheeler vehicle group.

Public Misperceptions about EVs

The largest obstacle to making EVs widely available in India is not the technology; it is the market and public misperceptions about EVs. USAID is working with Indian manufacturers, the Government of India, and innovative American electric motor manufacturers to facilitate a proper market environment for widespread EV use. USAID hopes to dispel three pervasive myths through the IZET Program.

The Simplicity of EVs. The first myth USAID hopes to dispel is that EVs represent an overly sophisticated technology. EVs are, in fact, designed to contain just a few moving parts – less than 35 compared with more than 1,500 for an ICE. Fewer parts mean less maintenance and simpler service. No oils, filters, or coolants need to be changed, and EVs never need tuning-up.

The Low Life-Cycle Cost. Another myth is that EVs are too expensive. Although two- and three-wheeled EVs will most likely cost more than their conventionally powered counterparts, their "life-cycle cost" (the overall expense in running the vehicle over the life of its operation) will be lower. According to a study conducted by the Central Electronics Engineering Research Institute (CEERI), even if the initial cost of an EV is almost double that of its ICE-powered counterpart, the extra cost may be offset by the EV's longer life and lower operations and maintenance costs. The simplicity of design and low maintenance also contributes to greater durability. The CEERI study (refer to the Table-2 below) estimated it costs only Rs. 0.16 per person to ride electric two-scooters as opposed to Rs. 0.38 in a petrol-driven one, which is more than twice the cost of using EVs.

[8] US Energy Information Administration Annual Report on India, 1999, p.2.

Table 2

Simple Operating Cost Comparison of Electric and Conventional Vehicles at 19,800 km/Year in 1995

No.	Parameters	Two-Wheeler *(Seating capacity=2)*		Three-Wheeler *(Seating Capacity=4)*	
		Electric	**Petrol**	**Electric**	**Petrol**
1.	Yearly run (km) (60 km/day)	19,800	19,800	19,800	19,800
2.	Net Cost (Rs.) of vehicle	40,000	20,000	81,000	40,000
3.	Net Fixed Cost	39,088	33,400	78,764	66,800
4.	Fixed Cost (Rs.)/year	3,258 (Life=12 years)	3,340 (Life =10 years)	6,564 (Life=12 years)	6,680 (Life =10 years)
5.	Energy/year @ -40 km/hr for two-wheeler -18 km/hr for three-wheeler	277.2 kw	495 ltr	537.37 kw	1,100 ltr
6.	Energy cost/year	Rs. 555 @ Rs. 2/kw	Rs. 9,900@ Rs. 20/ltr	Rs. 1,075 @ Rs. 2/kw	Rs. 22,000 @ Rs. 20/ltr
7.	Battery replacement cost per year (Rs. 2 per hr.)	1680 (Life=3 years)	100	3600 (Life = 3years)	200
8.	Maintenance cost/year	Rs. 782 (2% of net cost)	Rs. 1,670 (5% of net cost)	Rs. 1,575 (2% of net cost)	Rs. 3,340 (5% of net cost)
9.	Operating cost /year (6+7+8)	Rs. 3,017	Rs. 11,670	Rs. 6,250	Rs. 25,540
10.	Total cost/year (4+9)	Rs. 6,275	Rs. 15,010	Rs. 12,814	Rs. 32,220
11.	Cost/ km	Rs. 0.32	Rs. 0.76	Rs. 0.65	Rs. 1.63
12.	Cost/ km/passenger	Rs. 0.16	0.38	0.16	Rs. 0.41

Source: CEERI Report, Indo-US Workshop on Electronics/Electric Vehicles-Technology & Policy Issues, New Delhi, April 1995

The Government Subsidies Myth. The other myth USAID hopes to dispel is that expensive, government subsidies are needed to foster EV development and deployment. According to the CEERI study cited above, however, the lifecycle cost per kilometer per passenger for an EV comes to about 35 percent of that of an equivalent ICE-driven vehicle if only a 20 percent subsidy or tax exemption to the same extent is given on the initial cost. Based on these figures, no subsidy for EVs would be required, if some innovative financing mechanism could be devised. It should be possible for traditional financial institutions to blend the higher capital cost, lower operating costs, and much longer life of an EV through a creative financing package whereby the monthly out-of-pocket costs of an EV to a final customer would be comparable or even cheaper than that for a comparable conventional vehicle. This kind of financing will encourage the average customer to try out a new product more easily.

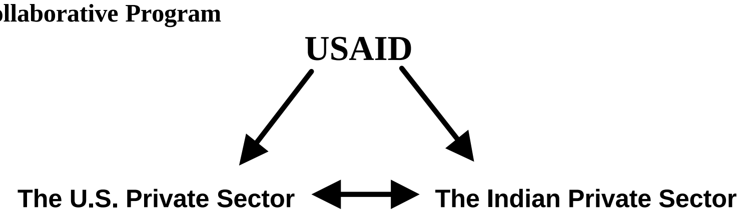
Nurturing Public-Private Partnerships

When USAID’s Global Environment Center studied environmental degradation in India’s cities, it was clear introducing EVs designed for the India marketplace would help significantly reduce urban pollution and related health problems. The difficult part was finding a means of economically demonstrating the utility of EVs to the Indian public to gain public acceptance and promote widespread EV use. After studying the issue, USAID chose for the IZET Program an innovative financing technique popularized by U.S. Vice President Al Gore called public-private partnerships. This technique enables USAID to fulfill its commitment to helping developing countries combat pollution through free-market solutions

Public-private partnerships harness private enterprise's expert technicians, proven market prowess, financial stake and incentive for success, minimized bureaucracy, and knowledge and expertise to help government entities achieve their goals. The idea is quite simple: both the public and private sector contribute resources and become stakeholders in the project. In this case, the USAID team has gone one step better and involved the private and public sectors of two countries: India and the United States. This emphasis on collaboration between the U.S. and Indian private sectors is shown in the following chart on IZET's objectives.

USAID India Zero Emission Transportation Program (IZET) Objectives

- **Initiate the Development of Market Driven, Environmentally Sensitive Transport Options**
- **Comprehensive Assessment and Demonstration**
- **Collaborative Program**



Using the public-private partnership approach, USAID designed IZET to introduce electric two- and three-wheelers to the India market via high-profile corporations. USAID then solicited interest from American electric motor manufacturers and Indian automobile manufacturers. The parameters of the program were clear to candidates: USAID would provide nominal financial assistance to the participants, and the payoff for the participating corporations would be a jump start into the potentially sizeable alternative transportation market in India.

IZET's main manufacturing partners and stakeholders met this past summer in Annandale, Virginia; and Washington, DC, to establish common technical performance criteria for the design of EVs between the U.S. firm and the Indian vehicle manufacturer. The manufacturing partners include one of the largest vehicle manufacturers in India, if not the world – Bajaj Auto – and one of the most innovative electric motor/vehicle companies in the United States – New Generation Motors. Another partner is Bechtel, a premium engineering and consulting firm with offices worldwide, that was chosen by USAID to provide overall project management. The Indian EVs – nicknamed "Zipp-shaws," are now in the design phase and are expected to be in place next year.

USAID has been spending the bulk of its time on the rigorous testing and demonstration of the EVs that Bajaj Auto eventually will mass-market. When the IZET EVs are ready for demonstration, Sheraton Hotels will be loaned up to six three-wheelers to transport guests of the Mughal Sheraton in Agra to and from the Taj Mahal and Pizza Hut restaurants will be loaned up to six two-wheelers to deliver pizza in New Delhi. These demonstrations will not only be used to collect critical data that will help perfect the commercial versions of these demonstration vehicles, but they will also serve as an important introduction of EVs to the average Indian motorist. USAID hopes that by seeing EV two- and three-wheelers in smooth-running daily operation, the average Indian motorist will not only grow accustomed to EVs, but will also come to appreciate their virtues, leading to a market for their commercial release throughout India.

The demonstration phase will be buttressed with a multiprong approach towards assessing the marketplace. These assessments will offer utility for public and private sector decision-makers on alternative transportation technologies. The following tasks will ensure the utility for above technologies.

- **Industry, Policy and Regulatory Assessment:** During the assessment, IZET will evaluate Industry and Transportation sector policy, Tax and Import regulations that will smooth the introduction and commercialization of EV.

- **Collection of Operational Performance and Emissions Data:** To measure in environmental quality during the commercialization process, IZET will assess operational and emissions performance of conventional two- and three-wheelers during the demonstration phase. IZET will also assess the emissions from the transport sector to incorporate into the financial assessment. This financial assessment will then evaluate the viability of the commercialization of EVs in India.

USAID Urban Reduction Programs in India

When designing the IZET Program, USAID's Global Environment Center drew upon the experiences of the USAID Mission to India. For many years, USAID/India has been tackling environmental problems in Indian's urban areas, including implementing several programs aimed at reducing the urban air pollution associated with the Indian transportation sector. These include an EV program called "REVA" and the Cycle Rickshaw Improvement Project.

REVA. REVA, which began in 1996, was a product of symbiotic joint venture between the U.S. and Indian private sector and included technology transfer between the two governments to reduce urban air and noise pollution and GHG emissions from the transport sector. It is a collaboration between two companies, Amerigon of the United States, which is known for its state of the art aerospace technology in manufacturing prototypes, and Maini of India, whose efficient infrastructure and facilities were used to manufacture these EVs.

During REVA's inception, USAID helped Maini-Amerigon develop the four-wheeled REVA EV designed especially for the Indian market. REVA runs on battery by eliminating radiating heat and has an 80-km range on one charge, a top speed of 80 km/h, and a ground clearance of 5.9 inch – ideal for the Indian road. REVA' s two-paddle control (just accelerator and brake) makes it the simplest thing in busy city traffic on four wheels, and its small size and small turning radius of just 11ft. gives it superb maneuverability for the narrow Indian roads.

USAID/India also provided support for field testing of REVA under USAID's Renewable Energy Commercialization (RECOMM) grant to Winrock International (WI), Renewable Energy Project Support Office (REPSO. The REPSO grant facilitated field-testing of REVA in New Delhi and helped create the awareness of clean and environmentally friendly vehicles among the Indian people. Amerigon and Maini have now formed a joint venture company, REVA Electric Car Co., Pvt. Ltd., to manufacture these vehicles in India. The joint-venture company plans to commercially produce REVA in India by the year 2000.

Cycle Rickshaw Improvement Project. The objective of this project is to improve the passenger and goods-hauling conventional rickshaws to protect the Taj Mahal and other monuments from damaging motor vehicle pollution. It intends to modernize the conventional rickshaw fleet by replacing polluting vehicles and making it easier for poor rickshaw-wallas (paddlers) to earn more income and exert less physical effort using a modernized vehicle weighing as much as 34 kg less than a conventional rickshaw. These newly designed rickshaws provide enhanced comfort and efficiency both for passengers and paddlers. The cost of these rickshaws is competitive with that of conventional rickshaws.

The project is also a public-private partnership and involves the Asian Institute for Transport Development, New Delhi; the Institute for Transportation and Development Policy (ITDP), New York; and the Indian Institute of Technology (IIT), New Delhi. Under this project, six prototypes have been developed and tested. In the second phase, 20 of these improved rickshaws have been fabricated and are being field tested in Agra on pilot basis.

Conclusion

The USAID IZET Program's creation of an EV market is expected to help decrease India's potentially fatal urban air pollution and boost its economy – through adding a new product to the country's vibrant automobile manufacturing sector as well as through reducing the billions of dollars the country is spending each year on foreign oil and environmental pollution. It brings the private sectors from two different countries together to reap the benefits of EV technology advancement and help dispel widespread myths about EVs. These include myths that EVs represent an overly sophisticated technology, are too expensive, and require expensive government subsidies. It is hoped the IZET Program will ultimately lead to widespread EV usage throughout India and help re-introduce EVs to the world.

Indian Zero Emission Transportation Program –

a driving force for change

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Abstract

Vehicular emissions are one of the primary contributors to deteriorating ambient air quality in the major urban areas of the Indian subcontinent. There has been remarkable growth in the number of registered vehicles during the last 10 years in India. The most popular vehicles are 2 and 3-wheelers. The consequences of these emissions include increased morbidity and mortality rates and dampened economic productivity. Few technologically advanced vehicles had been available for the consumer in India. The United States Agency for International Development (USAID), working with the Indian and U.S. private sector, has put into place a multi-pronged program to address these issues.

This paper provides the background of the trends and consequences of transport sector emissions in the Indian subcontinent. It examines the effects of the rise in vehicle miles traveled and provides the details to date of an innovative partnership between the private and public sectors. This partnership, Indian Zero Emission Transportation Program (IZET), has resulted in the development of electric two and three-wheeled prototype vehicles specifically designed for Indian road conditions and consumer needs. In India, a successful and potentially highly profitable electric vehicle venture is emerging that will offer consumers a technological option for environmentally benign transportation.

1. Introduction

A public-private partnership involving the United States Agency for International Development (USAID), Bajaj Auto Ltd. (BAL), and New Generation Motors (NGM) of the USA, long in gestation and challenged by geographic separation, is long on results. Catalyzed and managed by USAID, the Indian Zero Emission Transportation (IZET) Program has taken a large step towards providing advanced alternative transportation technology specifically designed to meet the Indian marketplace. Electric-driven autorickshaws are plying the roads of Agra and Pune. Soon, electric-driven scooters and the next iteration of electric-driven autorickshaws will be seen on the streets of Delhi.

The private partnership, led by Bajaj Auto Ltd. (BAL) and New Generation Motors (NGM), has merged complimentary strengths providing a vehicle design that meets a large segment of the Indian driving profile while offering the convenience of an efficient on-board charger.

The following sections of this paper address: why and how this partnership developed; and, what are the results to date and the plans to commercialize this technology.

2. Indian Transport Sector Overview

Air pollution is a serious issue for people living in urban areas of India. Deteriorating urban air quality is having a growing negative impact on human health and welfare. The transport sector is the primary contributor of urban air pollution, which is exacerbated by population growth, increasing number of vehicles, and the existing state of infrastructure.

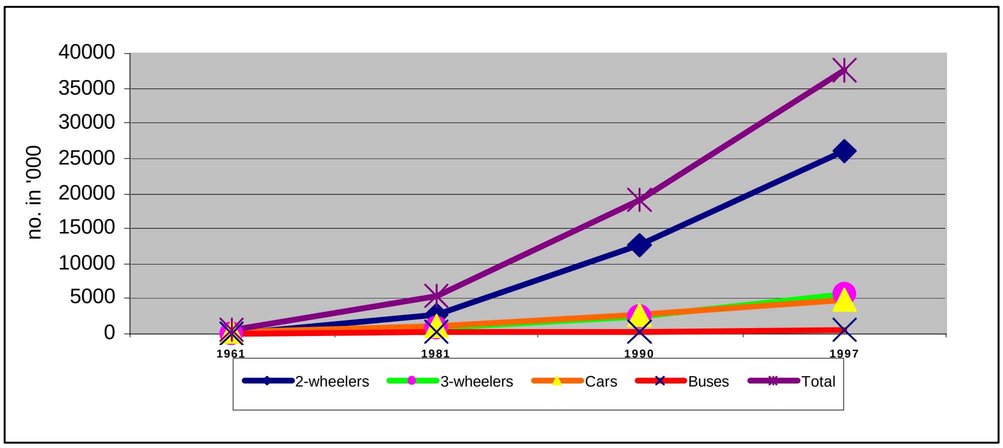
Urbanization. The booming economy, easier access to education, better jobs, and health care in urban areas have contributed to the migration from the rural areas to the cities where the majority of the population in India now live and, this trend is expected to continue. Urban population in India has grown ten fold since its independence in 1947. Along with population, per capita income of urban dwellers has also grown. Today urban India contributes more than 60% to the Indian economy compared to 29 percent in 1947.[1]

Economic Growth and Vehicle Population. The Indian economy/GDP has been growing at a constant rate of 5-6% annually for the past ten years. This economic boom has dramatically increased the number of middle-class families in urban areas. Ownership of vehicles increased as income levels and the borrowing power of Indian consumers has risen.

With an estimated 300 million middle class consumers, India is one of the fastest growing vehicle markets in the world. Consequently, over the last few decades, vehicle registration in India has sky rocketed to over 37 million vehicles by 1997 (Fig 1). The vehicle registration is growing at the rate of 12 percent per year and the number of registered vehicles has tripled in 10 years from 10.6 million in 1986 to 33.6 million in 1996.[2] Affordably priced two and three-wheelers captured the majority of market share.

Despite its vibrant vehicle manufacturing base, India has not kept up its road infrastructure to accommodate the growing number of vehicles. Inadequate infrastructure such as lack of automated traffic lights, narrow roads, and few roadways, coupled with an increasing number of vehicles have led to severe traffic congestion in major urban centers.

Figure 1. Growth of Indian Vehicular Population[3]



Increasing Vehicular/Urban Pollution. People in the urban areas of India are becoming increasingly vulnerable to air pollution since emissions from vehicles tend to stay at the ground level where most of the population works and lives.

Table 1. Contribution of Transport Sector to Total Pollution in Delhi *($CO+HC+NO_2+PM$)*

Sector	Percentage (%)
Transportation	64
Power	18
Industry	12
Domestic	8

Vehicles fitted with two-stroke engines are the major sources of vehicular emissions. These two-stroke engines typically have lower fuel efficiency than four-stroke engines, with as much as 40% of the fuel-air mixture escaping through the exhaust system. To make matters worse, more than half of the Indian vehicle fleet is

[1] Indian Census Bureau 2001
[2] Improving Urban Air Quality in South Asia by Reducing Emissions from Two-Strokes Engine Vehicles, The World Bank, Dec 2000
[3] SIAM 1999

comprised of two-stroke engines[4] and the majority of two & three-wheelers have this type of engine. In Delhi alone 60-70% of the urban air pollution is attributed to the transportation sector (Table 1) and two & three - wheelers account for 70 percent of total vehicle population. Over the past two decades, vehicular pollution has increased eightfold and emissions from industries have increased four times.

Though two-stroke engine vehicles are primarily blamed for pollution, other factors such as the illegal practice of fuel adulteration, the use of unregulated mixing of lubricant oil, lack of vehicle maintenance coupled with a large number of older vehicles have exacerbated vehicular emissions, where 32% of two-stroke vehicles are more than 10 years old.

Technological Options are Emerging. Until recently, consumers have had few options – technologically advanced vehicles were not available. Today, technologies are emerging and are available to curb vehicular emissions and recently, alternative fuels and engine types along with emission controlling devices have been introduced to consumers. Another conventional technology, which is becoming increasingly available in the two and three-wheelers is the four-stroke engine. Some of the popular alternative vehicles include EV, CNG and LPG. These vehicles usually emit no or less emissions compared to diesel or gasoline vehicles. Despite the Delhi Government's push to introduce CNG and LPG vehicles, these technologies face challenges in India because of their dependence on imports and a support infrastructure. India currently imports about 30-40 percent of LPG. CNG vehicles, for example, also face the challenge of an insufficient infrastructure such as filling stations. Recently, the GOI mandated that all public transport vehicles in Delhi be converted to CNG. Only 74 filling stations were available for more than 50,000 CNG vehicles as of August 2001 and drivers had to stand in line for hours to fill up their tanks.[5] On the other hand, electric vehicles have the potential to eliminate vehicular emissions at the source point but it also faces some challenges - availability of power and a support infrastructure.

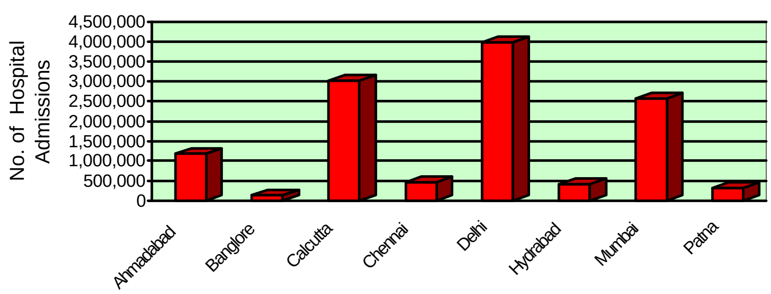
3. Environmental Impact of Vehicles upon Ambient Urban Air Quality

Urban air pollution and its adverse effect on human health is one of the most serious environmental concerns facing India. Thousands of premature deaths and millions of cases of respiratory illness are associated with urban air pollution in large cities. Inhalation of, or exposure to, suspended particles (PM-2.5 & 10), oxides of nitrogen (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), hydrocarbons (HC), ozone (O_3), and metals is known to cause adverse health effects.

According to a report published by the World Bank, nearly all vehicular emissions are extremely damaging to public health. Concentration of suspended particulate matter (PM) such as PM10 and PM2.5 in particular have been linked to respiratory symptoms, exasperation of asthma, changes in lung function, and premature mortality.

- **Morbidity.** The number of pollution related cases affecting health are rising in the larger cities. The effects include both chronic and acute exposures; the chronic exposures have a cumulative effect over time, while acute exposures typically take a heavier toll among the young, old, and ill. Annual hospital admissions from the effects of air pollution are growing at an alarming rate. In 1998, for example, Delhi had more than four million hospital admissions due to urban air pollution (Fig 2).

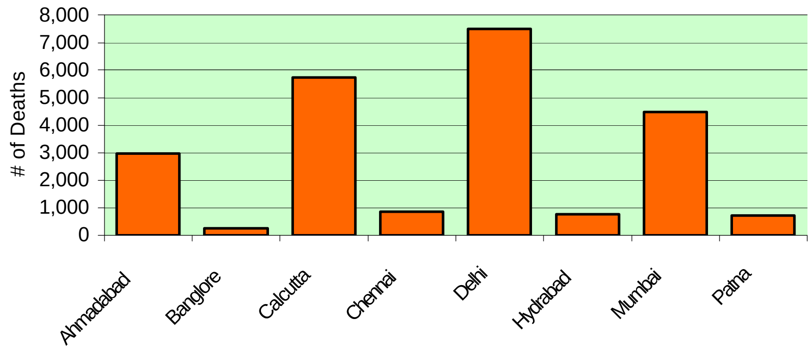
Figure 2. Annual Hospital Visits Due to Urban Air Pollution in Cities[6]



[4] Improving Urban Air Quality in South Asia by Reducing Emissions from Two-Strokes Engine Vehicles, The World Bank, Dec 2000
[5] Central Pollution Control Board
[6] Financial Times 1997

- **Mortality.** Air pollution claims human lives over time from continuous exposure. It is estimated that 0.5-1.0 million people die prematurely each year as a result of exposure to urban air pollution in developing countries around the world.[7] In 1996 more than 7,000 premature deaths occurred in Delhi alone (Fig 3).

Figure 3. Premature Deaths in Indian Cities due to Urban Air Pollution[8]



- **Economic.** Significant government resources are spent in caring for people affected by vehicular pollution in developing countries. The economic damage of air pollution is estimated to amount to billions of US dollars. In Delhi alone, the annual cost of air pollution impact on human health amounts to about US $ 100-400 million per year.[9]

Movement Towards Controlling Emissions. There is an urgency to control the growing vehicular emissions - serious enough to warrant the government to consider phasing out two strokes two & three –wheelers and/or introduce alternative fuel vehicles.

Until recently, both government and private industries had been slow to offer solutions or take actions on this major public health problem. In response to the deteriorating urban air pollution from vehicles, concerned government bodies have issued various directives on controlling vehicular emissions in major metropolitan areas. The Indian judiciary, in particular, has been vocal in their effort to curb growing vehicular emissions in urban areas.

- **Government Issued Directives on Vehicular Pollution.** The Indian government and judiciary have initiated significant efforts towards reducing urban air pollution by targeting two-stroke and diesel vehicle emissions. The federal and state governments have issued a series of stringent directives and regulations. In 1998, the Supreme Court prohibited registration of any new conventional three-wheel vehicles in the National Capital Region surrounding New Delhi that failed to meet EURO II emission norm after April 1, 2000 and mandating the replacement of all pre-1990 autos and taxis with new vehicles using clean fuels, effective March 2000.

Following the Supreme Court mandate, the Delhi government issued a directive to convert all diesel powered public transportation to CNG after April 1, 2001. Similarly, Delhi has provided financial incentives to owners to replace older three-wheel vehicles with new ones. There has been an overwhelming response from three-wheel owners to partake in this incentive. By March 2000, nearly 20,000 old three-wheelers had been replaced in New Delhi.

In a similar effort to curb vehicular emissions in Mumbai, the municipality has prohibited conventional three-wheelers from entering the city center.

In an effort to assess vehicular emissions, the Society of Indian Automobile Manufacturers (SIAM), with financial support from USAID/India, conducted a voluntary tailpipe emissions inspection program for two-wheelers in New Delhi. SIAM concluded that the two-wheelers constitute a significant part of pollution and a

[7] Urban Air Quality Management, The Transport–Environment-Energy Nexus; The World Bank; April 2000
[8] Financial Times, 1997
[9] Shah & Xie, The World Bank, "Reducing Transport Air Pollution: The Case of Two-Stroke Engine Vehicles in Asian Cities," May 2001

large number of old vehicles remain in circulation. SIAM also recommended that there is an urgent need to strengthen measures to reduce pollution from in-use vehicles by:

–periodic inspection and maintenance of vehicles,
–phasing out older vehicles, and
–most importantly, switching, at least partially, to alternate fuels

- **Private Sector Initiatives.** Parallel to government imposed legislation, the private sector is also taking initiatives to reduce vehicular emissions. The following are some of the examples of actions taken by the private sector to tackle growing urban air pollution from vehicular emissions:

  - Development of four-stroke engines – Four-stroke engine three-wheelers were not available in India until mid-2000. Bajaj Auto, with its commitment towards environment, began marketing this technology for two and three wheelers equipped with catalytic converters.
  - Introduction of CNG vehicles and catalytic converters.

3. USAID's Involvement

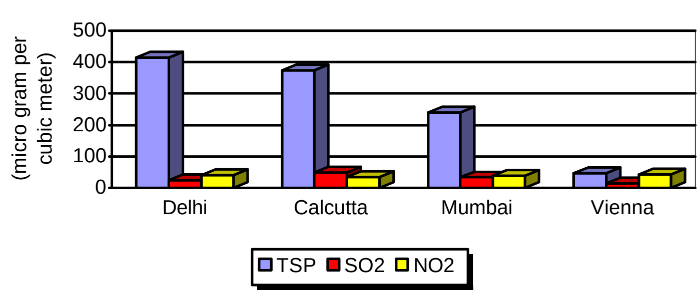
USAID spearheads the U.S. Government's efforts to assist in developing strategies to tap private capital and talent to meet the growing environmental challenges of host countries. At the heart of USAID programs is the recognition that a sustainable economy requires a market-based approach. In pursuit of this strategy, USAID collaborates with the U.S. and host-country private sectors, international financial institutions, and host-country agencies to leverage resources and encourage private sector participation through financing and partnerships.

India – with its relatively short driving distances, growing disposable income, increasing concern about urban air pollution, advanced vehicle manufacturing base, and, heavily congested streets – is an ideal ground for introducing alternative vehicles. The USAID's Mission in India and Global Environmental Center in Washington, D.C. have initiated the Indian Zero Emission Transportation (IZET) Program intended to stimulate the creation of an alternative vehicle market through partnerships with the private sector.

USAID, drawing upon it experience with a modest but successful public-private partnership and introduction of three-wheeled electric vehicles (EVs) in Thailand, has broadened its efforts in India with targeted EV demonstration programs involving scooters and autorickshaws. The results have been encouraging – in early 2001 India's first electric autorickshaws were introduced on the streets of Agra. The electric two-wheelers will be launched later this year in New Delhi.

The USAID interest in India developed in an effort to assist India in balancing economic needs with those of the environment. The goals of mitigating urban air pollution and leveraging linkages with the private sector to remove obstacles for cleaner transport options were clear. Within this broader context, USAID's approach to India began over seven years ago, starting with observations of the poor air quality in many urban areas and continued with identifying the main sources of urban air pollution. During this timeframe, technologies best suited for mitigating the air pollution, policy, regulatory, and public sentiment trends, and private sector resources and plans were obtained and assessed. The information obtained was challenged, screened, and updated. Although acknowledging this as a high-risk venture, electric vehicle technology emerged as a serious contender to mitigate urban air pollution. The figure 4 provides a comparison of air pollution in various cities.

Figure 4. Air Pollutants in Various Cities[10]



[10] World Development Indicators, The World Bank, 1998; TSP = total suspended particles

Because USAID has limited funds and programs such as this one have long gestation periods, careful selection of private sector collaborators is required to ensure their technical and financial commitment. An outreach program began with a series of meetings with Indian vehicle manufacturers to better gauge their commitment and resources. Similarly, public opinion was weighed, government policy and regulatory actions were measured, and economic performance on a macro and micro level was assessed. At the same time the resources and interest of the U.S. electric vehicle community were gauged.

USAID worked closely with several Indian vehicle manufacturers to better understand their views. Drawing upon this understanding, USAID developed a strategy to create more interest in the Indian vehicle manufacturers for electric vehicle technology. A series of focused one-on-one meetings with their senior and mid-level management team was particularly effective. Selected technological assistance was also provided. For example, the lessons learned from USAID's Thailand experience were shared. Meetings to provide specific technical exchanges were arranged with U.S. organizations. Throughout this process, USAID stood fast to a basic premise - a neutral position with respect to the advantages and/or disadvantages of technologies. Each Indian firm was provided information but the conclusions they reached needed to be based upon their decision process. Through these steps, USAID was able to catalyze several Indian firms into action.

During this period of activity, a convergence of factors began to develop making the timing right for a more hands on action by USAID:

- Growing concern for urban air quality;
- Enactment of more stringent emissions regulations;
- Markets for conventional vehicles are being limited;
- Increasing disposable income; and
- Indian vehicle manufacturers became committed to pursuing alternative transportation technologies.

The parameters of the specific programs to be developed were clear: USAID would provide nominal financial assistance and /or technical assistance to the participants, and the payoff for the participating corporations might be a jump-start into the potentially sizeable alternative transportation market in India.

One company, Bajaj Auto Limited (BAL), with good a track record in introducing new technologies emerged as the most committed. Following confirmation of their intentions and resources, programs were developed to:

- Increase public awareness for electric vehicle technology;
- Cost-share resources;
- Provide technical assistance;
- Initiate development of a market-driven technology for electric two- and three-wheeled vehicles;
- Provide commercially attractive technology options for reducing ambient urban air emissions; and
- Demonstrate the technology.

Indian Zero Emission Transportation Program (IZET). The goal of IZET is to accelerate the commercialization path for electric two- and three-wheelers. Both conventional platforms are often pointed to as a significant source of urban air pollution. Discussions took place between USAID and prospective partners for about one year. The program partners ultimately became Bajaj Auto Limited (BAL), New Generation Motors (NGM), the Archeological Survey of India (ASI), WELCOMGROUP, and TRICON Restaurants International. During this time a collaborative program was developed. Responsibilities and the overall schedule were agreed upon for the newly created IZET Program.

BAL was actively involved in screening electric drive systems best suited for the Indian marketplace. It has a large network of dealerships and is committed to providing substantial resources including design, testing, certification, operation, maintenance, oversight of data acquisition, and product evaluation. NGM, a U.S. firm, is a highly innovative electric drive system manufacturer and integrator. As an original equipment manufacturer and popular choice of solar car race teams, NGM holds patents on a highly efficient DC, brushless motor. NGM is the technology provider selected by BAL, and NGM is committed to cost-share their design and production activities with USAID.

4. Basis of Design

In South Asia, conventional two- and three-wheelers have traditionally been aimed at the economically weaker strata of society. They have therefore necessarily been low cost products - a two-wheeler sells typically for US$1000 while a three-wheeler for US$ 1300 ~ 2000. They have been fitted with small 2-stroke petrol or 4 stroke diesel engines, some carry a disproportionately larger load for their capacity, and, coupled with the stop-'n-go urban traffic means that the engines are, at times, grossly overloaded, operate inefficiently, and may be the single largest source of pollution and fuel wastage in the urban areas.

Three wheelers are primarily "public" service vehicles – being used mostly as taxis or "goods carriers". They have both fleet and individual ownership. Being revenue earners, they have to be economically viable to own and operate. If a market is to be generated for these electric three-wheelers, they have to have favorable operating as well as ownership costs. With predicted larger up-front costs, it would need imaginative financing to make them attractive to the buyer. It is therefore necessary to be careful in ascertaining that a chosen conversion technology would meet all performance goals while being reliable, and keeps operating and maintenance costs to a minimum.

Half the population of existing vehicles is out on hire for 20 hours or more, and typically covers over 130 km. in a day. Until high performance batteries become commercially available, the only practical manner to cover this operating profile is to swap discharged battery packs with fully charged ones during the day. This necessitates a ground-up design for a small 3-wheeler, as well as a suitable battery exchange infrastructure to be in place.

However there is the other half of the vehicle population, which is generally owner-driven, where the range requirement is only 80 km in a 10-hour operational day. With plenty of time available for charging batteries from a residential wall-socket, there is no need for a separate battery-exchange infrastructure to be put in place first. This is an operating profile, which can be a convenient target for EV conversion. Technically, the 3-wheeler is more amenable to modifications than a 2-wheeler in accommodating EV components. Also, being a "public service" vehicle, it can attract more sympathetic consideration for legislative and fiscal concessions.

Figure 5 - Vehicle Usage – Time vs. Torque

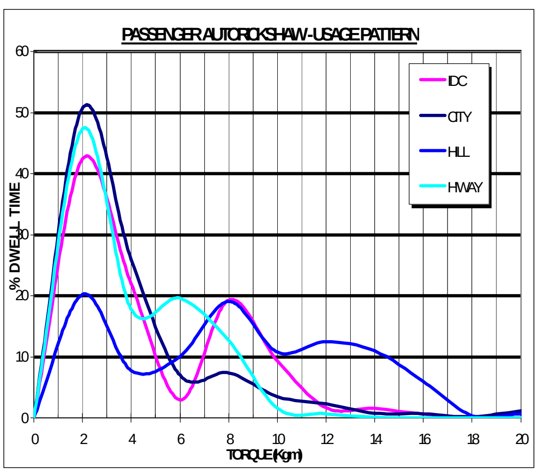
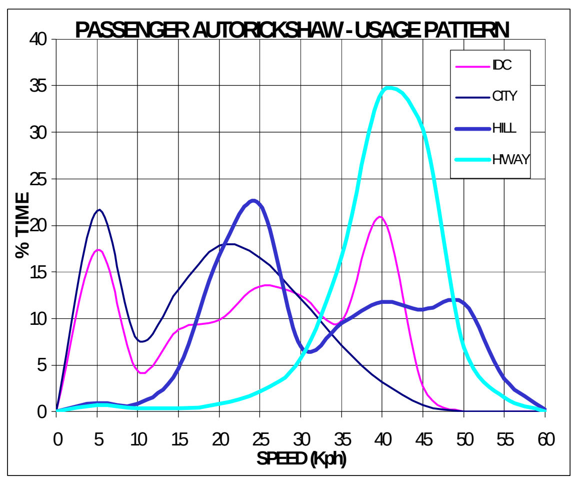
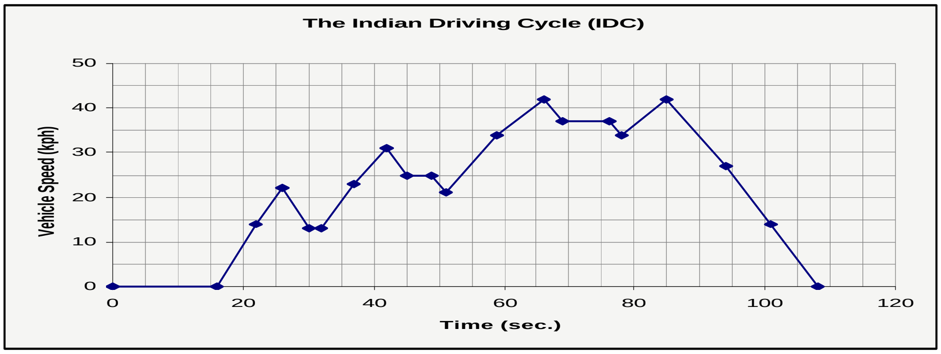


Figure 6 - Vehicle Usage – Time vs. Speed



Several driving cycles that represent various conditions of use are shown below in Figures 5 and 6. For the purposes of IZET, the Indian Driving Cycle (IDC) was the primary vehicle use pattern utilized in developing the drivetrain requirement, as it is a conservative representation of the typical use of the vehicle. The other 3 cycles (City, Hill, and Highway) were used to help establish the gradeability and top speed specifications for the vehicle. The Indian Driving Cycle, Figure 7, consists of a speed-time profile during which the vehicle travels 0.656 km in 108 seconds.

Figure 7 - Indian Driving Cycle



Performance characteristics. An electric three-wheeler can expect to create a market for itself only if it meets the expectations of the customer in terms of its overall performance, operating economics and reliability. Given its known lack of range, it must excel in all other parameters.

The target performance requirements of the electric 3-wheeler is listed in Table 2. A successful demonstration of the electric vehicles necessitates thoroughly designed, exceptionally performing vehicles. The collaborative development effort between NGM and BAL included a system level design approach for each vehicle subsystem in order to carefully perform the correct tradeoffs for a well-balanced final product. NGM's Axial Flux, Permanent Magnet, Brushless DC motor and controller technologies were the drivesystem components requiring careful sizing and design to meet the above objectives. The following sections will briefly address the determination of the detailed drivesystem requirements, followed by the resulting required performance specifications of the drivesystem.

Table 2 – Target Electric Three-Wheeler Performance Specifications

ITEM		Test Conditions	ICEV (Existing)	EV (Expected)
1	Shell Weight (kg)		276	530
2	Payload (kg)		334	334
3	Top Speed (kph)	Max GVW	55	55
4	Gradeability (%) @ 10 kph 20 kph 30 kph 40 kph 50 kph 55 kph	Payload= 334kg	16 – – – – –	19 10 5 3 1 –
5	Acceleration (sec) 0 to 20 kph 0 to 30 kph 0 to 40 kph 0 to 50 kph	Payload = 334kg	6 11 16 21	3 7 15 30
6	Range (km)	Payload = 150kg		> 80 @80% DOD
7	Power Consumption	Payload = 150kg		<0.06 kWh/Km
8	Battery Voltage	60 V Max		
9	General Features	• Throttle input for load sensing • Electric reverse (3 Wheeler) & Battery SOC monitor • Programmable acceleration for "Economy" and "Normal" modes • Limp home capability beyond 80% DOD • Full regenerative braking & Compression brake feeling • On board charger for opportunity charging in 6~8 hours from 80% DOD • DC/DC converter for vehicle Auxiliaries		

Drive system requirements. Based on the target performance specifications, analyses were performed to determine the torque, power, and energy consumption requirements of the vehicle. This is subsequently used in the design and selection of the vehicle subsystems, specifically the drive system. The torque and power requirements come from analyses of the standalone gradeability and acceleration specifications of the vehicle along with the Indian Driving Cycle requirements. The energy consumption requirements are derived from the range specification of the vehicle. The vehicle torque and power requirements based on the system level analysis are shown in Figures 8 and 9.

Figure 8 - 3W Summary Torque Requirements

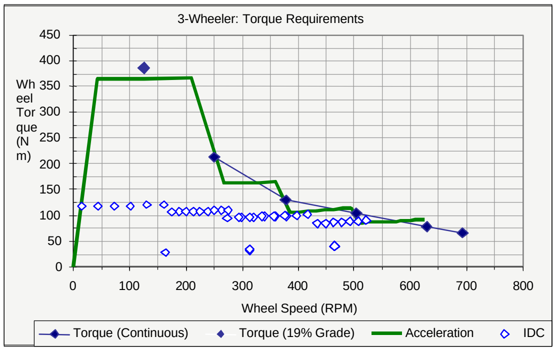
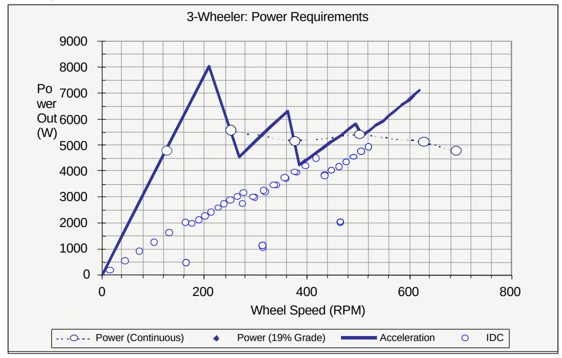


Figure 9 - 3W Summary Power Requirements



The primary specification that dictates the energy consumption and thus, the drivesystem efficiency of the vehicle is the range requirement of 80km. The system approach for understanding the energy use characteristics of the autorickshaw begins by noting the fixed vehicle characteristics. The drag parameters and drivetrain efficiency (transmission and final drive) are given as part of the baseline IC vehicle characteristics. The vehicle battery pack configurations were selected on the basis of several criteria, including energy density, reliability, and packaging. For the 3W, it consists of eight (8) Trojan T-105 6V modules. Summarized technical data from the Trojan Battery Company for the T-105 battery is found in Table 3. (C/5 data given at 30°C):

Table 3 - Trojan T-105 Specifications

	Voltage	C/5 rate	C/20 rate	Length (mm)	Width (mm)	Height (mm)	Mass (kg)
T-105	6V	171Ahr	225Ahr	264	181	284	28

An important factor in the vehicle's range performance is the battery temperature. Shown in Figure 10 are capacity curves for the T-105 as a function of current draw and temperature. The limits of 0 and 48 degrees Celsius coincide with the temperature range for the IZET environmental specifications.

Figure 10 - T-105 Capacity Data

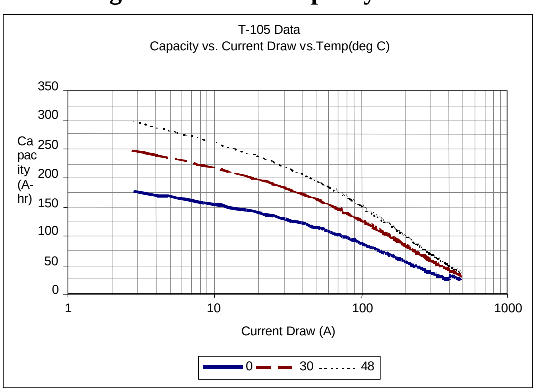
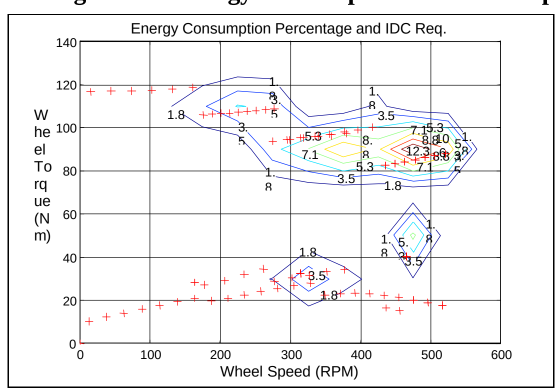


Figure 11 - Energy Consumption Contour Map



To obtain an estimate for the average power consumed by the auxiliary components, a detailed breakdown was performed of the individual auxiliary component loads and their duration of use over the IDC. Assuming daytime operation, brake light operation during decelerations, reasonable turn indicator and horn use, cooling loads for the drivesystem, and a margin of ancillary component loads, the total average auxiliary power requirement was calculated to be approximately 30W.

To determine the minimum average drivesystem efficiency required for the vehicle to achieve the range requirement when driving the IDC, the total energy required was subtracted from the total energy available from the energy storage system over 122 cycles of the IDC. 80km operating on repeated cycles of the IDC translates to about 122 cycles (80.3km) with a total duration of 3.66 hours. A discharge rate for the battery was determined by using a detailed estimate of the average current draw. The amount of energy recoverable from regenerative braking was also estimated based on experience with other electric vehicles. The end result was an excess of approximately 1128 Whrs that could be attributed to drive system losses. Therefore, in order for the vehicle to meet the range, the drivesystem was required to operate, on average, at 83.6% efficiency or above. Given an average drivetrain efficiency of 91%, the motor/controller must operate with an average efficiency of 91.9%. To meet that requirement, a more detailed analysis of the energy consumption was performed. This was done by “binning” the percentage of total energy consumed on a given IDC into torque-speed envelopes. This clearly identified where the majority of energy is consumed. This data was used to produce preliminary motor and controller designs that would meet the gradeability and acceleration requirements and have very high efficiency characteristics when performing on the IDC. Figure 12 shows the results of the energy “binning” process.

The Prototype Components and Vehicles - *The NGM MSF240140 Axial Flux Motor.*
The motor designed by NGM specifically for this application is the MSF240140 Axial Flux motor. This system is shown below in Figure 12, and the specifications are described in Table 4.

Figure 12 – Motor schematics

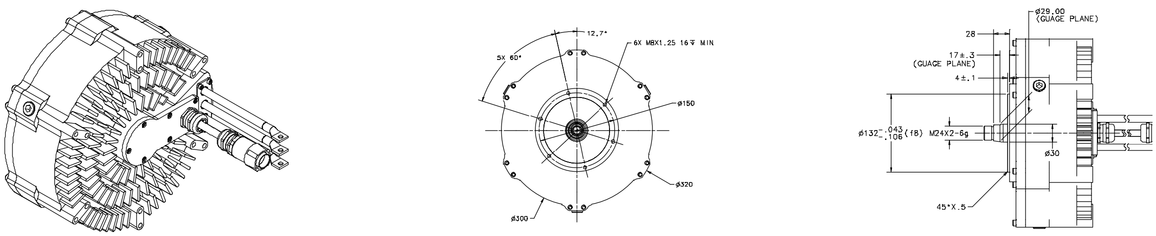
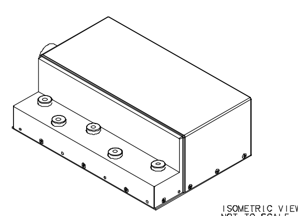


Table 4 - Motor Specifications

Detailed Design Specifications MDF-240/140		
Number of stators		1
Phase Design		Interleaved, 3 Phase
Configuration		1-Y
Number of total slots per stator		24
Number of poles		8
Peak Power	kW	11.1
Speed @ Peak Power	rpm	1900
Continuous Power @V_nom	kW	7.5
Speed @ Continuous Power	rpm	2300
Max Speed in Service	rpm	1841
DC bus Voltage Nominal (V_nom)	V	48
DC bus Voltage Range	V	42.5-60
Phase Current Max (I_max)	A_rms	249
Phase Current Continuous (I_c)	A_rms	148
Peak Torque @ I_max (T_p)	Nm	58.8

The NGM EVC400-043 Controller. The controller design specifically for this application is the EVC400-043 model. The system characteristics are shown below, and the specifications are described in Table 5.



- Sine-wave or trapezoidal control
- Serial Interface for configuration and data acquisition
- CAN Bus interface to external interface module for maximum flexibility and reduced wiring complexity.
- State-of-Charge (SOC) tracking with programmable battery profile
- Internal 150W, 12.0-14.4V power supply available for vehicle auxiliary loads such as lights, vehicle display and cooling fans.
- Motor Current Limiting (MCL) logic provides a speed governor, limp-home mode based off of SOC, Battery charge and discharge protection and phase current limiting for efficiency.

Table 5 - Controller specifications

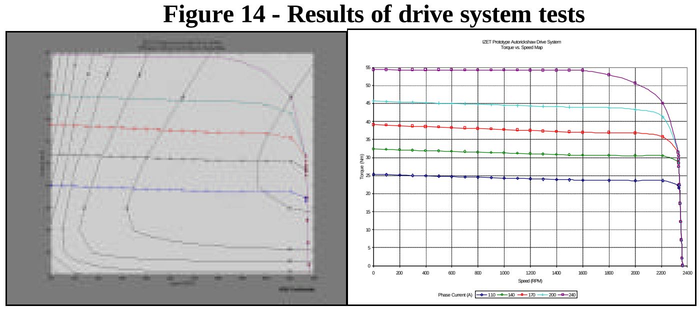
Peak RMS Phase Current (Amps)	265
Nominal Bus Voltage (Volts)	48
Min./Max. Operating Voltage (Volts)	36/60
Maximum Withstand Voltage (Volts)	75
Input Capacitance (uF)	15,120
Peak Efficiency %	99
Height (in.)	3.12
Width (in.)	5.95
Length (in.)	8.88
Weight (lbs.)	6

Component Test Data and Final Integrated System. The developed motor and controller system were built and tested at NGM to insure that the component level requirements were met. Figures 13 and 14 show the test setup and the results. The system met all the design requirements in terms of torque, speed, and efficiency.

The final integrated motor, controller, and rear axle assembly is shown in Figure 15. This assembly takes advantage of the transmission/differential/suspension components already in production by BAL. The final prototype vehicle and the integrated drive assembly and batteries are shown in Figures 16 and 17.

Figure 13 – Drive system bench test

Figure 14 - Results of drive system tests



Figures 15, 16 – integrated drive

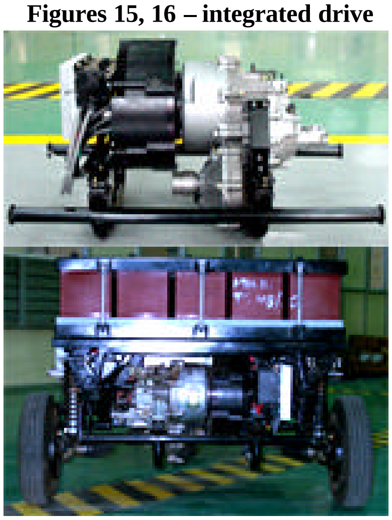


Figure 17 – Final prototype vehicle

6. Certification Tests

In October 2000 the first electric three-wheeler prototype was tested at the facilities of the Automotive Research Association of India (ARAI) and the Vehicle Research and Development Establishment (VRDE). These tests followed significant testing at the NGM facilities in the U.S., which was witnessed by parties from BAL and Nexant in September 2000.

The purpose of the tests was to evaluate the performance of the vehicle, to verify its compliance with the target technical specifications, and to obtain certification for compliance to the Central Motor Vehicles Rules, 1989.

The vehicle performance and its compliance with the requirements were evaluated based on the following four criteria, (1) top speed, (2) acceleration, (3) gradeability, and (4) range. Each one of these criteria was tested independently. The vehicle passed the requirements and received provisional certification on January 29, 2001. Tables 6 and 7 show the results of the testing as compared to the design requirements. In addition, it should be noted that the top vehicle speed in 4th gear was measured at 62 kph, and the range on the IDC nearly 80 km. Later testing conducted in normal city driving revealed a range of 110-115 km on a single battery charge.

Table 6 - Average Acceleration Time

Speed (KPH)	Average Time (sec)	
	Req'd	Measured
0 to 20	3.0	3.6
0 to 30	7.0	6.9
0 to 40	15.0	11.8
0 to 50	30.0	22.5

Table7 - Gradeability Test results

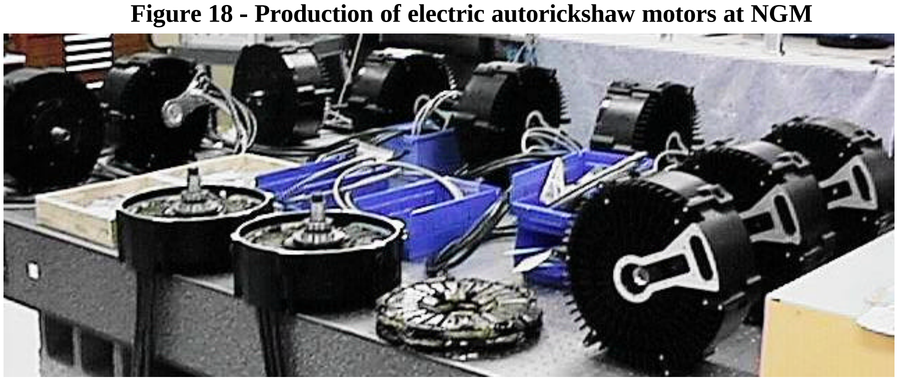
Speed (KPH)	Gear	Gradeability	
		Req'd	Estimated
10	1	19.0%	20.2%
20	2	10.0%	9.9%
30	3	5.0%	6.5%
40	4	3.0%	3.7%
50	4	1.0%	2.9%

7. Commercialization Phase

In order for electric 3-wheeler vehicles to become commercially viable in India, they must meet two criteria; namely meet or exceed all performance targets of comparable gasoline/diesel powered vehicles, and be cost competitive. The first criterion has been met through the efforts of the IZET project. The commercialization of low cost, sophisticated traction motors and controllers that incorporate rare-earth magnet technology and advanced silicon power devices is a challenge. Through a detailed life cycle cost analysis performed by Bajaj Auto it was determined that commercial viability of the electric autorickshaws can be achieved if the cost of the motor, controller, charger, and other electric drive ancillary parts would result in a final vehicle selling price that is no more than 25% higher than the conventional autorickshaw.

On June 5, 2001 BAL and NGM signed a Memorandum of Understanding (MOU) outlining three phases to pursue the commercialization of these vehicles, with the first phase involving the deployment of 200 vehicles, predominantly in Delhi, to test consumer acceptability. The initial systems for this phase would be produced at NGM's facilities in the U.S.A. (Figure 18). Following the successful deployment and testing of these vehicles, the second and third phases would be initiated consecutively with the full mass production of the electric autorickshaws. As a result of this MOU, NGM has initiated the next stage to re-engineer the drive system for large volume production, with support from several US and Indian motor and electronics manufacturers. This effort is funded in part by a USAID backed loan from ICICI Limited. The first phase vehicles are expected to be deployed in 2002.

Figure 18 - Production of electric autorickshaw motors at NGM



8. Conclusion

The anticipated short-term benefits of IZET include determining the feasibility and consumer acceptance of electric vehicles in the Indian market and raising awareness of environmentally benign urban transport options. Long-term benefits include developing commercial relationships among private sector firms, establishing EV technology as a reality in the Indian marketplace, and improving urban air quality and reducing attendant costs.

Electric Vehicle Technology – Moving to Commercial Reality: *Lessons Learned from a U.S. Government Agency's Initiatives with the Private Sector In South Asia*

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Introduction

India – with its relatively short driving distances, growing disposable income, increasing concern about urban air pollution, advanced vehicle manufacturing base, and, its heavily congested streets – is an ideal ground for introducing alternative vehicles. The USAID's Mission in India and Global Environmental Center in Washington, D.C. have initiated several programs intended to stimulate the creation of an electric vehicle market through partnerships with the private sector.

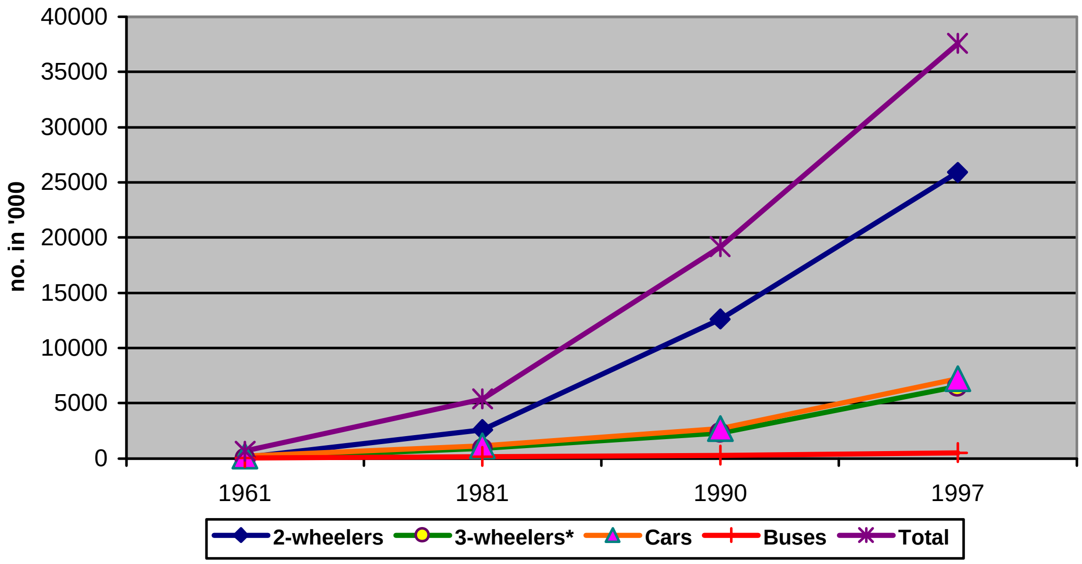
USAID, drawing upon its experience with a modest but successful demonstration and introduction of 3-wheeled electric vehicles (EVs) in Thailand, has broadened its efforts in India with targeted multi-prong EV demonstration programs involving scooters, autorickshaws, and automobiles. The results have been encouraging – during 2000 India's first electric automobiles will be rolling off the assembly line, and prototype electric scooters and autorickshaws will be on the streets of Delhi and Agra.

Why is USAID Involved in Alternative Transportation in India?

Inefficient vehicles and increasingly more congested roadways are key factors to deteriorating ambient urban air in India. Acceleration and deceleration, for example, produce much higher exhaust emissions (over 150 and 50 times, respectively) from steady speeds. Hospital admissions and deaths resulting from urban air pollution are exceedingly high in many of India's large cities. But, unlike other countries in the region, India has a vibrant vehicle manufacturing industry that is motivated to determine the feasibility of alternative transport technologies.

Indian Transport Sector. Production, trade, and investment reform since 1991 have provided new opportunities for business in India with an estimated 300 million-middle class consumers and a growing disposable income. This large and growing middle class has made India one of the fastest growing markets for vehicles. Overall vehicle population increased more than seven-fold between 1981 and 1997 from about 5 million to 38 million vehicles. Among all the vehicles, the growth in 2-wheelers (e.g., motorscooters), predominantly with two-cycle engines, has been the most dramatic, increasing by more than 10-fold between 1980 to 1997. The number of 3-wheelers (e.g., autorickshaws) in the same period increased approximately 6 fold. In the early 1990s, 2- and 3-wheelers accounted for about 70% of all registered vehicles. The growth of the Indian vehicle population is illustrated in Figure 1.

Figure 1.
Growth of Indian Vehicle Population



Source: Society of Indian Automobile Manufacturers, India Auto Statistics, 1999

Moreover, the Indian road system has not kept up with the growing number of vehicles resulting in severe congestion in urban areas – among the worst in the world. A majority of the vehicles in major cites, for example, stay idle in traffic for 20 to 25 percent of the time exacerbating the poor air quality.

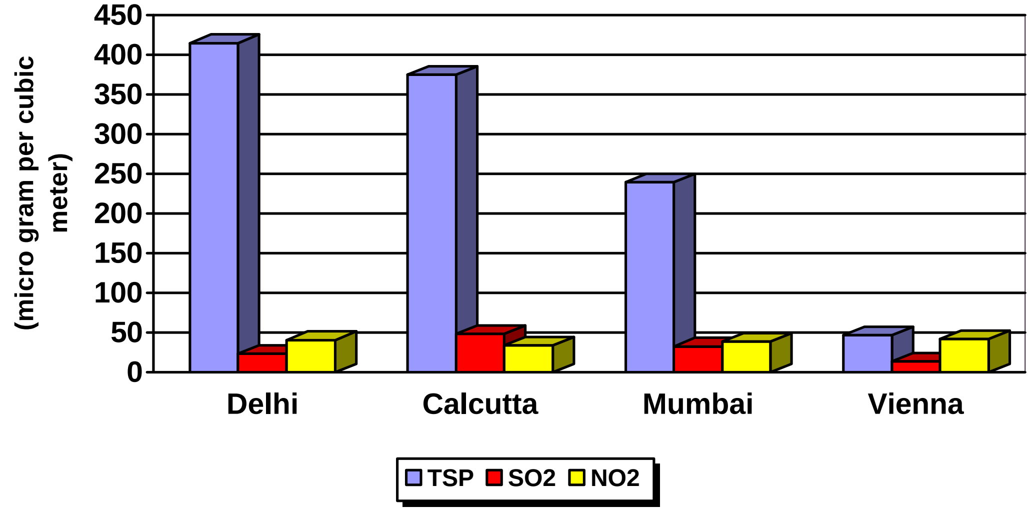
User Profile and Market. Relatively short trip distances, growing disposable income, congested roadways, and increased concerns for air quality together are creating a market for alternative vehicles in urban India. Driving distances are relatively short compared to Western nations. Moreover, travel in the three largest Indian cities accounts for 50% of total vehicle distances in the country. Average distance traveled per day within a city is 25-26 km[1], which is significantly less than 50-60 km in Western countries. Several studies also indicate the average speed in larger urban areas to be between 5-12 km per hour.[1] The top three income groups – middle, upper middle and upper class families have also grown from 10% in 1986 to 17% of the total Indian population.[2]

Worsening Urban Environment. Industrialization and urbanization in India have resulted in deteriorating air quality. India's gross domestic product has increased 2.5 times over the past two decades. There is a price for this growth - vehicular pollution has increased eight times and pollution from industries has quadrupled. Growing urban air pollution has become an issue of public and political concern throughout urban India. A comparison of air pollution in various cities is given in Figure 2.

Figure 2.

[1] Impact of Road Transport System on Energy and Environment- an analysis of metro pollution cites of India, A Report, Ministry of Urban Development, Govt of India, 1993
[2] Automobile Industry Association of India, Report to GoI, 1999

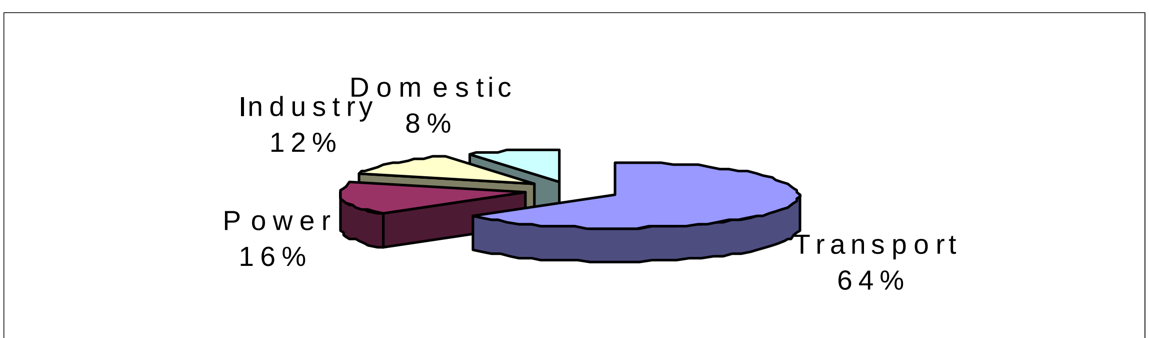
Air Pollutants in Various Cities[3]



Environmental Conditions in India

The Indian government and judiciary have made significant efforts in the field of environmental protection. The government, particularly for 3-wheelers, has issued a series of more stringent directives and regulations. In 1999, for example, the Indian Supreme Court prohibited registration of new vehicles in the National Capital Region surrounding New Delhi if they fail to meet EURO II emissions norms after April 1, 2000. Figure 3 provides the rationale for the government's decision for issuing new directives on transport emissions. In Mumbai, autorickshaws are banned within the central part of the city. Moreover, a directive was issued to retire older autorickshaws in Delhi supplemented with financing incentives for replacement with more efficient 3- wheelers. Leaded gasoline is also being phased out. Vehicle manufacturers are developing new products to maintain volume and market share, and there is an increased interest in alternative transport technologies.

Figure 3
Contribution of Transport Sector to Total Pollution In Delhi[4]
(CO+HC+NO2+PM)



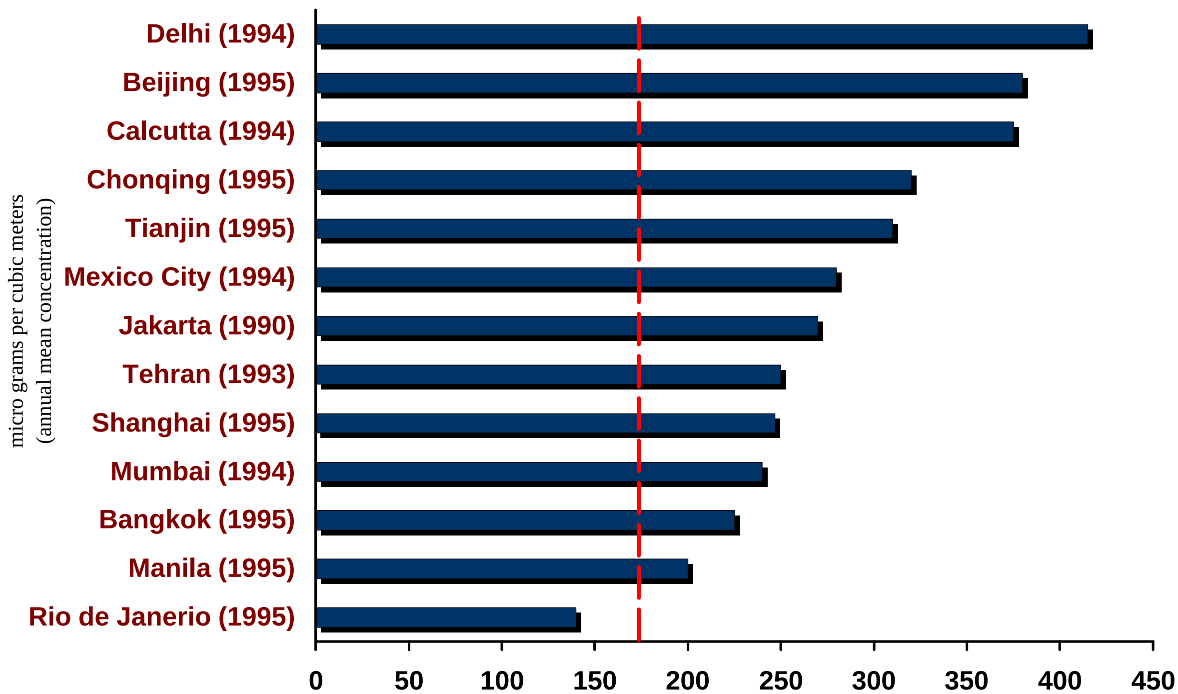
He
loa
(PM-2.5 microns), oxides of nitrogen (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), hydrocarbons

[3] World Development Indicators, The World Bank, 1998; TSP = total suspended particles
[4] N.V. Iyer, Bajaj Auto Ltd., Pune, India, "Workshop on Pollution From Motorcycles: Issues and Options", The World Bank March 9, 2000

(HC), ozone (O_3), and heavy metals are the primary causes of adverse health effects. Such effects result from both chronic and acute exposures; the chronic exposures have a cumulative effect, while acute exposures typically take a heavier toll among the young, old, and ill. Adverse health effects include premature or sudden death, as well as an increased incidence of chronic respiratory, coronary, and neurological disorders.

According to the World Health Organization (WHO), three major Indian cites, Delhi, Calcutta, and Mumbai, are among the most polluted cities in the world (Figure 4). The majority of this pollution comes from the Indian transport sector - primarily from two-stroke 2 & 3-wheelers. In Delhi alone almost seventy percent of the city pollution is attributed to transport sector. Moreover, forty percent of these emissions are attributed to 2 & 3 –wheelers.

Figure 4
Ambient Concentration of TSP Exceeding WHO Guidelines in Different Cities



Source: World Resources, 1998-99
Note: ------ Represents WHO Guidelines for TSP at 180 µg/m³

The estimated reductions in Particulate Matter (PM) resulting from replacement of 10, 50, and 100% of the 2- and 3- wheeler vehicle populations with EVs in Delhi are presented in Table 1. Secondary emissions resulting from increased fuel combustion required to satisfy the incremental demand for battery recharge are not considered as power generation occurs elsewhere and would not typically have a significant local impact.

Table 1. **Test Case – Estimated Reduction in Particulate Matter (PM) as a Result of Replacing Varying Percentages of the 2 & 3-Wheeler Population in Delhi**			
Scenario: (% EV Substituted for 2 & 3-Wheelers)	Total 2 & 3-Wheeler EVs introduced	Annual Reduction in PM emissions (metric tpy)[1]	Reduction in net annual PM emissions (%)[2]
10%	188,000	938	0.85
50%	940,000	4,690	4.25
100%	1,880,000	9,380	8.50

[1]All 2-strokes engines, assumes 25 km./day for 2-wheelers, and 80km./day for 3- wheelers
[2] GOI statistics

Table 2 presents the estimated reduction in number of deaths per year, by age group; as a result of replacement of 10, 50, and 100% of the 2 and 3-wheeler fleet by EVs in Delhi. Although the extrapolation and calculations are oversimplified, the values used are based on well-known and reasonably accurate concentration-response data. Estimates are based on an assumed annual average PM concentration of 400µg/m^3 It should be noted that actual exposures would vary, depending on location, activities, and health of the individual.

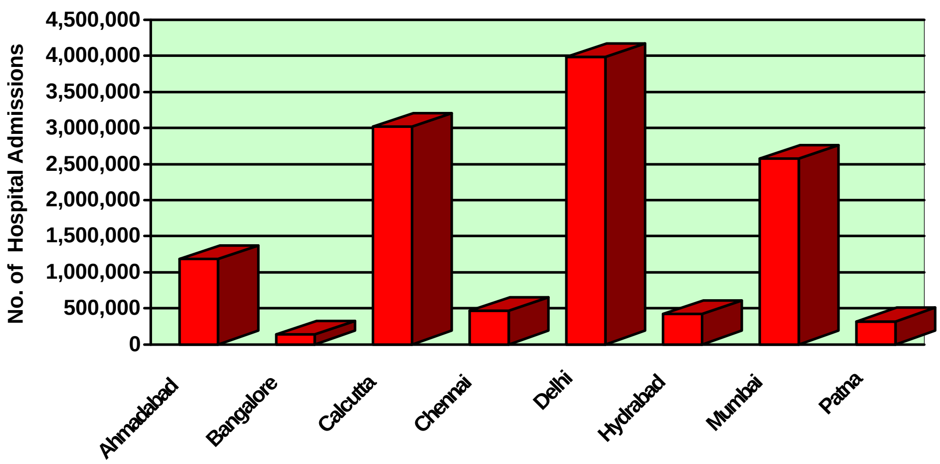
Table 2. Estimated Reduction in Number of Deaths Avoided, by Age Group, as a Result of Replacing 10%, 50%, and 100% of the 2-Cycle 2 & 3-Wheeler Fleets with Electric-Powered Equivalents in Delhi				
Age Group	**Reduction in Deaths/Year per 100 µg/m^3 Reduction in PM** [1]	**Reduction in Deaths/Year at 10% Substitution by EVs (16 µg/m3 reduction)**[2,3]	**Reduction in Deaths/Year at 50% Substitution by EVs (80 µg/m3 reduction)**[2,3]	**Reduction in Deaths/Year at 100% Substitution by EVs (160 µg/m3 reduction)**[2,3]
0-4	278	44	220	440
5-14	63	10	50	100
15-44	651	104	520	1,040
45-64	268	43	215	430
65 and >	125	20	100	200
Total	1,385	221	1,105	2,210

[1]Based on Table 8., and 1991 population figures "the Health Effects of Air Pollution in Delhi, India, World Bank PRD Working Paper 1860, M. Cropper, et. Al., 12/97
[2] Assumes 40% of PM emissions are from 2 & 3- wheelers, "Emissions and Control Options for Two-Stroke Engines in India", N.V. Iyer, et al., Workshop on Pollution from Motorcycles: Issues and Options, The world Bank, 3/9/00
[3] Prorated against assumed ambient loading of 400µg PM/m3

The health impacts of PM in the west are different than in Delhi. In the west, for example, the main impact to PM exposure is on persons over 65. In Delhi the impact on this age group is not that significant. The reasons vary but it is possible persons susceptible to the health effects of PM exposure are also more susceptible to infectious disease and will have died prior to reaching the age of 65.

It is perhaps more difficult to determine the effects of air pollution on morbidity. Again, a number of studies have investigated this issue and while quantification may be difficult, the magnitude can be reasonably estimated. The World Bank in one such study estimated the annual hospital admissions resulting from ambient urban pollution to be over 4 million in Delhi alone (Figure 5). Other estimates indicate the health damage cost from urban air pollution to be about $500 million per year for the major Indian cities.

Figure 5
Annual Hospital Admissions Due to Urban Air Pollution



Source: Financial Times, August 1, 1997

Environmental Impacts of Two- and Three-Wheeler EVs

The primary environmental impacts from electric vehicles overall are positive. In addition to reduced air, water, and noise pollution, there are also secondary and even tertiary impacts. A simple estimation of decreased local emissions of PM resulting from various levels of introduction of 2 and 3-wheeler EVs and the resultant increase in emissions from a coal-fired power plant located outside the urban area are presented in Table 3.

Table 3. Net Change in Mass Emissions of PM as a Result of the Introduction of Various Percentages of EVs to 2 & 3-Wheeler Vehicle Population in India

Percent of 2 & 3 -Wheeler Vehicles Replaced by EVs	Net Reduction Vehicular PM Emissions (annual, metric tpy)	Net Increase in Power Plant PM Emissions (annual, metric tpy)	Net Change in PM Mass Emissions (annual, metric tpy)
10	22,356	1,791	(20,565)
50	111,781	8,958	(102,823)
100	223,563	17,916	(205,647)

Assumptions:

- Population of ~32.5 million 2 & 3-wheelers, at 25 km/day & 80 km/day for 365 days, respectively
- Power required is 0.026 & 0.082 kWhr/km for 2 & 3-wheelers, respectively; thermal efficiency at 30% for power station, 20% losses for transmission & distribution, and 14% loss for charging
- .1 lb. PM per MBTU thermal input (USEPA NSPS 1971)

USAID's Involvement

Overall Approach. USAID spearheads the U.S. Government's efforts to assist in developing strategies to tap private capital and talent to meet the growing environmental challenges of host countries. At the heart of USAID programs is the recognition that a sustainable economy requires a market-based approach. In pursuit of this strategy, USAID collaborates with the U.S. and host-country private sectors, international financial institutions, and host-country agencies to leverage resources and encourage private sector participation through financing and partnerships.

Recognizing the Economic and Environmental Needs in India. The USAID interest in India developed in an effort to assist India in balancing economic needs with those of the environment. The goals of mitigating urban air pollution and leveraging linkages with the private sector to remove obstacles for cleaner transport options were clear. Within this broader context, USAID's approach to India began over seven years ago, beginning with observations of the poor air quality in many urban areas and continued with identifying the main sources of urban air pollution. During this timeframe, technologies best suited for mitigating the air pollution, trends with policies, regulations, and public sentiment, and private sector resources and plans were obtained and assessed. The information obtained was challenged, screened, and updated. Although acknowledging this as a high-risk venture, electric vehicle technology emerged as serious contender to mitigate urban air pollution.

Because USAID has limited funds and programs such as this one have long gestation periods, careful selection of private sector collaborators is required to ensure their technical and financial commitment. An outreach program began with a series of meetings with Indian vehicle manufacturers to better gauge their commitment and resources. Similarly, public opinion was weighed, government policy and regulatory actions were measured, and economic performance on a macro and micro level was assessed. At the same time the resources and interest of the U.S. electric vehicle community were gauged.

USAID/India sponsored the Indo-US Workshop on Electronic/Electric Vehicles – Technology & Policy Issues in Delhi during 1995 to bring together the Indian and U.S. private and Indian public sectors by providing a forum for the free exchange of thoughts and interests. This workshop was well attended by industry and government and was widely viewed as a success in initiating serious dialogue and action into determining the feasibility of electric vehicles. USAID/India also sponsored two publications, Electric Vehicle Investment Opportunities in India and, A Directory of the U.S. Electric Vehicle Industry. These documents were aimed at providing information to the private sectors of both countries to sustain the interest begun at the workshop and to partially respond to their requests for additional data.

Brokering. Following these activities, USAID worked closely with the several Indian vehicle manufacturers to more fully understand their views. Drawing upon this understanding, USAID developed a strategy to create more interest in the Indian vehicle manufacturers for electric vehicle technology. A series of focused one-on-one meetings with their senior and mid-level management teams was particularly effective. Selected technological assistance was also provided. For example, the lessons learned from USAID's Thailand experience were shared. Meetings to provide specific technical exchanges were arranged with U.S. organizations. Throughout this process, USAID stood fast to a basic premise - a neutral position with respect to the advantages and/or disadvantages of technologies. Each Indian firm was provided information but the conclusions they reached needed to be based upon their decision process. Through these steps, USAID was able to catalyze several Indian firms into action.

During this period of activity, a convergence of factors began to develop making the timing right for a more hands on action by USAID:

- Growing concern for urban air quality;

- Enactment of more stringent emissions regulations;
- Markets for conventional vehicles are being limited;
- Increasing middle class disposable income; and
- Indian vehicle manufacturers became committed to pursuing alternative transportation technologies.

The parameters of the specific programs to be developed, including a concept electric automobile, were clear: USAID would provide nominal financial assistance and /or technical assistance to the participants, and the payoff for the participating corporations might be a jump-start into the potentially sizeable alternative transportation market in India.

Two companies, Bajaj Auto Limited (BAL) and the Reva Electric Car Company (REVA), emerged as the most committed. Following confirmation of their intentions and resources, programs were developed with each firm to:

- Increase public awareness for electric vehicle technology;
- Cost-share resources;
- Provide technical assistance;
- Initiate development of a market-driven technology for electric vehicles;
- Provide commercially attractive technology options for reducing vehicular emissions in urban areas; and
- Demonstrate the technology.

REVA

USAID was interested in accelerating the commercialization path for a concept electric automobile. REVA was initially a joint venture between Maini, an Indian conglomerate, and Amerigon, an U.S. electric vehicle firm. This sector in U.S. can be characterized as generally highly entrepreneurial and innovative with scarce capital. Discussions between USAID and REVA executives quickly identified targeted assistance efforts in keeping with the objectives of the organizations. Specific assistance included funding product certification tests at the Automobile Research Association of India, marketing surveys, and a demonstration of the vehicle in Delhi.

The marketing survey, for example, was aimed at determining the price sensitivity and demand curves for the REVA. Performed in Bangalore, this effort initially determined the target audience and then conducted the survey. The results of the survey provided a ranking of preferred features and demand curves at four pricing points.

The demonstration and field testing of the REVA took place in Delhi where two REVAs were used by USAID and Winrock India International staff for approximately 12 months during their daily activities. In doing so, data was collected for REVA and public awareness was raised.
REVA is scheduled for commercial launch this year. A new factory in Bangalore, India, facilitated by USAID/India's involvement with the Industrial Credit and Investment Corporation of India to secure financial assistance for REVA for approximately $1.8 million, has been built to produce this vehicle. Initial production calls for about 1,500 vehicles to be produced and, when fully operational, the plant will have an annual capacity of about 12,000 electric vehicles. Pricing is expected to be attractive for the intended market. It is estimated that USAID funds were leveraged 1: 50.

Indian Zero Emission Transportation Program (IZET)

As with the REVA program, USAID is interested in accelerating the commercialization path for electric 2- and 3-wheelers. The 2 wheeler is the fastest growing vehicle segment in India and the 3- wheeler is a widely used vehicle throughout Asia. Both conventional platforms are primarily equipped with two-stroke engines and are often pointed to as a significant source of urban air pollution. Discussions took place between USAID and prospective partners for about one year. The program partners ultimately became Bajaj Auto Limited (BAL), New Generation Motors (NGM), WELCOMGROUP, and TRICON Restaurants International. During this time a collaborative program was developed. Responsibilities and the overall schedule were agreed upon for the newly created IZET Program.

BAL is the leading manufacturer of conventional 2- and 3-wheelers, was actively involved in screening electric drive systems best suited for the Indian marketplace, has a large network of dealerships, and is committed to providing substantial resources: design; testing; certification; operation; maintenance; oversight of data acquisition; and, product evaluation. NGM, an U.S. firm, is a highly innovative electric drive system manufacturer and integrator. As an original equipment manufacturer and popular choice of solar car race teams, NGM holds patents on a highly efficient DC, brushless motor. NGM is the technology provider selected by BAL, and NGM is committed to cost-share their design and production activities with USAID.

The other two private sector partners are the WELCOMGROUP's Mughal Sheraton Hotel in Agra and TRICON Restaurants International (Pizza Hut) in Delhi. Sheraton will use the 3-wheelers and Pizza Hut will use the 2-wheelers during the demonstration as part of their normal operations. These firms are well managed, willing to provide resources, and committed to use the electric vehicle prototypes in real market applications.

Design Considerations. The objective of IZET is to design safe and reliable electric 2 and 3- wheelers that look, operate, and feel, as much as possible, like conventional units at a production cost that is within reach of the intended markets. Another aspect is to draw upon the brand name and familiarity consumers have with BAL's products. This offers serious challenges to the BAL/NGM design team. That said and knowing the electric vehicles will be heavier, it is expected that the electric vehicles, with the same payload as the conventional counterparts, will meet or exceed most current road performance parameters – top speed, gradeability, and acceleration. The range @ 80% depth of discharge is expected to be greater than 80 km. Power consumption is anticipated to be <0.02 kWh/km and <0.06kWh/km for the 2 and 3-wheelers, respectively. A 48-volt system was selected to coincide with existing Indian safety concerns. Key considerations for the selection of the batteries were availability, cost, and performance. The batteries chosen for the initial demonstration fleet are flooded lead-acid Trojan T-105 and sealed lead-acid Hawker G16-EP for the 3 and 2- wheelers, respectively. The integration of the units is a joint effort of the BAL/NGM team. The 2 wheeler presents the greater challenge due to limited space. A series of tests at BAL's test center are planned as is product certification tests at the Automotive Research Association of India. More specifics concerning the design, integration, and tests are available in a paper given elsewhere in this volume entitled, " India Zero Emissions Transportation Project (IZET)…an International Collaborative Electric vehicle Initiative" by T. Basu, et al.

Cost Considerations. Two wheelers in urban areas are generally used for personal transportation. The anticipated market is viewed as being dominated by a more sophisticated consumer; one that recognizes the life cycle costs and is more concerned for the environment. Given these conditions, as long as the electric vehicle is reliable and meets performance expectations, a higher initial cost for an electric vehicle can be rationalized.

Three wheelers are primarily used as taxis and goods carriers. Operating in fleets and individual ownership, these businesses need to be profitable. Market demand for this vehicle is price elastic and operational costs need to be minimized. Since the initial cost for an electric driven 3- wheeler is expected to be more than a conventional unit, alternative marketing approaches will need to be considered such as extended warranties or financing incentives. This said, the anticipated cost to the consumer for an electric 3- wheeler, without subsidies, is about $2,600 or about twice the price of a gasoline two stroke 3- wheeler which is about $1,300. The running costs of an electric 3- wheeler are expected to yield an annual savings of about $300. Given the trend to finance and the high interest rates in India, a simple breakeven point for the consumer is about five years.

Demonstration. This year, up to 15 electric-driven 2- and 3-wheelers will be field-tested on the streets of Delhi and Agra, respectively, for 6-12 months. TRICON will sponsor the 2 wheelers and the Mughal Sheraton will sponsor the 3- wheelers. After thorough training the drivers will travel their customary routes. Periodic checks of the vehicles will be performed to assess reliability and safety factors. Several of the vehicles will be equipped with data acquisition systems. During that time data will be acquired, reduced, analyzed, and the lessons learned will be applied towards the next iteration of vehicles.

Conclusion

The anticipated short-term benefits of IZET include determining the feasibility and consumer acceptance of electric vehicles in the Indian market and raising awareness of environmentally benign urban transport options. Long-term benefits include developing commercial relationships among private sector firms, establishing EV technology as a reality in the Indian marketplace, and improving urban air quality and reducing attendant costs. It is estimated that USAID funds for this initial program are leveraged about 1:4. Should IZET realize commercial reality the ratio would be much higher.

USAID is and has been an active player in India in raising awareness of the potential advantages of electric vehicle technology. As recently as this past November, USAID participated in and sponsored a conference, Automotive Electronics and Alternate Energy Vehicles, in Kanpur, India. USAID has also helped to catalyze two other Indian firms, Mahindra & Mahindra and Scooters India, develop their electric 3- wheeler vehicles, the Bijlee and Vikram, respectively.

Electric vehicles may not be the entire total solution to growing urban air pollution in India but given the increasing road usage and driving profile, electric vehicles appear to provide an environmentally benign option for the consumer. Innovative but commercially proven technology is an option that is or will soon be available and one that is reasonably priced. An option to help mitigate urban air pollution and the debilitating effects of growing tailpipe emissions. USAID is pleased to be a part of the process for evaluating the feasibility of this technology.

Indian Zero Emission Transportation Project (IZET)

…an International Collaborative Electric Vehicle Initiative

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Abstract

India is coming to a point where its major cities are becoming virtually unlivable due to rapidly increasing environmental pollution. There has been tremendous growth in the number of registered vehicles during the last ten years and the country is now at the crossroads for options to speedily reduce transport related emissions in the urban centers. Public and regulatory pressures dictate the need for a market strategy to plan for alternative transportation technologies.

By far the most popular vehicles in the country are two and three-wheelers (scooters and autorickshaws) with two-stroke engines. Two key vehicle market characteristics in the country are a relatively benign urban driving profile and a price elastic market demand. The Indian Zero Emission Transportation Project (IZET) is aimed at addressing these concerns, leading to accelerated commercialization of electric driven scooters and autorickshaws.

This paper presents the background for a viable market for electric vehicles in India. It affords a detailed look at the international collaboration between two motivated firms, the technical and commercial decisions reached and their basis, and, the efforts associated with design, development, testing, certification and demonstration of the product, along with lessons learned. The results provide an insight into what is expected to be a fast-track path to commercialization of innovative vehicles for the intended market.

Introduction

The automotive industry in South Asia has been registering an impressive growth and is on the verge of a virtual boom in the coming decade, bringing in its wake, enormous pressure on the quality of the urban environment and supply of conventional petroleum fuels. Most cities in the region now have almost unmanageable pollution and traffic congestion problem – Bangkok, Djakarta, Kathmandu, Delhi and Mumbai are cases in point (

Table 1). The effect of pollution from vehicular exhausts has been linked to damage to human health, directly burdening the local population, and indirectly, the entire nation. This cost is quantifiable and is alarming.

Though improving technology and legislative controls could partially regulate and ameliorate the ambient air quality, effective control requires a multiprong strategy depending upon resource availability, economic feasibility, energy security, and environmental impact. Electric vehicles have zero local-pollution potential, and provide a good solution for energy security.

Table 1
Ambient Air Pollution in Various Asian Cities (Annual mean values)

City	CO (mg/m^3)	PAH (ng/m^3)	NO_2 ($\mu g/m^3$)	SO_2 ($\mu g/m^3$)	SPM ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)
WHO Guidelines	10 (8hr)	(10)*	150 (24hr.)	50	60	40
Delhi (~1999)[1]	5.5	40	150	25	426	300
Mumbai (~1999)[2]	3.2	—	228	10	–	288
Kathmandu (~1993)[3]	—	—	47	37	380	137
Bangkok						

*– Indian AQS

A Case for Small EVs

Energy, which is the most abundant resource in the universe, is in shortest supply in the EV. Aside from this, an EV is a superb transportation device. They have no exhaust emissions, are virtually maintenance free, and can be conveniently refueled at home utilizing existing infrastructure. The shift of concept, where fuel is converted into usable energy at a remote facility instead on board the vehicle, simplifies tasks of utilizing alternative fuels, producing maximum energy with minimum resources.

Even with the existing limitation in energy storage technologies, mission-specific EVs have the potential to markedly reduce harmful emissions and lower dependence on petroleum motor fuels. Over the near term, integrating the EV into the transportation system is essentially a marketing challenge, rather than one of technology.

South Asia is peculiarly positioned in respect to personal transport. Because of a very difficult environmental situation in many urban areas, there is an urgent need for economically affordable ZEVs. Further, it is heavily burdened by imports of petroleum products eating away precious foreign currency reserves. Unlike the more industrialized countries, personal transport is mostly limited to a single urban area, with low operating speeds due to heavy congestion (***Table 2***). In this scenario, the traditional automobile is too large, powerful and poorly utilized.

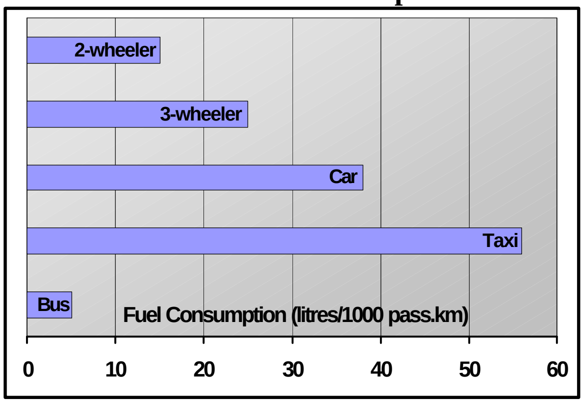
Table 2
Mobility Statistics in India[4]

Mode	Share of Passengers (%)		Travel Demand 1991→2000		Travel Data	
	Average	Range	Increase in vehicles (%)	Pass. Share – Personal Transport (%)	Occupancy (No.)	Travel Dist. (km)
Total Travel demand	–	–	600K → 900K (nos.)			
Bus	69	–	17			
Car	8	2 ~ 22	4	20→13	2.6	26
3 Wheeler	3	0.5 ~ 23	13	20 →14	1.8	75

2 Wheeler	19	2 ~ 22	26	60 → 73	1.5	25

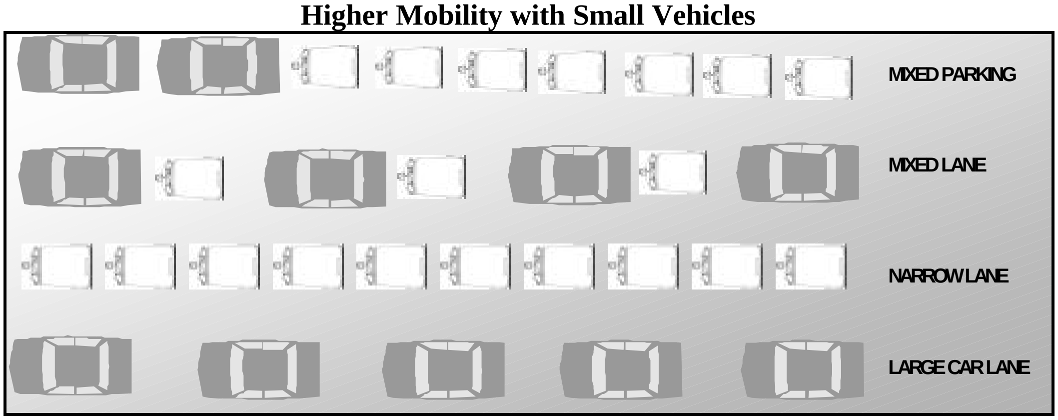
Minimizing the vehicle itself is a most straightforward way of achieving energy savings – smaller vehicles directly reduce workload and equally smaller engines and drivetrains work synergistically to reduce the overall energy appetite. Since the vehicle consumes roughly the same energy whether the seat is occupied or vacant, it makes sense to design vehicles to fit travel preferences. From the collated data, it would seem that the optimum layout is for single or two occupants. Such vehicles would accommodate over 70% of all trips made. A three-place vehicle would increase this to almost 90%. A small vehicle also reduces energy demand (***Figure 1***). These vehicles excel at reduced load factors, and in city driving, where the lower system mass directly translates to lower transport energy utilization.

Figure 1
Vehicle Fuel Consumption



The second most significant waste of energy in urban traffic occurs because of congestion.. Studies have shown that, due primarily to decreased headway requirements, roadway capacity is significantly improved beyond their raw geometric size ratio when very small vehicles are substituted for large ones. The improvement can be of the order of 30% for mixed lanes and 100% for special segregated lanes for small vehicles (***Figure 2***). Also on signalized traffic for intersections in series, a 50% reduction in length of vehicles improves traffic flow by over 70%.

Figure 2
Higher Mobility with Small Vehicles



On an average, over 33% of expensive urban real estate is dedicated to automobile infrastructure and smaller vehicles can free up this land for other productive uses. Thus, with no change in land apportionment, smaller vehicles can relieve congestion and increase capacity at no extra cost.

Small vehicles also have an effect on emissions. Given equal technology, low-mass fuel-efficient vehicles produce lesser exhaust emissions. Urban driving is almost all acceleration, deceleration and idling, with very few steady-speed cycles in between. Periods of acceleration and deceleration produce extremely high exhaust emissions (over 150 and 50 times, respectively, of that at steady speeds) and idle produces emissions with no benefits in distance traveled. Traffic congestion merely increases the idling time with attendant increase in pollution. Smaller vehicles with smaller engines directly reduce emission in all driving modes, but more importantly, during acceleration and deceleration where the reduced vehicle-mass and engine-size have the most direct effect.

Reducing the hardware overhead of the private transport can, therefore, significantly lower the cost of mobility, in terms of traffic congestion, pollution and resource depletion. Fortunately, the Asian region already has markedly downsized products in the form of motorcycles, scooters and 3 wheelers in use over 40 years and which seem to fit the concepts of efficient transportation as outlined above. Since they represent optimum use of energy, they form a prime candidate for conversion to EVs.

The Electric Option for 2 and 3 wheelers.

In South Asia, conventional 2 and 3 wheelers have traditionally been aimed at the economically weaker strata of society. They have therefore necessarily been low cost products - a 2 wheeler sells typically for US$1000 whilst a 3 wheeler for US$ 1300 ~ 2000. They have been fitted with small 2-stroke petrol or 4 stroke diesel engines (3 wheelers), some carry a disproportionately larger load for their capacity, and, coupled with the stop-'n-go urban traffic means that the engines are, at times, grossly overloaded, operate inefficiently and may be the single largest source of pollution and fuel wastage in the urban areas.

Effect on Pollution

Electrical Vehicles have no tailpipe emission. Hence there is no pollution in high-density human settlements. However, the plants that produce electricity use some form of energy source. These may vary from coal burning thermal power plants, which emit pollutants, to clean sources such as hydro and wind power stations. There may, therefore, be an attendant increase in the emissions at the remotely located generating source, some of which, depending on geographical and meteorological conditions, may find its way back to the urban area itself. But emissions from these few, stationary, generating stations can be controlled more efficiently, and are only 1/6 as costly to implement, when compared to those on millions of individual tailpipes.

Further, over the fuel cycle, EVs are inherently cleaner and more efficient (***Table 3***).

Table 3

Emissions Related to Transportation[5] **(for BEVs all emissions are at the remote generating sites**

Vehicle Type/Fuel	Efficiency Over Fuel Chain (%)	Net Emissions Over Fuel Chain (g/km) for a Mid-sized car				
		SO2	NOx	CO	HC	CO2
IC-Engine Vehicle						
Gasoline	10.2	0.12	0.39	2.13	0.22	275
CNG	10.8	-----	0.25	1.06	0.1	209
Hydrogen	9.4	-----	0.37	0.01	.047	240
BEV by Source Fuel						
Coal	16.5		0.5	0.04	0.006	300
Natural Gas	15.1		0.33	0.06	0.006	187
Nuclear	14.4		0.22	0.12	0.04	15
Fuel Cell Vehicle						
Methanol	17.6	----	0.17	0.006	----	146
Natural Gas	21.7	----	----	----	----	122

Hydrogen	21.0	----	0.07	0.006	----	122

It has also to be noted that, unlike IC engined vehicles, EVs are not subject to deterioration in their operating efficiency with age. Also, with newer power plants replacing older ones and with better pollution abatement measures, stack emissions improve every year at an estimated factor of 5 in 10 years. Thus, a meaningful comparison must factor such considerations too.

The effect of pollution abatement can be directly seen in the economic gains to society from better health and productivity. This gain can form a major input in the decision making process of legislating conversion to EVs in a particular area.

Effect on Operating Economics

Two wheelers in the metropolises are largely limited to personal transportation. The acceptance of an electric scooter or motorcycle is therefore largely dependent on personal preferences. Studying present market trends for conventional vehicles, it is predicted that, as long as the product has acceptable performance, and, is comfortable, convenient and reliable, the owner is likely to take a long term view of the overall economics of ownership and not be unduly perturbed by up-front costs.

Three wheelers, however, need a different perspective. These vehicles are primarily "public" service vehicles – being used mostly as Taxis or "goods carriers". They have, both, fleet as well as individual ownership. Being revenue earners, they have to be economically viable to own and operate. If a market is to be generated for these electric 3 wheelers, they have to have favorable operating as well as ownership costs. With predicted larger up-front costs, it would need imaginative financing to make them attractive to the buyer. It is therefore necessary to be careful in ascertaining that a chosen conversion technology would meet all performance goals while being reliable, and keeps operating and maintenance costs to a minimum. ***Appendix I*** (***Table 7***) shows a sample calculation for a passenger 3-wheeler operating in an average urban environment in India.

Indian Zero Emission Transportation Project (IZET)

With the above background, Bajaj Auto Ltd, India, (BAL) the largest manufacturer of 2 and 3 wheeled transport in India, in its intention to look ahead into emerging technologies which are, both, efficient and cost effective, has joined forces with a technology firm from the U.S., New Generation Motors, Inc., VA, (NGM) to demonstrate the viability of environmentally responsible, and, commercially practical, two and three wheeled electric vehicles. This is the IZET Project.

BAL, with its established mass-manufacturing base provides the requisite platforms for conversion and is undertaking to support these vehicles in the field. NGM, whose expertise is in high efficiency drive systems, is designing custom solutions for both the platforms, so that they meet the expected performance goals and can efficiently integrate into BAL platforms.

Present plans call for a high-visibility demonstration program to create public awareness, by putting on the road a fleet of 5 Autorickshaws near the Taj Mahal in Agra and 5 Scooters for fast-food delivery in Delhi. A series of sustained urban tests are being designed to collect data. These tests will take place in actual service conditions providing a thorough assessment of the technology, which should ultimately lead to the best possible performance for the intended markets.

A partner in this venture is the United States Agency for International Development (USAID). USAID's Mission in India and the Global Environmental Center in Washington, D.C. initiated the program and its intention to stimulate the creation of an electric vehicle market through collaborative partnerships with the private sector. The infrastructure to host and run these vehicles is being provided by local arms of the Sheraton Group of Hotels, and Tricon Restaurants International (through its Pizza Hut chain), respectively. The yearlong program also aims to assess related issues of Environment, Policy and Regulatory mechanisms, Industry and Infrastructure, Performance and Safety and Economics and Finance.

Performance Goals for IZET Vehicles

As noted earlier, EVs can expect to create a market for themselves only if it meets the expectations of the customer in terms of its overall performance, operating economics and reliability. Given its known lack of range, it must excel in all other parameters. Also, any practical vehicle must require a minimal of training in its operation and must be close enough in its performance to make the transition to EVs as seamless as possible.

Electric 2 Wheelers

Two wheelers are essentially “personal” vehicles with a stress on convenience and maintainability. They are generally limited to short journeys with long halts, which lend themselves to opportunity charging. The penalty of weight and bulk of batteries can be minimized by careful design. A conventional 2W may not always have convenient location and volume for the necessary battery pack. Further, their maneuverability is sensitive to location of the extra mass of batteries. This factor alone could necessitate viewing 2W-EVs as ground-up designs and not as mere conversions from their ICE predecessors.

Since, weight, inertia, bulk and range have some contradictory requirements in terms of component selection, it is necessary to fine-tune each major aggregate for maximum efficiency. Choice of lightweight high efficiency motors, controllers with complex algorithms and high-energy batteries are necessary to achieve requisite performance levels.

IZET has targeted an existing BAL 2 wheeler (SPIRIT) for conversion to Electric drive, after extensive modification. The expected performance is as in ***Table 4***

Electric 3 Wheelers

In India, a 3-Wheeler (Autorickshaws) is primarily used as a Taxi for passenger transportation. Since these are “wage earners” for the driver, they must retain this potential, and also have life-cycle costs comparable to the present ICEVs.

Half the population of existing vehicles is out on hire for 20 hours or more, and typically covers over 130 km. in a day. Until high performance batteries become commercially available, the only practical manner to cover this operating profile is to swap discharged battery packs with fully charged ones during the day. This necessitates a ground-up design for a small 3-wheeler, as well as a suitable battery exchange infrastructure to be in place.

However there is the other half of the vehicle population, which is generally owner-driven, where the range requirement is only 80 km in a 10-hour operational day. With plenty of time available for charging batteries from a residential wall-socket, there is no need for a separate battery-exchange infrastructure to be put in place first. This is an operating profile, which can be a convenient target for EV conversion.

Technically, the 3-wheeler is more amenable to modifications than a 2-wheeler in accommodating EV components,. Also, being a “public service” vehicle, it can attract more sympathetic consideration for legislative and fiscal concessions.

IZET has targeted an existing BAL 3-Wheeler Autorickshaw for conversion to Electric drive with expected performance as in ***Table 4***

Table 4
Small Electric Vehicles – Target Specifications

	ITEM	2 WHEELER			3 WHEELER		
		Test Conditions	**ICEV (Existing)**	**EV (Expected)**	**Test Conditions**	**ICEV (Existing)**	**EV (Expected)**
Vehicle Weight							
1	Shell Weight (kg)		67	132		276	530
2	Payload (kg)		130	130		334	334
Road Performance:							
3	Top Speed (kph)	@ Max. GVW	55	60		55	55
4	Gradeability(%) @	Payload= 75kg			Payload= 334kg		
	10 kph		16	19		16	19
	20 kph		–	–		–	10
	30 kph		–	10		–	5
	40 kph		–	–		–	3
	50 kph			–		–	1
	55 kph			1		–	–
5	Acceleration (sec)	Payload = 75kg			Payload = 334kg		
	0 to 20 kph						
	0 to 30 kph		2	2		6	3
	0 to 40 kph		6.1c	5		11	7
	0 to 50 kph		10	9		16	15
			16	18		21	30
Indian Driving Cycle Performance (Payload = 75kg)							
6	Range (km)	Payload = 75kg	~200	> 80 @80% DOD	Payload = 150kg	> 80 @80% DOD	
7	Power Consumption	Payload = 75kg	–	<0.02 kWh/Km	Payload = 150kg	<0.06 kWh/Km	
Common Features							
8	Battery Voltage	60 V Max					
9	General Features	• Throttle input for load sensing • Electric reverse (3 Wheeler) • Programmable acceleration for "Economy" and "Normal" modes • Limp home capability beyond 80% DOD • Full regenerative braking • Compression brake feeling • Battery SOC monitor • On board charger for opportunity charging in 6~8 hours from 80% DOD • DC/DC converter (14V, 80W DC) for vehicle Auxiliaries (2 Wheeler) • DC/DC converter (14V, 1100W DC) for vehicle Auxiliaries (3 Wheeler)					

Drivesystem Requirements Development

A successful demonstration of the 3 and 2-wheeler vehicles necessitates thoroughly designed, exceptionally performing vehicles. The collaborative development effort between NGM and BAL included a system level design approach for each vehicle subsystem in order to carefully perform the correct tradeoffs for a well-balanced final product. NGM's Axial Flux, Permanent Magnet, Brushless DC motor and controller technologies were the drivesystem components requiring careful sizing and design to meet the above objectives. The following sections will briefly address the determination of the detailed drivesystem requirements, followed by the resulting required performance specifications of the drivesystem. The information given is for the 3-wheeled autorickshaws, a similar process being employed for the 2-wheeler.

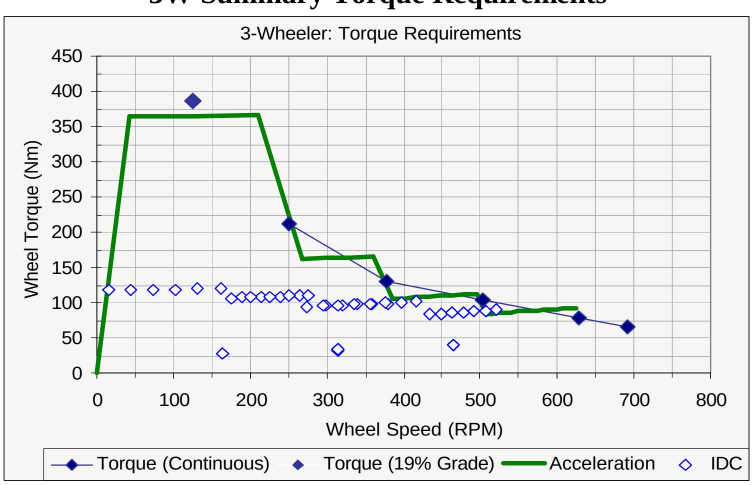
Torque and Power Requirements

Based on the target performance specifications given in ***Table 4***, analyses were performed to determine the torque, power, and energy consumption requirements of the vehicle. The findings were subsequently used in the design and selection of the vehicle subsystems, specifically the drive system. The torque and power requirements come from analyses of the standalone gradeability and acceleration specifications of the vehicle along with the Indian Driving Cycle requirements. The energy consumption requirements are derived from the range specification of the vehicle.

Gradeability Performance Requirements. The torque and power requirements of the vehicle to meet steady state conditions defined in ***Table 4*** were determined with a classic steady-state vehicle performance model using the drag parameters provided. The results are summarized in ***Figure 3*** and ***Figure 4.***

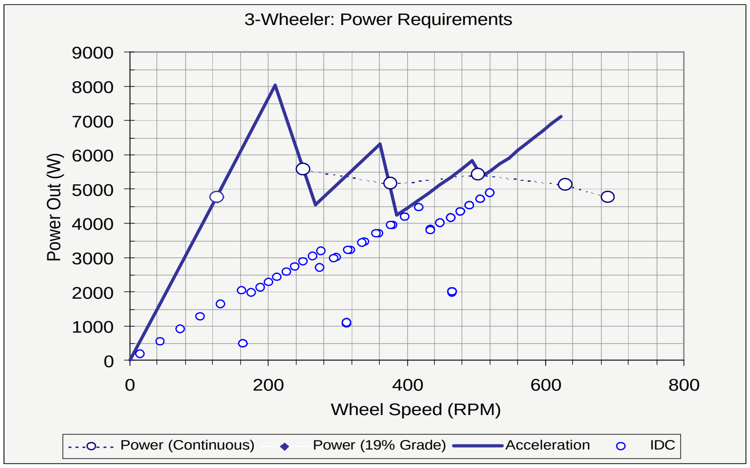
Acceleration Performance Requirements. To determine the required torque and power loads of the drive system to achieve the acceleration requirements the simple approach was taken to calculate the torque needed to achieve the desired average acceleration rate and overcome the drag forces on the vehicle. This determines the "average" torque output required of the drive system with respect to output speed. Starting from rest or accelerating from one rate to another, the drive system has to be capable of instantaneously delivering the required average torque. Therefore, it becomes necessary to account for a certain amount of response lag, which affects the average required torque output. Shown in ***Figure 3*** is the torque-speed curve that represents this "average" torque requirement.

Figure 3
3W Summary Torque Requirements



This approach to achieving the acceleration requirements is not necessarily the final solution. If minimizing the required output power is important, a linearly decreasing torque profile as the speed increases is desirable. Nonetheless, what is shown in ***Figure 3*** is considered a more conservative requirement, as it is generally more difficult to provide a required constant torque as the speed increases. If more torque is available from the drive system than is required, there will be a reduction in the torque (and powers) required at higher speeds. For the preliminary design effort, however, this torque profile was assumed to be the requirement. As a result, the related power requirements are as shown in ***Figure 4.***

Figure 4
3W Summary Power Requirements



Drive Cycle Torque & Power Requirements. The autorickshaw in India, as discussed above, is primarily used as a Taxi for passenger transportation. Several driving cycles that represent various conditions of use are shown below in ***Figure 5*** and ***Figure 6***. For the purposes of IZET, the Indian Driving Cycle (IDC) was the primary vehicle use pattern utilized in developing the drivetrain requirement, as it is a conservative representation of the typical use of the vehicle. The other 3 cycles (City, Hill, and Highway) were used to help establish the gradeability and top speed specifications for the vehicle. The Indian Driving Cycle, (***Figure 7),*** consists of a speed-time profile during which the vehicle travels 0.656 km in 108 seconds.

Figure 5
Autorickshaw Usage – Time vs. Torque

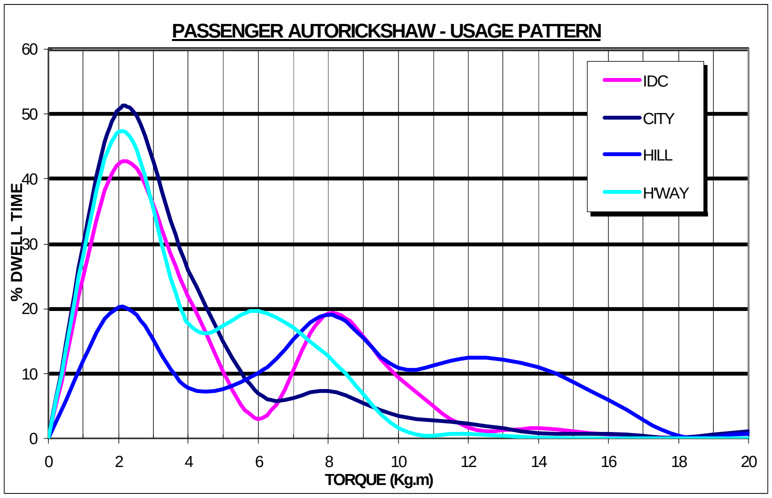


Figure 6
Autorickshaw Usage – Time vs. Speed

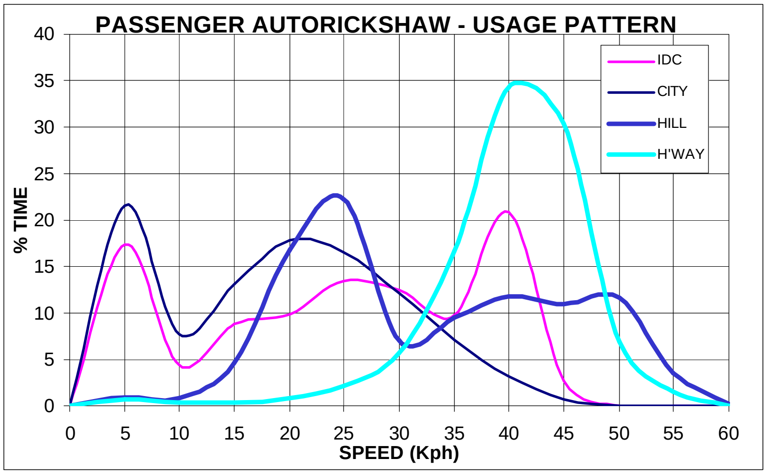
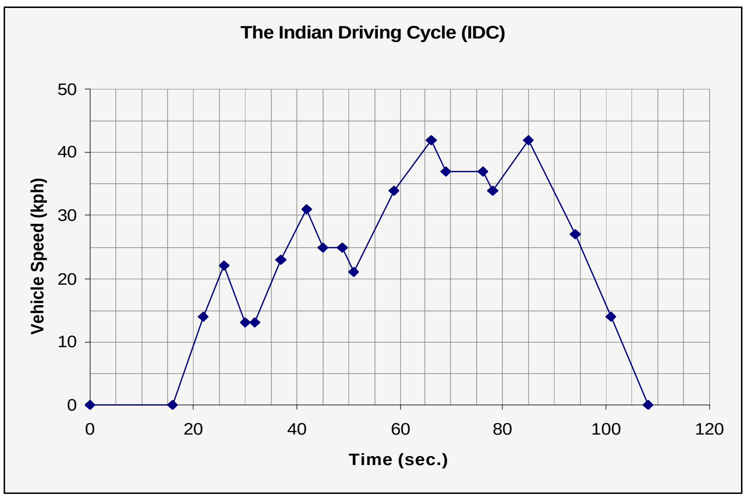


Figure 7
Indian Driving Cycle



To calculate the wheel torque requirements of the vehicle operating on the IDC, a transient model of the vehicle was utilized. These results are shown in ***Figure 3*** , labeled "IDC". The peak torque requirement was determined to be around 125 Nm and the top wheel speed reached on the IDC was around 525 RPM. This corresponds to a vehicle speed of 42 kph. ***Figure 4*** plots the power requirements associated with driving the IDC. The duration of time spent at the various points indicates that, in general, these torque and power requirements are continuous requirements.

Torque and Power Requirements Summary. It is important to distinguish between "continuous" requirements and those requirements that must be sustained for timeframes associated with "intermittent" or "peak" operating modes of the vehicle. "Continuous" requirements result in thermal loading that does not result in an overload of the system operating for an extended period of time. "Intermittent" requirements are such that the thermal loads incurred by the system only allow for the duration of time spent to be less than the thermal time constant of the system. Lastly, "peak" loads are such that the duration of time must be a small fraction of the thermal time constant of the system.

The "continuous" gradeability requirements are labeled appropriately in ***Figure 3*** and ***Figure 4*** above. Comparing the IDC requirements with the continuous gradeability requirements, if the vehicle meets the continuous gradeability requirements; the IDC profile can be driven on a continuous basis as well. The acceleration profile and the 19% gradeability specification, however, are both cases in which the time duration that the requirements must be sustained is relatively short. The acceleration profile indicates that the entire time span is only 25 seconds. Given the vehicle's capability to meet the acceleration profile, this leads to performing the 19% grade specification in a timeframe consistent with the acceleration profile of less than 30 seconds. Therefore, if the thermal time constant of the drive system is greater than 30 seconds (with some margin), the acceleration and 19% grade specifications fall into the classification of "intermittent" requirements

Energy Consumption Requirements

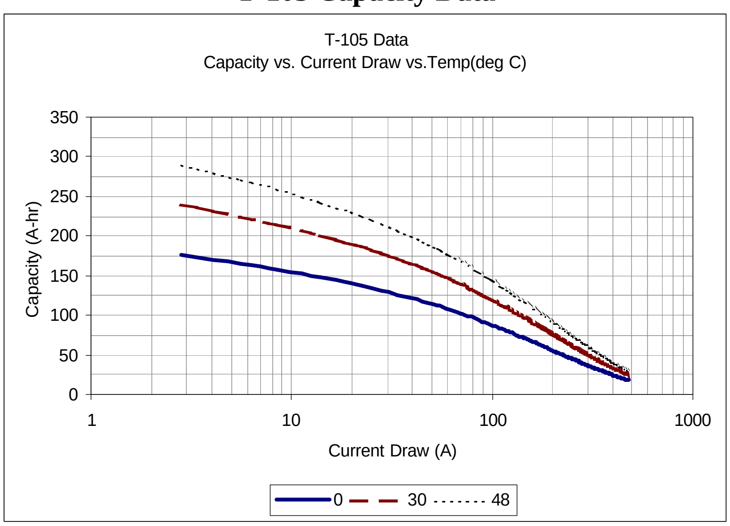
The primary specification that dictates the energy consumption and thus, the drivesystem efficiency of the vehicle is the range requirement of 80km. The system approach for understanding the energy use characteristics of the autorickshaw begins by noting the fixed vehicle characteristics. The drag parameters and drivetrain efficiency (transmission and final drive) are given as part of the baseline IC vehicle characteristics. The vehicle battery pack configurations were selected on the basis of several criteria, including energy density, reliability, and packaging. For the 3W, it consists of eight (8) Trojan T-105 6V modules. Summarized technical data from the Trojan Battery Company for the T-105 battery is found in ***Table 5***. (C/5 data given at 30°C):

Table 5
Trojan T-105 Specifications

	Voltage	C/5 rate	C/20 rate	Length (mm)	Width (mm)	Height (mm)	Mass (kg)
T-105	6V	171Ahr	225Ahr	264	181	284	28

An important factor in the vehicle's range performance is the battery temperature. Shown in ***Figure 8*** are capacity curves for the T-105 as a function of current draw and temperature. The limits of 0 and 48 degrees Celsius coincide with the temperature range for the IZET environmental specifications.

Figure 8
T-105 Capacity Data

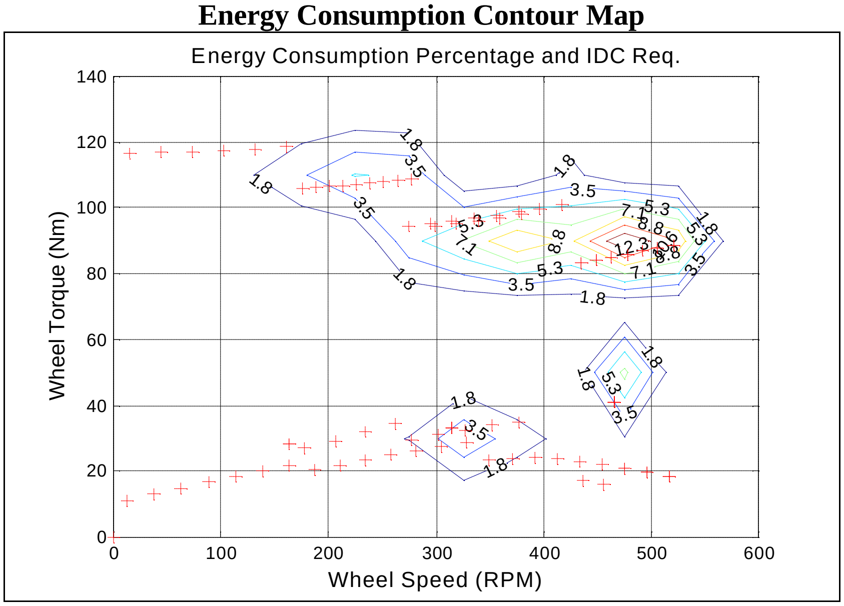


To obtain an estimate for the average power consumed by the auxiliary components, a detailed breakdown was performed of the individual auxiliary component loads and their duration of use over the IDC. Assuming daytime operation, brake light operation during decelerations, reasonable turn indicator and horn use, cooling loads for the drivesystem, and a margin of ancillary component loads, the total average auxiliary power requirement was calculated to be approximately 30W.

Range and Energy Consumption Specification. To determine the minimum average drivesystem efficiency required for the vehicle to achieve the range requirement when driving the IDC, the total energy required was subtracted from the total energy available from the energy storage system over 122 cycles of the IDC. 80km operating on repeated cycles of the IDC translates to about 122 cycles (80.3km) with a total duration of 3.66 hours. A discharge rate for the battery was determined by using a detailed estimate of the average current draw. The amount of energy recoverable from regenerative braking was also estimated based on experience with other electric vehicles. The end result was an excess of approximately 1128 Whrs that could be attributed to drive system losses. Therefore, in order for the vehicle to meet the range, the drivesystem was required to operate, on average, at 83.6% efficiency or above. Given an average drivetrain efficiency of 91%, the motor/controller system must operate with an average efficiency of 91.9%.

In order to average motor/controller efficiency as high as 91.9%, a more detailed analysis of the energy consumption was performed. This was done by "binning" the percentage of total energy consumed on a given IDC into torque-speed envelopes. This clearly identified where the majority of energy is consumed. This data was used to produce preliminary motor and controller designs that would meet the gradeability and acceleration requirements and have very high efficiency characteristics when performing on the IDC. ***Figure 9*** shows the results of the energy "binning" process.

Figure 9
Energy Consumption Contour Map



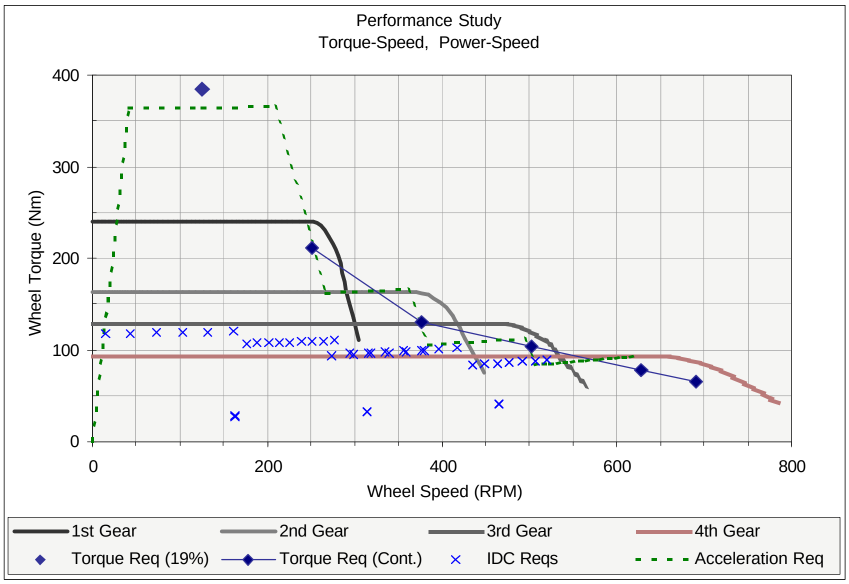
Drivesystem and Proposed Vehicle Performance

Using the requirement data presented above and the preliminary design information for the drivesystem, analyses of the proposed vehicle performance were completed.

Proposed Drivesystem

Figure 10 shows the continuous drivesystem capabilities with respect to all of the torque-speed requirements (continuous and non-continuous). The drivesystem characteristics are shown at the lowest required value of 40% SOC. A discussion of the gear selection is beyond the scope of this paper, however, the basic approach was to provide a range compatible with the drivesystem capabilities and vehicle requirements. 1st gear was selected to be around 3:1 and 4th gear around 8:1.

Figure 10
Vehicle Torque and Power using Proposed Design

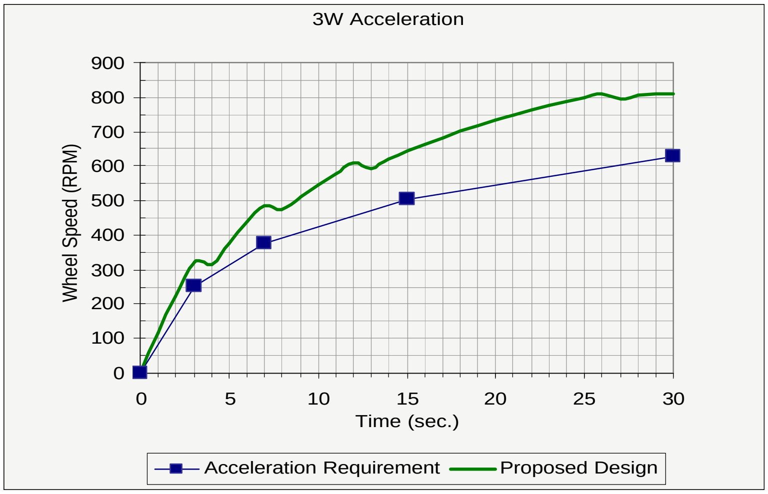


In regards to the continuous gradeability requirements and the IDC torque requirements, the proposed drivesystem meets all of the requirements. From a strict torque requirements perspective, the continuous capabilities meet all but the first step of the acceleration requirements.

The short-duration capability of the drivesystem is designed to be approximately 175% greater than the continuous output to achieve the 19% grade and peak acceleration requirements. The very short duration peak capability of the system will be even greater.

With these peak capabilities, the acceleration profile could probably be met using only 2nd and 4th gear. A simulation was performed to determine what the maximum acceleration performance of the vehicle is if all 4 gears were shifted. Taking into account the loss of torque during the shifting time period (disengaging and engaging the clutch), ***Figure 11*** plots the actual acceleration achieved against the specified acceleration profile. Assuming that no loss of traction occurs, the overall requirement of 0 to 50kph can be achieved in approximately 15 seconds (in comparison with the 30 second requirement). The only concern with the acceleration performance would be the physical state of the batteries due to the voltage drop under high current draw. This may reduce the actual performance of the drivesystem.

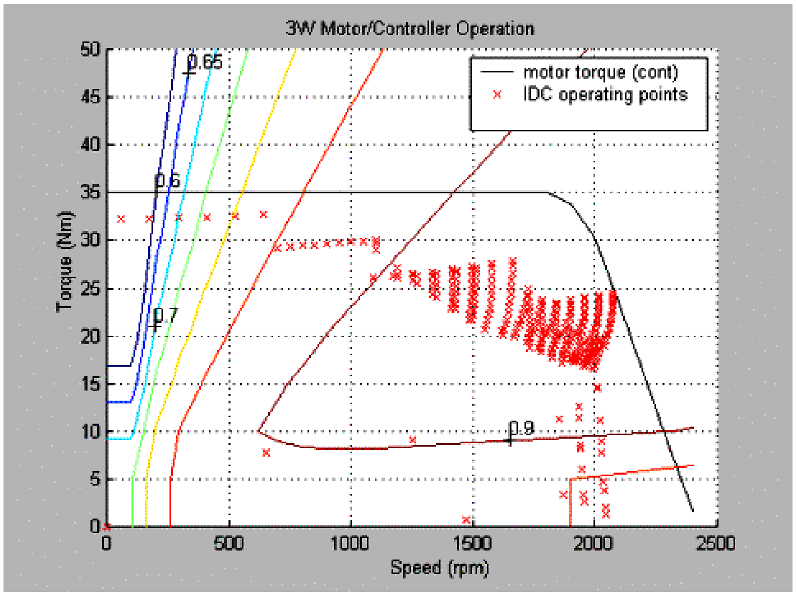
Figure 11
Actual Acceleration Performance



Regarding the system's performance compared to the basic torque-speed requirements, the drivesystem proposed can meet the objectives. The vehicle's expected drivesystem performance operating on the IDC is given in ***Figure 12***. The vehicle is presented operating in 3rd gear for the entire duration of the IDC. Several iterations of driving on the IDC with different "shifting schemes" were simulated to try to improve the overall vehicle efficiency. The time lost during shifting, clutch losses, and the complexity of operating the vehicle in such a manner made any small improvement in operation impractical. Under normal use of the vehicle, the choice of the proper gear could greatly affect the range performance of the system.

Note, the majority of the IDC operation occurs where the motor/controller is about 90% efficient, this is a result of designing the system to the constraints of the energy consumption "binning" process as described in the previous section.

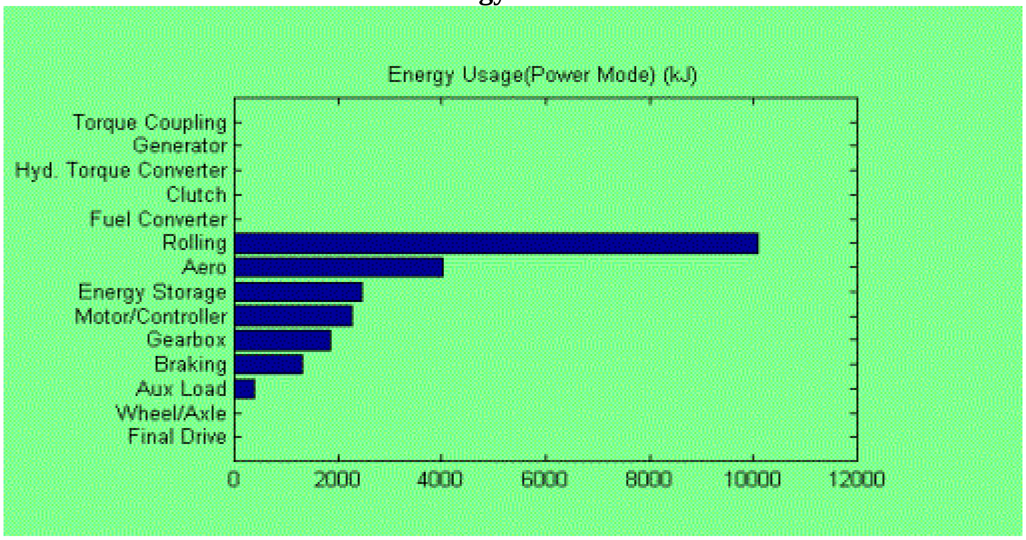
Figure 12
Motor/Controller Performance on IDC



Vehicle Performance Summary

Given the expected performance of the vehicle's drivesystem, the range of the vehicle operating on the IDC (at about 30°C) should be approximately 78km, slightly below the 80km desired target. Several factors may affect this, including the battery performance at various temperatures and at various points in its lifecycle. If the batteries are maintained at 0°C the range would be reduced by as much as 20%, whereas if the batteries are maintained at 48°C, the range would increase by 15%.

Figure 13
3W Energy Breakdown



A bar chart of the estimated energy usage by subsystem is presented in ***Figure 13***. This shows that the rolling resistance losses are the dominating factor in the vehicle's energy consumption. Even significant changes in the drivesystem efficiency will have much less of an overall affect compared to a significant improvement in the rolling losses.

This brief overview of the development approach and the resulting proposed design specifications indicates that an Electric 3-Wheeler can be produced within the confines of the vehicle's normal use pattern and resulting performance needs. This approach was taken to look at the Electric 2-Wheeler and similar conclusions were reached.

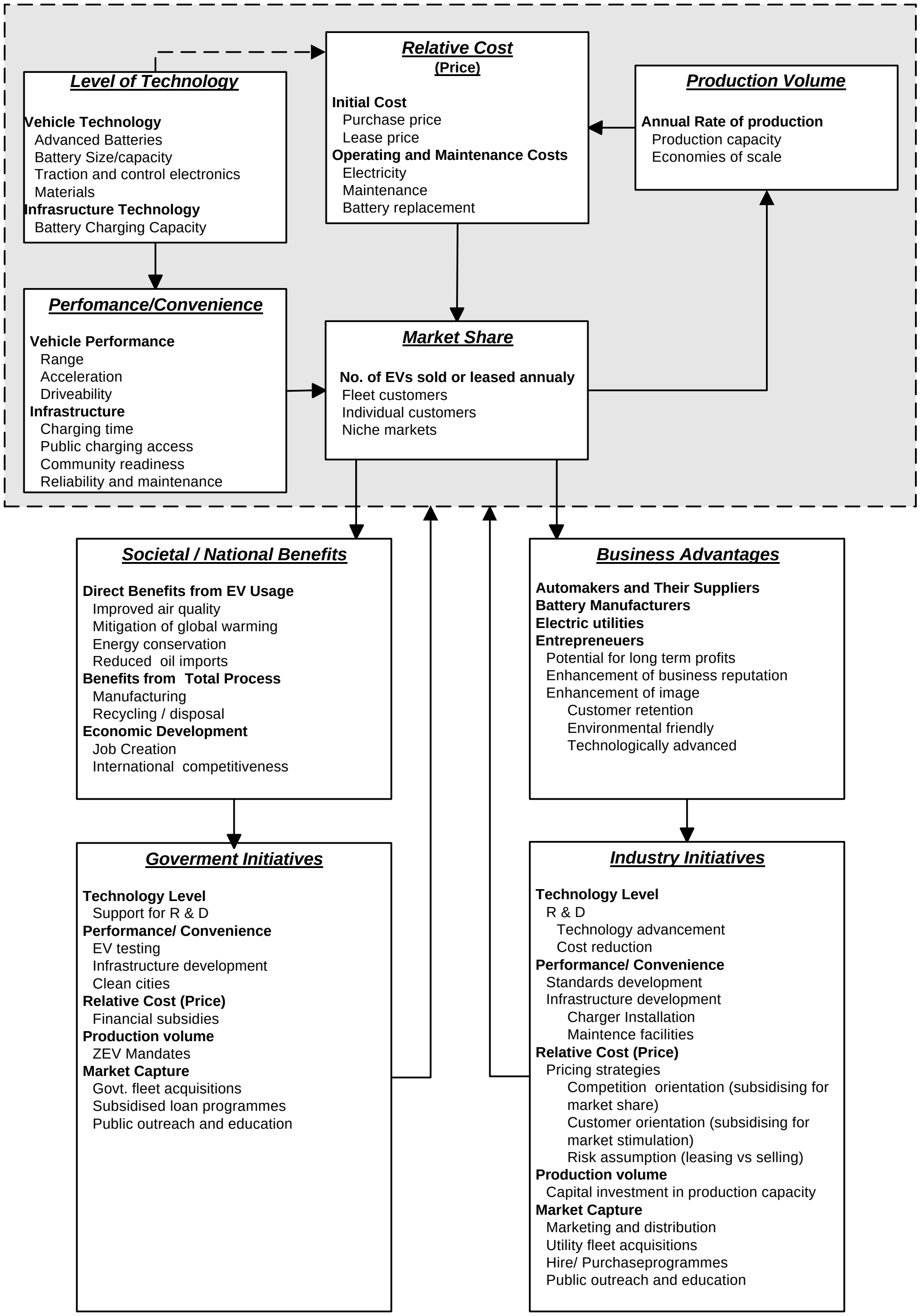
Vehicle Integration and Demonstration

Given the final system layout, several vehicles of each platform will be integrated as demonstration vehicles. The electric 2 and 3-wheeled vehicles will be placed into monitored demonstration service at selected locations in India. They will be operated over a period consistent with the IZET program schedule to provide data concerning the day-to-day operational characteristics and requirements of the vehicles. The data collected will be analyzed to provide an assessment of the requirements and operational and commercial feasibility of these vehicles in India.

Summary

To make a serious dent in the ever-worsening quality of the environment, in the most effective and the shortest time frame, a cooperative effort between the Government, at all levels, and, the Industry is a must. Any suitable solution is likely to require considerable nursing to make it socially and economically self-sustaining (***Table 6***). For this, it will be necessary to lay down long-term policies and a road map covering various activities, strategies and time bound goals to help in successful implementation.

Table 6 – A Framework for Assessing Measures to Encourage Electric Vehicles



Appendix I

Table 7

Economics of Electric 3- Wheeler Operation - Sample Calculation

ITEM		I.C.ENGINE	NO GOVERNMENT INCENTIVES		WITH GOVERNMENT INCENTIVES		COMMENTS
			ELECTRIC (CASE 1)	Assump's	ELECTRIC (CASE 2)	Assump's	
1	Net Manufacturing Cost	38,000	84,375		69,863	Concession/ Waived Customs, Excise and Sales duties	US$750 for Motor, Controller. etc.
2	Government Levies	9,950	21,259		3,493		
3	Other Costs	4,932	5,860		5,346	Concession Road Tax	
4	On Road Price	52,882	111,494		78,702		(1)+(2)+(3)
5	Less Govt. Cash Subsidy				(-)15,740	@20%	
6	***Net Cost to customer***	***52,882***	***111,494***		***62,962***		(4)-(5)
7	Loan	47,594	100,344		56,666		Margin=10%; Term=5yrs.
8	Interest on Loan	21%	21%	21%	12%	*Soft loan for EVs*	
9	Net fixed cost	60,177	126,874		53,413		Cost of capital, resale value etc
10	***Fixed cost / Year***	***8,597***	***12,687***		***5,341***		Assumed life (yrs.) - Petrol=7 // EV=10
11	Distance travelled/yr. (Kms.)	24,000	24,000		24,000		300 days usage/ yr.
12	Running cost (Rs/ Km)	*1.20*	0.64		0.48		-Petrol = Rs.30/l -Electricity= Rs3/kWh - Battery change every $2^1/_2$ yrs.
13	Running cost / year	28,880	15,303		11,489		(10)*(11)
14	Maintenance cost / year	5,500	2,750		2,750		Assumed
15	Operating cost / year	34,300	18,053		14,239		(13)+(14)
16	Cost / year (Total)	42,897	30,740		19,580		*(15)+(10)*
17	Cost / Km (Total)	1.79	1.24		0.82		
18	Saving – Rs./ Km		0.51		0.97		
19	***Saving – Rs. per year***	**–**	***12,157***		***23,386***		**Earnings (ICEV) = Rs.*66,300 pa***

References:

1. Pandey, Rita and Bharadwaj, Geetesh – Report-Economic policy Instruments for Controlling Vehicular Pollution, March 2000
2. Study by Brihan Mumbai Corporation at CST intersection – Dec 1998 to Jan. 1999
3. Shah, Jitendra and Nagpal, Tanvi– Urban Air Quality Management Strategy, Kathmandu Valley Report, World Bank, 1997
4. TERI – Impact of Road Transportation Systems on Energy and Environment – An Analysis of Metropolitan Cities of India, May 1993
5. OECD paper, U.S. Dept of Energy

India Zero Emissions Transportation Project (IZET)

Air pollution is increasing so rapidly in India that its major cities are becoming unlivable. Hospital admissions and deaths resulting from urban air pollution are extremely high (see Figure 1). Unhealthy air is producing not only increased rates of sickness and death but also dampened economic productivity.

Motor vehicle emissions are a primary contributor to deteriorating air quality in the major urban areas of the Indian subcontinent. Until recently both government and private sectors had been slow to offer solutions or take action on this major public health problem. Environmental regulations, until very recently, were often rendered ineffective by lax enforcement. Consumers have had few options – mass transportation is inadequate and technologically advanced vehicles have not been available.

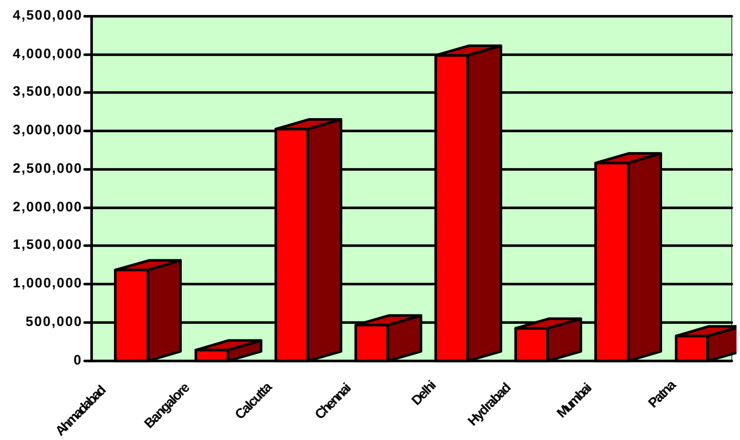
The United States Agency for International Development (USAID), working with the private sectors in the U.S. and India, is addressing these issues with a variety of approaches. In India, electric vehicle demonstration programs involving two- and three-wheeled vehicles and automobiles are being launched. India's first electric automobiles will be rolling off the assembly line by the end of 2000, and IZET prototype electric scooters and autorickshaws will soon be on the streets in Delhi and Agra.

Why is USAID Involved in Alternative Transportation in India?

Indian Transport Sector. Inefficient vehicles and increasingly congested roadways are key factors in the deteriorating ambient urban air in India. But, unlike other countries in the region, India has a vibrant vehicle manufacturing industry that is motivated to introduce alternative transport technologies. Economic reforms since 1991 have provided new opportunities for business enterprises in India.

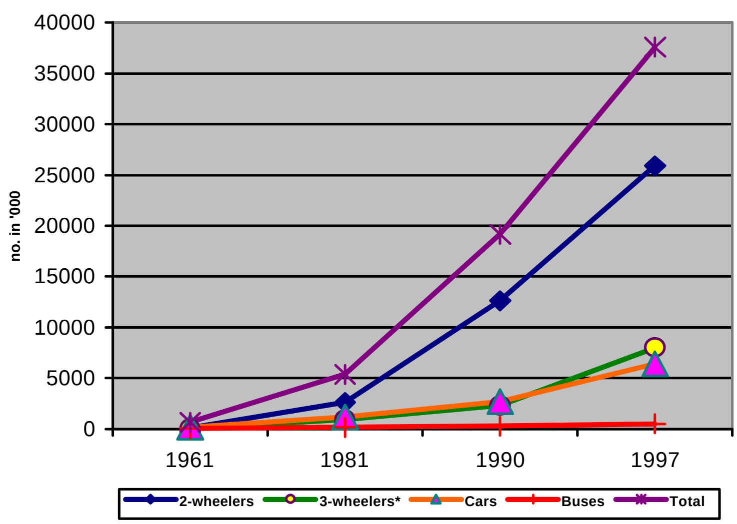
An estimated 300 million middle-class consumers, with their growing disposable income, constitute one of the fastest growing markets for vehicles in the world. The top three income groups – middle, upper middle, and upper class families have also grown from 10% in 1986 to 17%

Figure 1
Annual Hospital Admissions Due to Urban Air Pollution



Source: *Financial Times*, August 1, 1997

Figure 2
Growth of Indian Vehicle Population



Source: Society of Indian Automobile Manufacturers, India Auto Statistics, 1999

of the total Indian population.[1] The growth of the Indian vehicle population is illustrated in Figure 2.

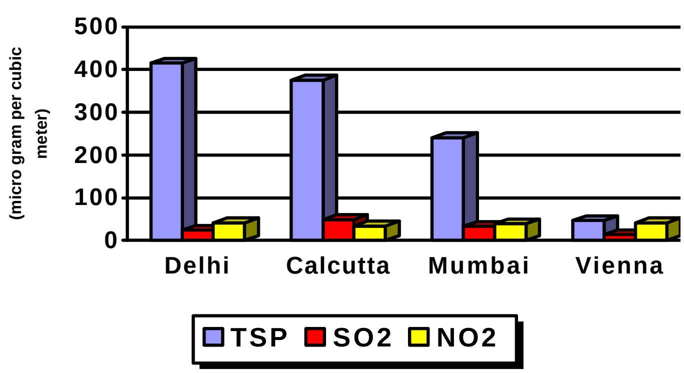
[1] Society of Indian Automobile Manufacturers, Report to Govt. of India, 1999.

Average distance traveled per day within a city is 25-26 km[1] compared with 50-60 km in Western countries. Several studies also indicate the average speed in larger urban areas to be between 5-12 km per hour.[2]

Worsening Urban Environment. India's gross domestic product has increased 2.5 times over the past two decades. There is a price for this growth - vehicular pollution has increased eight times and pollution from industries has quadrupled. A comparison of air pollution in various cities is given in Figure 3.

Environmental Protection in India. The Indian government and judiciary have initiated significant efforts towards greater environmental protection. The government, particularly for conventional three-wheeled vehicles, has issued a series of stringent directives and regulations. In 1999, for example, the Indian Supreme Court prohibited registration of any new conventional three-wheeled vehicles in the National Capital Region surrounding New Delhi that fail to meet EURO II emissions norms after April 1, 2000. In Mumbai, conventional autorickshaws are banned within the central part of the city.

Figure 3
Air Pollutants in Various Cities[3]



Health Risk. The primary and most pressing reason for controlling urban vehicle emissions is their effect on human health. Chronic exposures have a cumulative effect, while acute exposures typically take a heavier toll among the young, old, and ill.

Adverse health effects include premature or sudden death, as well as an increased incidence of chronic respiratory, coronary, and neurological disorders. According to the World Health Organization (WHO), three major Indian cites, Delhi, Calcutta, and Mumbai, are among the most polluted cities in the world.

Studies, including the World Bank, estimate the health damage cost from urban air pollution to be about $500 million per year for the major Indian cities. Table 1 presents the estimated reduction in number of deaths per year, by age group; as a result of replacement of 10, 50, and 100% of the two- and three-wheeled fleet by electric vehicles in Delhi.

USAID's Involvement

Overall Approach. USAID spearheads the U.S. Government's efforts to assist in developing strategies to tap private capital and talent to meet the growing environmental challenges of host countries. At the heart of USAID programs is the recognition that a sustainable economy requires a market-based approach. In pursuit of this strategy, USAID collaborates with the U.S. and host-country private sectors, international financial institutions, and host-country agencies to leverage resources and encourage private sector participation through financing and partnerships.

Economic and Environmental Needs in India. USAID's efforts in India began over seven years ago with identifying the main sources of urban air pollution. During this period, information on the technologies best suited for mitigating air pollution were obtained, assessed, and updated. Although electric vehicle technology was a high-risk venture, it emerged as a serious contender to mitigate urban air pollution.

Given the constraints on USAID funding and the long lead time needed for the development of a commercially viable electric vehicle technology specifically suited to Indian conditions, private sector collaborators were carefully selected to ensure long-term technical and financial commitment.

To facilitate serious dialogue and to determine the feasibility of electric vehicles, USAID/India sponsored the Indo-US Workshop on Electronic/Electric Vehicles – Technology & Policy Issues in Delhi during 1995, which brought together Indian and U.S. private and Indian public sectors. USAID/India also sponsored two publications, "Electric Vehicle Investment Opportunities in India" and a "Directory of the U.S. Electric Vehicle Industry." Follow-up activities provided information to the private sectors of both countries to sustain the interest begun at the workshop.

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[2] Impact of Road Transport System on Energy and Environment- an analysis of metropolitan cites of India, A Report, Ministry of Urban Development, Govt. of India, 1993.

[3] World Development Indicators, The World Bank, 1998; TSP = Total Suspended Particles

Table 1
Estimated Reduction in Number of Deaths Avoided, by Age Group, as a Result of Replacing 10%, 50%, and 100% of the Two-Cycle 2 & 3-Wheeler Fleets with Electric Vehicles (Evs) in Delhi

Age Group	Reduction in Deaths per Year			
	Per 100 µg/m³ Reduction in PM [1]	10% EVs (16 µg/m3 reduction)[2,3]	50% EVs (80 µg/m3 reduction)[2,3]	100% EVs (160 µg/m3 reduction)[2,3]
0-4	278	44	220	440
5-14	63	10	50	100
15-44	651	104	520	1,040
45-64	268	43	215	430
65 and >	125*	20	100	200
Total	1,385	221	1,105	2,210

[1] Based on Table 8., and 1991 population figures "the Health Effects of Air Pollution in Delhi, India, World Bank PRD Working Paper 1860, M. Cropper, et. Al., 12/97
[2] Assumes 40% of PM emissions is from 2 & 3- wheelers, "Emissions and Control Options for Two-Stroke Engines in India", N.V. Iyer, et al., Workshop on Pollution from Motorcycles: Issues and Options, The World Bank, 3/9/00
[3] Prorated against assumed ambient loading of 400µg PM/m3
* PM health impacts in the west are different than in Delhi. Reasons vary, but it is possible that persons susceptible to health impacts of PM exposure are also more susceptible to infectious disease and will have died prior to reaching the age of 65.

Brokering. USAID worked closely with several Indian vehicle manufacturers to create greater interest in electric vehicle technology. Meetings to provide specific technical exchanges were arranged with U.S. organizations. USAID shared its experience with an alternative vehicles program in Thailand but maintained strict neutrality on the advantages and/or disadvantages of technologies. Indian firms were provided information, but the conclusions they reached were based upon their own decision-making processes.

USAID's assumed the role of providing nominal financial and technical assistance. The payoff for the participating corporations could be a jump-start into the potentially sizeable alternative transportation market in India.

IZET Program Profile

Discussions took place between USAID and prospective partners over four years. During this time a collaborative program was developed. The program partners ultimately became Bajaj Auto Limited (BAL), New Generation Motors (NGM), WELCOMGROUP, and TRICON Restaurants International. Responsibilities and the overall schedule were agreed upon for the newly created IZET Program.

BAL, which is India's leading manufacturer of conventional two- and three-wheeled vehicles with a large network of dealerships, was actively involved in screening electric drive systems for the Indian marketplace. BAL committed to providing substantial resources: design, testing, certification, operation, maintenance, oversight of data acquisition, and, product evaluation. Programs were developed with BAL to:

- Increase public awareness of electric vehicle technology through various media outlets;
- Cost-share resources among all participants;
- Provide technical assistance in planning, and vehicle design and integration;
- Initiate development of a market-driven technology for electric vehicles by accelerating the commercialization process;
- Provide commercially attractive technology options for reducing vehicular emissions in urban areas; and
- Demonstrate a technology.

NGM, an innovative electric drive system manufacturer and integrator in the United States, is the technology provider selected by BAL. A popular choice of solar car race teams, NGM holds patents on a highly efficient DC, brushless motor. NGM is committed to cost-share their design and production activities with USAID.

The other two private sector partners are the WELCOMGROUP's Mughal Sheraton Hotel in Agra and TRICON Restaurants International (Pizza Hut) in New Delhi. During the demonstration phase of IZET, Sheraton will use electric three-wheelers and Pizza Hut will use electric two-wheelers as part of their normal operations. These firms are committed to using the electric vehicle prototypes in real market applications.

Cost Considerations. Because two-wheelers in urban areas are generally used for personal transportation, the anticipated market is likely to be fairly sophisticated consumers who recognize the life cycle costs of a vehicle and are concerned about the environment. For this market, the higher initial costs of electric vehicles that are reliable and meet performance expectations can be rationalized.

Three-wheelers are primarily used as taxis and goods carriers. Profit and cash flow are of particular interest to these owners. Market demand for these vehicles is price elastic and operational costs need to be minimized. Given these conditions and current interest rates in India, a breakeven point when financing a three-wheeler is about five years.

Demonstration. Fifteen two- and fifteen three-wheeled electric vehicles will be field-tested on the streets of Delhi and Agra for 6-12 months. TRICON will deploy the two-wheelers and the Mughal Sheraton will deploy the three-wheelers. Data will be acquired, reduced, analyzed; lessons learned will be applied toward the next iteration of vehicles.

Conclusions

The primary environmental impacts from electric vehicles overall are positive. It is estimated that there would be a net decrease in particulate matter, carbon monoxide, and carbon dioxide emissions resulting from various levels of introduction of two- and three-wheeled electric vehicles.

The anticipated short-term benefits of IZET include determining the feasibility and consumer acceptance of electric vehicles in the Indian market and raising awareness of environmentally benign urban transport options.

Long-term benefits include developing commercial relationships among U.S. and Indian private sector firms, establishing electric vehicle technology as a reality in the Indian marketplace, and improving urban air quality and reducing attendant costs.

It is estimated that USAID funds for this initial program are leveraged about 1:4.

USAID is and has been an active player in India in raising awareness of the potential advantages of electric vehicle technology. In November 1999, USAID co-sponsored and participated in a conference – "Automotive Electronics and Alternate Energy Vehicles" organized by the Institution of Electronics and Telecommunication Engineers and ITT/Kanpur, in Kanpur, India. USAID has helped to catalyze two additional Indian firms, Mahindra & Mahindra and Scooters India, to develop their electric three-wheel vehicles.

Reasonably priced innovative but commercially proven technology is an option that is, or will soon be, available in India. Electric vehicle technology can help mitigate the debilitating effects of the growing contribution of tailpipe emissions to urban air pollution. USAID is pleased to be a part of the process for evaluating the feasibility of this technology.

For more information on this project, or other Office of Energy, Environment, and Technology projects, please contact:

USAID Center for Environment

Office of Energy, Environment, and Technology

Ronald Reagan Building

Room 3.08

Washington, D.C. 20523-3800

India Zero Emission Transportation (IZET)

The Problem of Air Pollution in India

India's three major cites—Delhi, Calcutta, and Mumbai—are among the world's most polluted cities according to a World Health Organization (WHO) study. The human, health, and economic costs to India of this pollution are enormous. For example, in Delhi alone there are more than 4 million hospital admissions annually resulting from ambient urban air pollution. The cost of health impacts from urban air pollution is estimated to be about $500 million per year for each of India's major cities.

For urban inhabitants, smog is not merely an inconvenience; it has real consequences. Premature or sudden death and an increased incidence of chronic respiratory, coronary, and neurological disorders are all a result of air pollution with children and the elderly among the most effected.

The Role of Transportation

India's economy has more than doubled during the past two decades, precipitating rapid urbanization and industrialization. As a result, air pollution from industry has quadrupled and vehicular pollution has increased eight-fold. A World Bank study indicates that 70 percent of Delhi's air pollution can be attributed to the transport sector alone.

Indian roads are choked with an estimated 27 million two-and three-wheelers, 25 percent of which are the poorly maintained and highly polluting.[1] In urban India, 40 percent of vehicular emissions are attributed to these vehicles with their inefficient two-stroke engines.[2] Fortunately, viable technologies are available to replace India's two-stroke engine vehicles with zero-emissions alternatives. Thus, the potential for reducing emissions is tremendous given the domestic market of five million per year and growing for these two-and three-wheelers. Given the private sector assumptions regarding the potential market and economies of scale, zero-emissions vehicles can become a commercial reality and a partial answer to reducing India's urban air pollution.

The Program

The United States Agency for International Development (USAID), working with the Indian and U.S. private sector, has initiated the Indian Zero Emission

Sponsored by the United States Agency for International Development

Ambient Air Pollution in selected Cities

City	TSP (μg/m^3)
Delhi	415
Calcutta	375
Mumbai	240
WHO guideline	180
Vienna, Austria	47

2 & 3-Wheel Vehicles Growth Pattern

Year	Total ('000)
1956	57
1976	1,455
1997	27,122

[1] From private conversation with Bajaj Auto Limited, India
[2] N.V. Iyer, Bajaj Auto Limited – Presentation at the World Bank, March 9, 2000

Transportation Program (IZET) to help mitigate the health impact of urban transportation.

IZET is accelerating the commercialization of electric vehicle technology, specifically for two and three-wheelers, to offer consumers an environmentally benign and alternative transport option.

IZET is collaborating with motivated private firms possessing the technological, financial, and commercial resources to take electric vehicle technology from demonstration to full commercialization. This approach enables the private sector to develop pragmatic solutions that will extend beyond USAID's involvement.

Technology Partnership

The USAID partnership with Bajaj Auto Limited, India's premier two- and three-wheeler manufacturer, and New Generation Motors, an innovative U.S. technology firm, is now testing the technology under actual operational conditions. WELCOMGROUP's Mughal Sheraton in Agra and TRICON Restaurant (Pizza Hut) in Delhi, are deploying the three-wheelers and two-wheelers, respectively.

Prior to this actual testing phase, IZET conducted a thorough assessment of consumers' driving habits and expectations to prioritize the attributes of the vehicles. Each component of the electric vehicles has been designed to meet Indian driving conditions and match the demands of the Indian consumer. For example, a highly efficient drive system allows the designers to use a less costly battery. Significant resources also have been allocated to integrate the electric drive system so that operating characteristics of the electric vehicles will remain as close as possible to the conventional versions of the two- and three-wheelers.

Benefits

- Cleaner environment
- Mitigation of urban air pollution and attendant health effects
- Technology transfer and industrial development in India
- Indo-U.S. trade and business partnerships
- Lower life-cycle costs

For More Information

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Tel: (91-1) 419-8712
e-mail: rberry@usaid.gov

Dr. S. Schweitzer
USAID/G/ENV/EET, Washington, D.C. USA
Tel: (202) 712-1766
e-mail: sschweitzer@usaid.gov

Features of IZET

- Design, integrate and transfer electric vehicle technology
- Accelerate commercialization
- Technology transfer
- Demonstration phase and environmental assessment

Locations

INDIA
Agra, New Delhi, Pune

USA
Ashburn, VA

Project Duration
1998 – 2001

Partners

INDIA

- Bajaj Auto Limited
- TRICON Restaurants (Pizza Hut, India)
- WELCOMGROUP's Mughal Sheraton

USA

- New Generation Motors
- NEXANT/A Bechtel Technology & Consulting Company

United States Agency for International Development (USAID)

Bajaj Auto Ltd., Pune, India

New Generation Motors, Virginia, U.S.A

WELCOMGROUP's Mughal Sheraton, Agra, India

Cordially invite you to the

Inauguration of the Electric Three-Wheeler

Wednesday, March 14, 2001 at 11:00 a.m.
Taj Khema Hotel Compound, Agra

The Electric Three-Wheeler was developed with support from USAID under India Zero Emission Transportation (IZET) Program

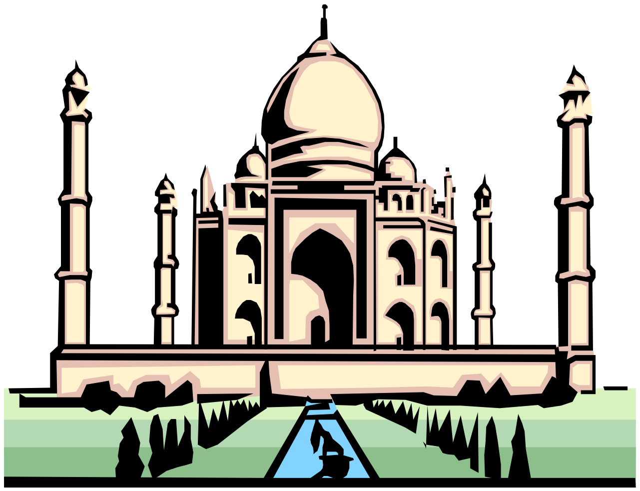
The inauguration ceremony will be followed
by test rides and lunch at the Mughal Sheraton Hotel

RSVP
Name:
e-mail:
Tel: ------------

The Program

Master of Ceremonies: Mr. Richard Edwards, USAID/India

Time:	11:00 AM	Mr. Walter North, Director, USAID/India *Greetings and Welcome Address*
Time:	11:10 AM	Guest Speaker: Mr. Pradeep Kumar Principal Secretary Environment, Govt. of U.P.
Time:	11:20 AM	Dr. Samuel Schweitzer, USAID, Global Environment Center *Topic: Indo-U.S. Partnership*
Time:	11:30 AM	Mr. Tapan Basu, Deputy General Manager, Bajaj Auto Ltd. *Topic: Changing Market Strategy*
Time:	11:40 AM	Dr. Nabih Bedewi President, New Generation Motors, Ltd. *Topic: Innovative Technology*
Time:	11:50 AM	Mr. Sarabjit .S Dhawan Managing Director, ITC Hotels *Topic: Eco-Tourism*
Time:	12:00 PM	USAID Handing-over of the "Keys" of a vehicle to the Archaeological Survey of India- Mr. D.V. Sharma, Superintendent
Time:	12:10 PM	Ribbon-Cutting of Three-Wheeler
Time:	12:30 PM	Inaugural Run of Three-Wheelers
Time:	01: 00 PM	Lunch at Mughal Sheraton



India Zero Emissions Transportation Program (IZET)

Partners:

bajaj auto ltd

NEW GENERATION MOTORS CORPORATION

WELCOMGROUP Hotels, palaces and resorts

Coordinator:

NEXANT
A BECHTEL TECHNOLOGY & CONSULTING COMPANY

Invitation to Attend Inauguration of Electric Three-Wheelers in Agra

	New Generation Motors Corporation			
	Title:	IZET DAQ On-Board Hardware Technical Specifications	Date:	21-NOV-2001
	Document #:	061-000011	Page:	1 of 23

On-Board Hardware Technical Specifications
For
IZET Data Acquisition System
IZET

Document Revision Record			
Rev:	Date:	By:	Description of Change
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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

	New Generation Motors Corporation			
	Title:	IZET DAQ On-Board Hardware Technical Specifications	Date:	21-NOV-2001
	Document #:	061-000011	Page:	3 of 23

1 INTRODUCTION

1.1 Overview

The Indian Zero Emissions Transportation (IZET) program is a collaborative effort among USAID, Bechtel, Bajaj Auto and New Generation Motors (NGM) to provide a commercially attractive mode of transportation that reduces ambient air and noise pollution. Under this program, several prototype electric two and three-wheeled vehicles have been developed. These vehicles will be placed in service in selected locations in India.

In order to monitor the performance of the vehicles and to gather data on the day-to-day operational characteristics, some of these vehicles will be instrumented with Data Acquisition (DAQ) systems. This document presents an overview of the technical specifications for the on-board components (hardware) of the data acquisition system.

1.2 Related Documents

Document #	Description
NGM 061-000010 Rev. A	IZET DAQ System Preliminary Definition
23865-E-107S-EV-NGM REV. 3	IZET Electric Scooter (2W) Technical Specifications
23865-E-107A-EV-NGM Rev. 3	IZET Electric Autorickshaw (3W) Technical Specifications

1.3 Definitions

The following terms and acronyms are define here for convenience

Term	Definition
2W	2-Wheeled Electric Scooter
3W	3-Wheeled Electric Autorickshaw
BAL	Bajaj Auto Ltd.
IZET	Indian Zero Emission Transportation
NGM	New Generation Motors Corporation
SOC	State Of Charge

2 System Specifications

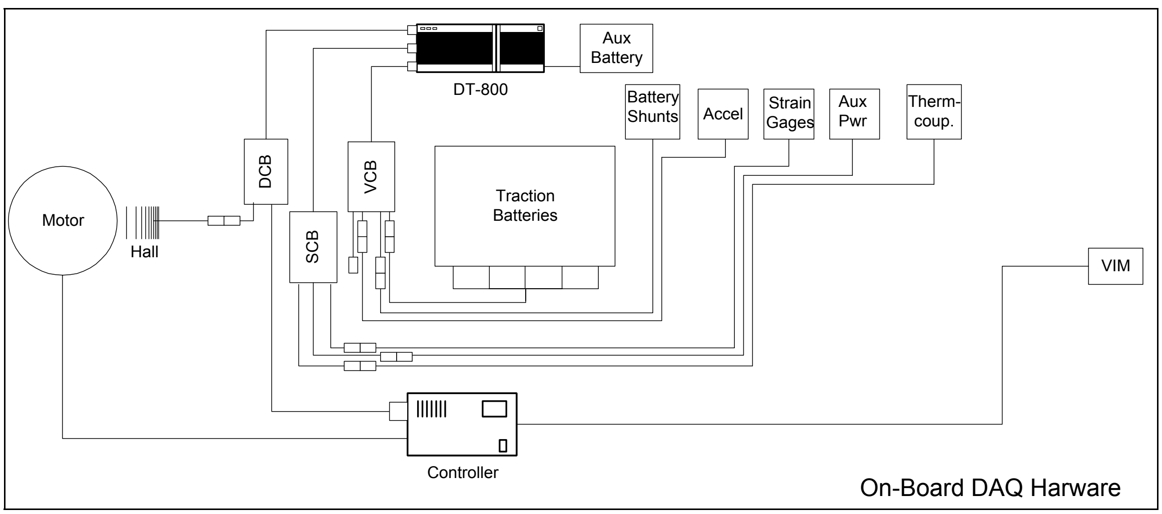
2.1 System Overview

The on-board hardware for the data acquisition system consists of four main components, namely:

- Data Logger Unit
- Sensors
- Data Storage Unit
- Signal Conditioning Modules

Figure 1 presents an overall schematic layout of the DAQ system hardware.

Figure 1 - On-Board Harware: Overall Schematic Layout



2.2 Data Logger Unit

The data logger selected for this program is the DataTaker DT800. The DT800 is a data acquisition and logging instrument capable of measuring and recording a wide variety of sensor data. Specifications for the DataTaker DT800 are listed in Appendix I. The DT800 will be repackaged for environmental protected to IP-67 standards. The repackaging will also include connectors for easy connection to the signal conditioning modules.

2.3 Sensors

Table 1 presents a list of the parameters to be stored by the data logger along with the data 'source' (sensor). Signals from these sensors will be conditioned by the signal conditioning modules prior to being acquired.

Table 1 - IZET DAQ Sensor List

Parameter to be measured	Qty	Source			Signal Type
		Type	Make	Model	
Bus Voltagte Battery Current Motor Phase Current Motor Speed Throttle Position Brake Position Vehicle Drivestate Controller Fault codes Motor Temperature Controller Temperature Battery State-Of-Charge	1	EV-C400 Motor Contrller	New Generation Motors (NGM)	EV-C400	Serial Input
Battery Current - String 1 Battery Current - String 2	2	Shunt	Deltec	MKA-100-50	Analog Input
Component Strain	3	Strain Gage	TBD	TBD	Analog Input
Longitudinal Acceleration Lateral Acceleration Vertical Acceleration	1	3-axis Accelerometer	Crossbow	CXL04M3-R	Analog Input
Voltage, Batery 1 Voltage, Batery 2 Voltage, Batery 3 Voltage, Batery 4 Voltage, Batery 5 Voltage, Batery 6 Voltage, Batery 7 Voltage, Batery 8	8	Voltage Conditioning Board (VCB)	New Generation Motors (NGM)	020-000461-004	Analog Input
Auxiliary Power Voltage	1	Signal Cond. Board	NGM	020-000461-002	Analog Input
Auxiliary Power Current	1	Power Resistor	Ohmite	12FR005	Analog Input
Ambient Temperature	1	IC Temp. Sesnor	National Semiconductor	LM35DM	Analog Input
Battery Temperature Temperature (unasigned)	2	Thermocouple	Omega	F-K-24-TCB	Analog Input
Vehicle Speed Distance Traveled	1	Hall Sensor	Micronas	HAL502-UA-E	Digital Input

2.4 Data Storage Unit

Test data will be temporarily stored in a PCMCI Type II memory card. Storage capacity requirements are set by the number of channels (parameters) to be stored, the acquisition rates, and the elapsed time between downloads.

The data stored will be downloaded approximately every week for archival and for further data reduction and analysis. The data can be downloaded in two ways: the memory card can be physically removed from the data logger and connected to a PC, or the data logger can be connected to the PC via Ethernet.

Based on the storage capacity requirements presented in Table 2, a memory card with a minimum of 260MB is needed. The card selected is a 320MB ATA Flash memory card from Viking, Model # FL320MDVA. Specifications for this card are listed in Appendix II.

	New Generation Motors Corporation			
	Title:	IZET DAQ On-Board Hardware Technical Specifications	Date:	21-NOV-2001
	Document #:	061-000011	Page:	7 of 23

Table 2 - Scan Rates and On-Board Data Storage Capacity Requirements

Parameter to be Logged	Filter cutoff (Hz)	Schedule	Time between scans (sec/scan)			Scan Frequency (scans/sec)		
Mode			Run	Burst	Idle	Run	Burst	Idle
% of Time			34.1%	0.9%	65.0%	34.1%	0.9%	65.0%
Battery Voltage		A	0.5	0.25	120	2	4	0.0083
Batteryr Current								
Brake Position								
Controller Fault Codes								
Motor Phase Current								
Motor Speed								
Throttle Position								
Vehicle Drivestate								
Battery Current - String 1	3.95							
Battery Current - String 2	3.95							
Strain Gauge #1		B	0.5	0.25	120	2	4	0.0083
Strain Gauge #2								
Strain Gauge #3								
Longitudinal Acceleration	3.95							
Lateral Acceleration	3.95							
Vertical Acceleration	3.95							
Voltage, Battery 1	0.918	C	5	1	120	0.2	1	0.0083
Voltage, Battery 2	0.918							
Voltage, Battery 3	0.918							
Voltage, Battery 4	0.918							
Voltage, Battery 5	0.918							
Voltage, Battery 6	0.918							
Voltage, Battery 7	0.918							
Voltage, Battery 8	0.918							
Auxiliary Power Voltage	0.918							
Auxiliary Power Current	0.918							
Ambient Temperature		D	5	5	120	0.2	0.2	0.0083
Battery State of Charge	0.159							
Battery Temperature								
Controller Temperature								
Motor Temperature								
Temperature (unassigned)	0.156							
Vehicle Speed		E	5	5	3600	0.2	0.2	0.0003
Distance Traveled								

bts/scan	56				
bts/chan	8				
Schedule	Channels	Bytes /scan	Bytes/sec		
			Run	Burst	Idle
A	10	136	272.00	544.00	1.13
B	6	104	208.00	416.00	0.87
C	10	136	27.20	136.00	1.13
D	6	104	20.80	20.80	0.87
E	2	72	14.40	14.40	0.02
		SUM	542.40	1131.20	4.02
				Tot/ Bites/sec Avg	197.75
# Days	10			**MB Required**	**170.9**

2.5 Signal Conditioning Modules

As shown in the IZET DAQ Layout figure (Figure 1), three separate modules will be used for conditioning the sensor signals, namely:

- Voltage Signal Conditioning Board (VCB)
- Sensor Signal Conditioning Board (SCB)
- Digital Signal Conditioning Board (DCB)

Each of these boards will have pigtail cables with connectors to interface to the data logger and to their respective sensors. The boards will be enclosed in metallic enclosures for electromagnetic shielding (measurement noise reduction), and will be encapsulated for environmental sealing to IP-67 standards.

The VCB consists of a series of voltage divider circuits for measurement of individual battery voltages. The VCB will also be used to filter and condition the battery current measurements (from the battery shunts) and the accelerometer signals.

The SCB will be used to filter and condition auxiliary power voltage and current measurements. In addition, this board will have the IC Temperature sensor for measurement of Ambient temperature. Finally, this board is used to 'pass-through' the strain gage signals. It should be pointed out that since the stain gages to be used are not dictated by NGM, the stain gage bridge circuit will have to be completed external to this board.

The DCB board will condition all digital signals, including the hall sensor signals and the serial communication signals between the motor controller and the data logger.

Appendix III presents a schematic representation of the connections to and from each of these three modules. Appendix III also presents the pin assignment for each of these connections.

	New Generation Motors Corporation			
	Title:	IZET DAQ On-Board Hardware Technical Specifications	Date:	21-NOV-2001
	Document #:	061-000011	Page:	9 of 23

APPENDIX I – DATATAKER DT800 SPECIFICATIONS

dataTaker DT800 Specification

*(first release v1.0)**

The new DT800 combines the roles of a data acquisition module, data logger and controller into a single robust unit. Equally at home at an unattended, harsh and remote site or on the desktop, the DT800 is a cost effective monitoring and control solution. The DT800 is fast, low power and very flexible.

Fast and Accurate. The DT800 is the first truly high-speed dataTaker. With a basic sampling rate of 100kHz at 16 bit resolution, the DT800 more than adequate for a wide range of applications. It exploits its speed advantage in two ways. For high-speed signals, waveforms can be captured in a triggered burst mode similar to a digital oscilloscope. For low speed signals, the speed allows effective noise filtering, automatic error correction and virtual simultaneous sampling by channel interleaving over a line cycle period (16.7 or 20 ms). Thus the DT800 achieves the best performance in both the high speed and low speed domains, without compromise.

Fine pedigree. The DT800 comes with a fine pedigree. It retains and enhances the popular features of the DT500 series of dataTakers. The 12 analog input channels are flexible - each channel can handle the widest range of sensor types without additional signal conditioning modules. The list includes thermocouples, RTDs, bridges, vibrating wire and accelerometers. Further, each channel can be split into two differential channels or three single ended channels if internal excitation is not required. This for example allows 36 thermocouple to be connected.

Isolation. The DT800's analog sub-system is isolated from the rest of the system for reliability and the effective rejection of common mode noise. Inter channel isolation within the analog sub-system is ±40V relative to analog common. The useful common mode range is ±12V relative to analog common.

Digital I/O. In addition to the analog channels, there are 16 digital channels and one universal serial sensor channel. The serial sensor channel may be configured for RS232, RS485 or SDI-12 and comes with programmable prompt and data parsing strings. The serial sensor channels can also be used for a printer, barcode reader or a link to a PLC or even another dataTaker.

Data collection schedules. The DT800 has up to 10 data collection schedules. Each is an independent list of channels that can be scanned from sub-second intervals to days. Schedules can be enable and disabled under program control. Collected data can be stored and / or forwarded via one of the communications ports. Internal data storage is more than 700,000 time-stamped data points. Additional data can be stored in memory PC Cards (ATA Flash or SRAM).

Conditional commands, statistical, variable and expression channels can also be included in schedules. These provide considerable power for manipulating data and for providing control functions.

Alarms. Alarm channels can be included in schedules and configured to issue messages to the communications port and the alarm log. Commands may also be issued in alarm conditions.

Strong communications. Fitted with 10BaseT Ethernet, RS232, USB and a PC Card socket interfaces as standard, the DT800 is able to communicate with most other systems. Port arbitration is fast and automatic.

All in one. Due to its unique feature mix, the DT800 can function as a fast real-time data acquisition unit, data logger and controller. Traditionally, data acquisition has been the realm of plug-in boards. This architecture has now become obsolete except for very fastest of requirements. An external self-contained DT800 has many advantages:

- removes low level signals from the noisy internal environment of a PC;
- can be located close to sensors reducing wiring cost and reducing noise pickup;
- continues to function when the PC crashes or looses power;
- can free the PC's operating system of time critical tasks;
- can with stand a harsher environment than a PC.

To become a data logger, simply add memory and reduce power. The DT800 can store over 700,000 readings in its internal battery backed memory. If that is not enough, insert a SRAM or FLASH PC Card for up to 16 million readings.

The DT800 is very efficient in its power consumption. When sampling intermittently, the internal 12V 2Ahr battery will last for several months. With a small solar panel, this duration becomes indefinite, making the DT800 ideal for remote unattended sites that must be monitored.

Frequently a monitoring task also has some control requirement – for example to maintain a tank level by controlling a pump. The DT800 can function as a controller with up to 12 I/O lines.

Thus, the DT800 has blurred the demarcation between data acquisition, data logger and controller. The one piece of equipment can satisfy a far wider range of applications than ever before.

Technology. The DT800 employs a fast PowerPC MPC860 processor from Motorola that is optimise for communications and low power operation. This technology gives the new dataTakers the edge on performance while extending internal battery life up to several months for remote applications.

Another advanced feature of the DT800 is the use of a field programmable gate array (FPGA) inserted between the digital I/O and the processor. The processor can configure the function of this logic block as counters, phase decoders, interrupts or control logic. The FPGA provides the programmable hardware needed for special applications.

Maintenance is simple. The DT800's built-in software is stored in FLASH memory and is simply field upgradable. Free upgrades are available via the Internet at www.datataker.com. All calibration information is stored in separate protected EEPROMs. There are no manual adjustments or other failure prone devices for calibration.

The electronics of the DT800 can be separated as one compact module from the wiring terminals for bench testing. The main 12V battery and the 3.6V lithium battery are part of the removable electronics module and are simply replaced.

**First release v1.0*

This specification covers the initial release of the DT800 in October 99. There are many hardware features in the DT800 that are not supported in this initial firmware release. These include USB (12M baud), modems, PC Card socket, vibrating wire sensors, frequency measurement, AC voltage and AC resistance measurement and other temperature sensors. As these features are progressively supported over the coming months, they will become available as free upgrades from datataker.com

October 99 page 1of 3

New Generation Motors Corporation			
Title:	IZET DAQ On-Board Hardware Technical Specifications	Date:	21-NOV-2001
Document #:	061-000011	Page:	11 of 23

Analog Channels

Number of Input Channels depends on sensor wiring configuration

Configuration	Number
Two wire	24
Two wire with one shared terminal	42
Three wire	12
Three wire with one shared terminal	18
Three wire with two shared terminals	36

Sensor configurations may be mixed in any way.

Fundamental Input Ranges

Full Scale Range	Resolution
10mVdc	1uV
20mVdc	2uV
50mVdc	5uV
100mVdc	10uV
200mVdc	20uV
500mVdc	50uV
1Vdc	100uV
2Vdc	200uV
5Vdc	500uV
10Vdc	1mV
20 Ω	0.1 mΩ
50 Ω	0.25 mΩ
100 Ω	0.5 mΩ
200 Ω	1 mΩ
500 Ω	2.5 mΩ
1,000 Ω	5 mΩ
2,000 Ω	10 mΩ
5,000 Ω	25 mΩ
10,000 Ω	50 mΩ

Note: The DT800 hardware supports AC voltage and resistance measurement, however these are not yet supported by the embedded software.

Accuracy

Measurement	25 °C	-20 °C to 60 °C
DC Voltage	0.02%	0.10%
AC Voltage	0.05%	0.20%
DC Resistance	0.04%	0.20%
AC Resistance	0.07%	0.30%

Two Sampling Modes

Burst mode sampling with pre and post triggering:

Maximum burst mode sample speed	100kHz
Minimum burst mode sample speed	1kHz
Effective resolution	13 bits
Max number of samples in a burst	100,000

Normal mode sampling for accuracy and noise rejection by interleaved sampling of channels over line cycle period:

Effective simultaneous sampling	5 channels
Maximum sample speed	40Hz
Effective resolution	16 bits
Common mode rejection 10mV range	130db
Line (50/60Hz) series mode rejection	60db

Sensor Excitation

Programmable with 12 bit resolution, available on any analog channel terminal pair as a balanced output:

DC Voltage mode	0 to 10V
DC Current mode	0 to 20mA
DC Power mode	0 to 200mW

Analog Output

Number of analog output channels	1
Voltage range	-10V to +10V
Resolution	10mV
Output impedance (nominal)	<1Ω
Maximum current	20mA

Comments: Shared with burst mode trigger level

Internal Channels

Temperature (thermocouple reference junction)	1
Reference voltage channel (2.5000V)	1
Zero reference	1
Battery voltages (Gel cell, Lithium)	2
External supply voltage	1
Internal current distribution monitoring	5
Internal voltage rail monitoring	4

Sensor Support

Supports a wide range of sensors types including, but not limited to the following:

Thermocouple Support

Types supported	B, C, D, E, G, J, K, N, R, S, T
Standard	ITS-90
Accuracy (case at 25C)	as per NIST Monograph 125 or better
Thermocouple Reference Junction Compensation	
Accuracy at 25C	0.2C
Accuracy over -20 to +60	0.6C
Thermocouple integrity testing	yes

RTD's (Resistance Temperature Detectors)

Materials supported	Platinum, Nickel, Copper
Alpha	0.00385, 0.00392
Resistance range	10 to 10,000 Ω
Resistance measurement accuracy	
4 wire	0.05%
3 wire	0.15%

Monolithic Temperature Sensors

Types supported	LM34, 35, 45, 50 & 60, TPS17, 34, 35, Si Diode

Bridge Sensors

Configurations	4-wire and 6-wire
Bridge completion	external

Comments: a wide range of sensor scaling and linearizing facilities is provided including polynomials, expressions and functions.

Note: The DT800 hardware supports vibrating wire, conductivity and other sensors, however these are not yet supported by the embedded software.

Digital Channels

Number of Channels

Bi-directional channels	8
Input only channels (logic level)	8
Sensitive magnetic pick-up channels (shared with bi-directional)	2

Counters

Number (shared bi-directional channels)	8
Length	32 bit
Speed	1 kHz max
Operation in sleep mode	yes

Digital Output

Output type	Open drain FET
Rating	30V, 100mA

Serial Sensor Channel

Modes	RS232, RS485, SDI-12
Handshake lines	DTR, DTS
Baud rate	300 to 56k baud
Programmable prompt string	yes

A programmable data parsing string allows multiple assignment to variables.

Variable Channel

Number	200

Calculation Channels

Any expression involving variables and functions.

Functions	sin(), cos(), tan(), asin(), acos(), atan(), abs(), sqrt()

Scheduling of Data Acquisition

Number of schedules	10
Maximum schedule rate	100ms
Maximum number of scheduled channels	500

Alarm Channels

Number	500
Operation	embedded in any schedule
Alarm buffer	circular 4k byte buffer that can be dumped any time

October 99

page 2of 3

New Generation Motors Corporation			
Title:	IZET DAQ On-Board Hardware Technical Specifications	Date:	21-NOV-2001
Document #:	061-000011	Page:	12 of 23

Data Storage

Internal RAM	
Dual battery backed RAM	4M Byte
Capacity	>700,000 data points
PC Card	
SRAM types	all sizes, 4 M Byte (typical)
FLASH	48 M Byte ATA types
Card voltage	3V or 5V types

Capacity of PC Cards: 250,000 time-stamped data points per M Byte.

Real Time Clock

Normal resolution	1ms
Extended resolution	1us
Accuracy at 25 ℃	2 ppm
–20 ℃ to +60 ℃	10 ppm

Power Supply

Voltage range	11V to 28Vdc

Power Consumption

In normal mode, excluding battery charging and PC Card operation	4W
In normal mode with maximum battery charging and 600mA PC Card	15W
Sleeping (powered from internal 12V battery), digital I/O pull-ups turned off	2mW
Typical low power operation	10mW
Battery charger capacity	200mA

The battery charger is temperature compensated over –10 ℃ to +70 ℃

Internal Main Battery

Chemistry	Lead Acid Gel Cell
Voltage	12V
Rating	2.2Ahrs
Life (depends on program)	Normal full power – 6 hours Low power – 2 months

Memory and Real-Time Clock Battery

Chemistry and size	Lithium, 1/2AA
Voltage	3.0V
Rating	400mAHr

PC Card (PCMCIA) Support

Number of Card Slots	1
Card Sizes	Type 1,2 and 3
Implementation	Full, to PCMCIA 2.1
Card Types	SRAM, FLASH (ATA), Modem GSM Modem, GPS
Socket voltage	3.3V and 5V
Socket current	500mA max
12V Power	30mA

Communications Interfaces

Ethernet	
Interface	10Base-T
Protocols	TCP/IP (UDP)
Wake from sleep	no (must remain awake)
RS232	
Lines supported	TX, RX, CD, DSR, DTS, RTS, CTS
Speed	300 to 115k Baud
Wake from sleep	yes

Note: The DT800 hardware supports USB, PC Card and Modem communications, however the embedded software does not yet support these.

System

Processor type	Motorola PowerPC MPC850 50MHz, 32 bit bus
Program Storage	in FLASH, 2M Byte, field upgradable
Data Storage	4M Byte, battery backed SRAM
User program and configuration	FLASH or RAM
Indicator LEDs	Attention, Sampling, Logging, Charging
Y2k Compliant	yes

Physical

Dimensions	280x110x90mm
Weight including batteries	3.1 kg
Environment	
Temperature range	-20 ℃ to 60 ℃
Reduced specification	–40 ℃ to 70 ℃
Humidity	85%, non-condensing
Protection	IP45

Bundled Software and Accessories

Software (on CD)
- DeLogger Plus V4
- DeTransfer
- DeTerminal for Windows
- DeTerminal for Dos

Accessories
- Getting Started with DT800 Manual
- DT800 Concise Manual
- RS232 cable
- USB cable
- Ethernet 10BaseT cable
- AC Power Pack
- Cage clamp tool kit
- Sensor kit

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	New Generation Motors Corporation			
	Title:	IZET DAQ On-Board Hardware Technical Specifications	Date:	21-NOV-2001
	Document #:	061-000011	Page:	13 of 23

APPENDIX II - VIKING ATA LASH CARD SPECIFICATIONS

ATA FLASH PC CARD

General Description

The Viking ATA Flash Type II PC Card can support from 16MB up to 1GB of flash memory. The card is constructed with up to sixteen 128Mb, 256Mb, or 512Mb NAND FLASH devices. It is compatible with standard operating systems, application software and provides high speed Read/Write operations that eliminate latency and seek-time associated with a hard disk drive. This ATA Flash PC Card employs an intelligent power management scheme that provides the lowest total power consumption. Additionally, advanced error correction and defect mapping assures data integrity over the life of the flash product.

Features

- Dual Voltage +3.3 or +5V ± 10%.
- Auto switching between ATA FLASH PC CARD and IDE mode.
- Standard 68-Pin PCMCIA connector.
- Up to 8MB/second from host.
- Designed with an embedded error correction code (ECC) function.
- Auto Power-Down Mode.
- Minimum 1 million write/erase cycles.
- Unlimited read cycles.
- Data reliability: < 1 error in 10^{14} bits read.
- 0 to 70 °C operating temperature.

CONNECTOR PIN ASSIGNMENTS

1	GND	18	NC	35	GND	52	NC
2	D3	19	NC	36	#CD1 (GND)	53	NC
3	D4	20	NC	37	D11	54	NC
4	D5	21	NC	38	D12	55	NC
5	D6	22	A7	39	D13	56	#CSEL
6	D7	23	A6	40	D14	57	#VS2
7	#CE1	24	A5	41	D15	58	RESET
8	A10	25	A4	42	#CE2	59	#WAIT
9	#OE	26	A3	43	#VS1 (GND)	60	#INPACK
10	NC	27	A2	44	#IORD	61	#REG
11	A9	28	A1	45	#IOWR	62	#SPKR
12	A8	29	A0	46	NC	63	#STSCHG
13	NC	30	D0	47	NC	64	D8
14	NC	31	D1	48	NC	65	D9
15	#WE	32	D2	49	NC	66	D10
16	#IREQ	33	#IOIS16	50	NC	67	#CD2 (GND)
17	VCC	34	GND	51	VCC	68	GND

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Doc. # PS000001 – Revision F – Created By: Brian Ouellette
Page 1 of 9

	New Generation Motors Corporation			
	Title:	IZET DAQ On-Board Hardware Technical Specifications	Date:	21-NOV-2001
	Document #:	061-000011	Page:	14 of 23

VIKING

ATA FLASH PC CARD

PIN FUNCTION DESCRIPTION

A0 – A10	Address	INPUT	In I/O and Memory modes, these are the Host Address lines that select the I/O port address registers or the memory mapped port address registers, and the control and status registers. In true IDE mode, only A [2:0] are used to select the control, status and data register; A [10: 3] are not used in this mode.
#CE1 – #CE2	Card Enable	INPUT	These inputs select the card and indicate to the controller whether a byte or word operation is being performed. #CE2 always accesses the odd byte of the word; #CE1 accesses the even or odd byte of the word depending on the status of A0 and #CE2.
#CD1 – #CD2	Card Detect	OUTPUT	These output pins tied to ground. By sensing these signals, the host determines that the card is fully inserted into the socket.
#CSEL	Cable Select	INPUT	This signal is not used in the Memory or I/O modes. In true IDE mode, this signal configures the drive as a Master or Slave. If the signal is de-asserted (low), the drive is configured as a Master. If the pin is open, the drive is configured as a slave.
D0 – D15	Host Data Bits	INPUT/OUTPUT	These bi-directional signals carry the data, commands, and status information between the host and the controller.
#OE	Output Enable	INPUT	This input signal is used to gate Memory Read data from the memory card. In Memory mode it is used to read both data and the CIS and Configuration registers. In I/O mode, this signal is used to read the CIS and Configuration registers only.
RESET	Reset	INPUT	In CF card mode, the controller is reset when this signal is set to VIH, initializing the control and status registers and aborting any command in progress. In IDE mode, this signal is active low.
#WE	Write Enable	INPUT	In Memory mode, this input signal is used for strobing Memory Write data into the controller. In both Memory mode and I/O mode, this signal is used for writing the configuration register, in conjunction with the REG signal.
#INPACK	Input Acknowledge	OUTPUT	In memory mode, this signal is not use. In true IDE mode, this signal is not use and should not connect to host. In I/O mode, this signal is asserted by Compact flash Storage card when the card is selected and responding to an I/O read cycle at the address at on the bus. This signal is use by the host to control the enable of any input data buffers between the Compact flash and CPU.
#IORD	Input/Output Data Read	INPUT	In I/O mode, and true IDE mode, this input pulse clocks I/O data from the internal controller to the card bus.
#IOWR	Input/Output Data Write	INPUT	In I/O mode, and true IDE mode, this input pulse, along with HCSO clocks I/O data from the card bus to the internal controller.

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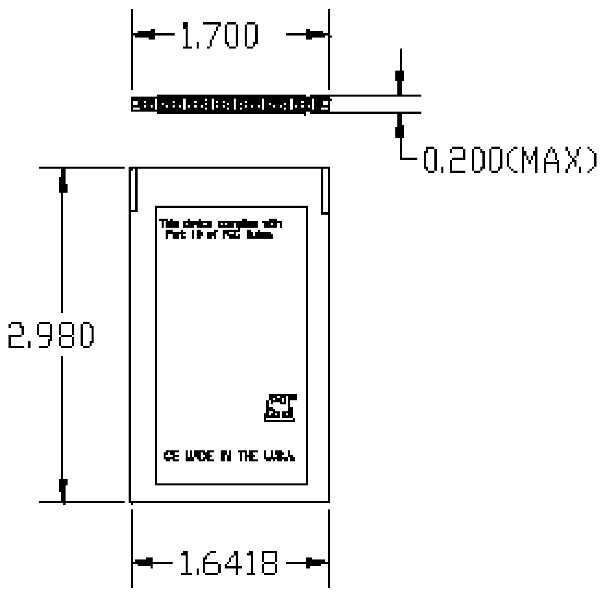
Doc. # PS000001 – Revision F – Created By: Brian Ouellette
Page 2 of 9

	New Generation Motors Corporation			
	Title:	IZET DAQ On-Board Hardware Technical Specifications	Date:	21-NOV-2001
	Document #:	061-000011	Page:	15 of 23

ATA FLASH PC CARD

MECHANICAL DIMENSIONS
All dimensions are in inches



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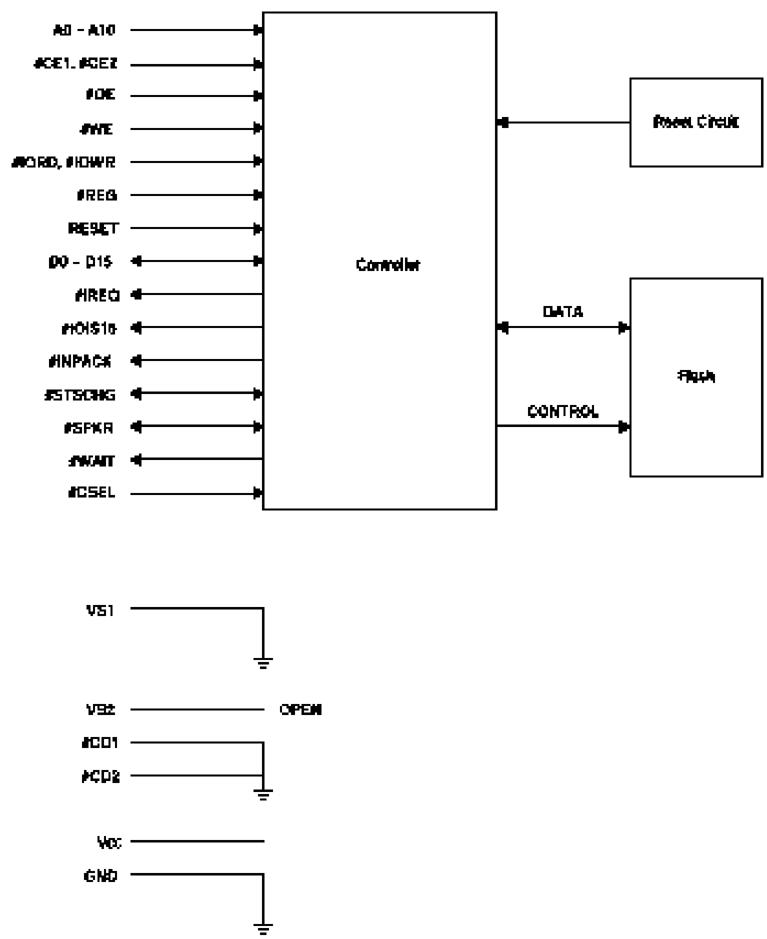
Doc. # PS000001 – Revision F – Created By: Brian Ouellette
Page 4 of 9

	New Generation Motors Corporation			
	Title:	IZET DAQ On-Board Hardware Technical Specifications	Date:	21-NOV-2001
	Document #:	061-000011	Page:	16 of 23

ATA FLASH PC CARD

Functional Block Diagram



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ATA FLASH PC CARD

ABSOLUTE MAXIMUM RATINGS

Supply Voltage		VCC	-0.5 ~ 4.6 -0.5 ~ 6	V
Input Voltage	LVTTL	V	-0.5 ~ 4.6	V
	5 V Full Swing Buffer		-0.5 ~ 6.0	
Output Current	IOL = 3 mA	IO	10	mA
	IOL = 6 mA		20	
	IOL = 9 mA		30	
	IOL = 18 mA		60	
Storage Temperature		TST	-55° to +125°	°C
Operating Temperature		TOPR	0° to +70°	°C

Note: Permanent device damage may occur if 'ABSOLUTE MAXIMUM RATINGS' are exceeded. Functional operation should be restricted to recommended operating condition. Exposure to higher than recommended voltage for extended periods of time could affect device reliability.

DC OPERATING CONDITIONS AND CHARACTERISTICS

Recommended operating conditions (Voltages referenced to GND, TA = 0 to 70°C)

Supply voltage		VCC	2.7 4.5	3.3 5.0	3.6 5.5	V
Input high voltage	LVTTL	VIH1	2.0			V
	CMOS	VIH2	Vccx0.7			
	TTL	VIH3	2.2			
Input low voltage	LVTTL	VIL1			0.8	V
	CMOS	VIL2			Vccx0.3	
	TTL	VIL3			0.8	
Output high voltage	LVTTL IOH = -3mA; -6mA; -9mA	VOH	2.4			V
	5V Full Swing IOH = -6mA; -18mA		VCC-0.4			
Output low voltage	LVTTL IOL = 3mA; 6mA; 9mA	VOL			0.4	V
	5V Full Swing IOL = 6mA; 18mA					

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Doc. # PS000001 – Revision F – Created By: Brian Ouellette
Page 6 of 9

VIKING

ATA FLASH PC CARD

ENVIRONMENTAL SPECIFICATIONS

Storage Temperature:	-55 to 125°C
Operating Temperature:	0 to 70°C
Humidity (non-condensing):	95%
Vibration:	15 G peak to peak half sine wave
Shock:	50 G at 11ms

CAPACITANCE

Input capacitance	Cin	-	20	pF
Output capacitance	Cout	-	20	pF
Bidirectional capacitance	CI/O	-	20	pF

AC Characteristics

Setup time Standby/Power down to Active (Typ.) Power on to ready (Typ.) Change zone to zone (Typ.)	 512 50 50	 µsec msec msec
Media transfer rate Read Write	 1.2 0.6	MB/sec
Burst Read from Flash to Controller Burst Write from Controller to Flash	4 4	MB/sec
PC card interface transfer rate from host	8	MB/sec

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	New Generation Motors Corporation			
	Title:	IZET DAQ On-Board Hardware Technical Specifications	Date:	21-NOV-2001
	Document #:	061-000011	Page:	19 of 23

ATA FLASH PC CARD

VIKING

ORDERING INFORMATION

Viking Part number	Description
FL16M5VA	16MB 5 Volt Flash Card
FL32M5VA	32MB 5 Volt Flash Card
FL48MDVA	48MB Dual Voltage Flash Card
FL64MDVA	64MB Dual Voltage Flash Card
FL80MDVA	80MB Dual Voltage Flash Card
FL96MDVA	96MB Dual Voltage Flash Card
FL128MDVA	128MB Dual Voltage Flash Card
FL160MDVA	160MB Dual Voltage Flash Card
FL192MDVA	192MB Dual Voltage Flash Card
FL256MDVA	256MB Dual Voltage Flash Card
FL320MDVA	320MB Dual Voltage Flash Card
FL448MDVA	448MB Dual Voltage Flash Card
FL512MDVA	512MB Dual Voltage Flash Card
FL640MDVA	640MB Dual Voltage Flash Card
FL768MDVA	768MB Dual Voltage Flash Card
FL1024MDVA	1GB Dual Voltage Flash Card

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Doc. # PS000001 – Revision F – Created By: Brian Ouellette
Page 8 of 9

	New Generation Motors Corporation		
Title:	IZET DAQ On-Board Hardware Technical Specifications	Date:	21-NOV-2001
Document #:	061-000011	Page:	20 of 23

ATA FLASH PC CARD

REVISION HISTORY

Revision	Release Date	Description of Change	Checked By / Approved
A	-	Initial release	
B	June 7, 2000	Released as Rev B	Dennis Vaillencourt Tung Nguyen
C	August 10, 2000	Correct Operating Temp reference (Was 5% to 95% Is: 5 to 95 °C)	Tony Bitetti
D	January 5, 2001	Correct Operating Temp. (Was: 0–60°C on page 1; 5–95°C on page 6. Is: 0–70°C). Correct Storage Temp. (Was: -60 –100°C on page 6; 5–95° on page 6. Is: -55–125°C).	Mike Roberts
E	March 8, 2001	New format for Datasheet, Changed PCB and max capacity. Temperature ranges in Rev D adjusted for current build.	Jim Walker
F	May 14, 2001	Correction to Storage Temperature and Operating Temperature ranges.	Jim Walker

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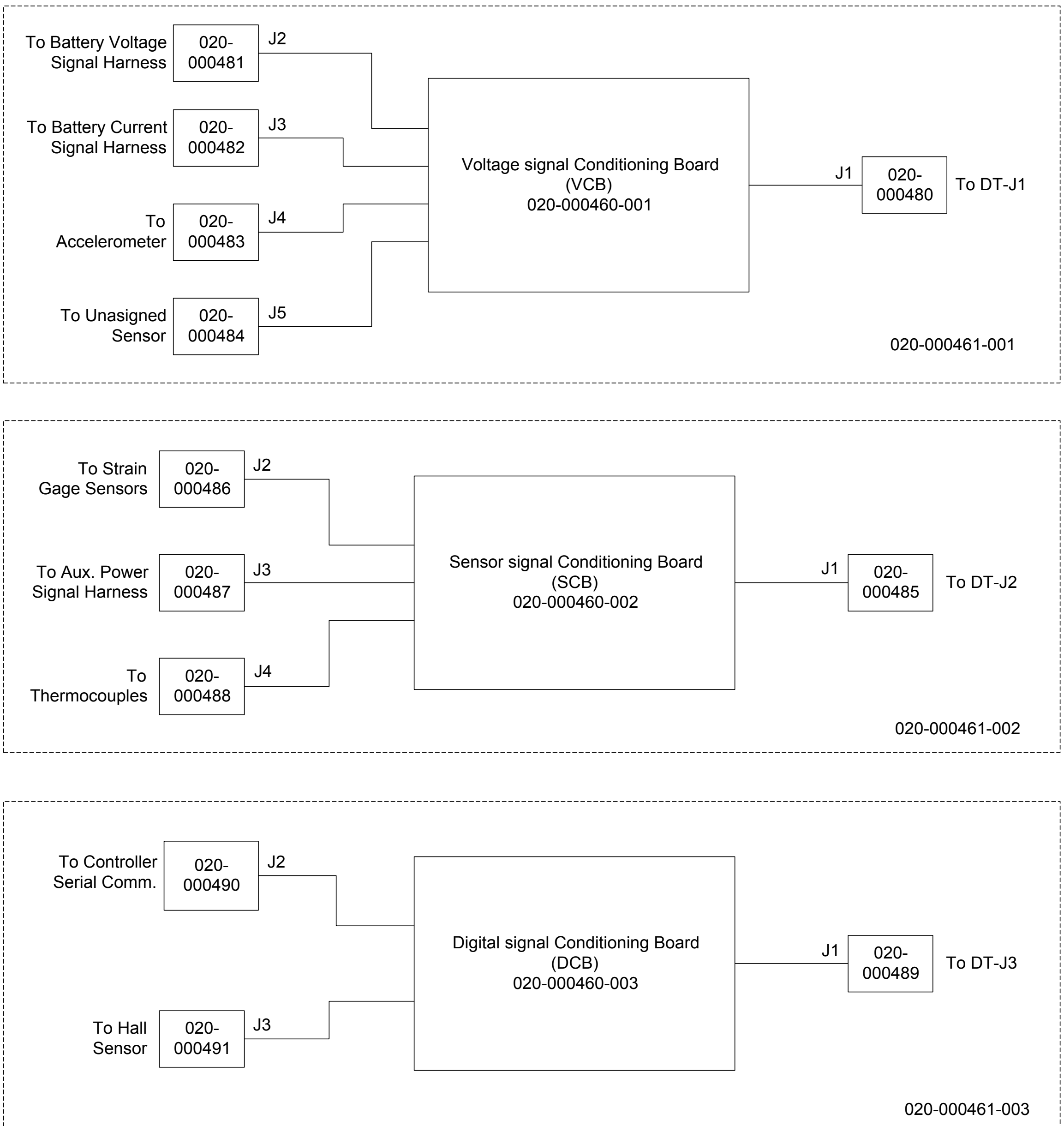
	New Generation Motors Corporation			
	Title:	IZET DAQ On-Board Hardware Technical Specifications	Date:	21-NOV-2001
	Document #:	061-000011	Page:	21 of 23

APPENDIX III – CONNECTIONS TO SIGNAL CONDITIONING MODULES

Figure 2 - Connection to Signal Conditioning Modules



	New Generation Motors Corporation			
	Title:	IZET DAQ On-Board Hardware Technical Specifications	Date:	21-NOV-2001
	Document #:	061-000011	Page:	22 of 23

Figure 3 - VCB Connections Pin Assignment

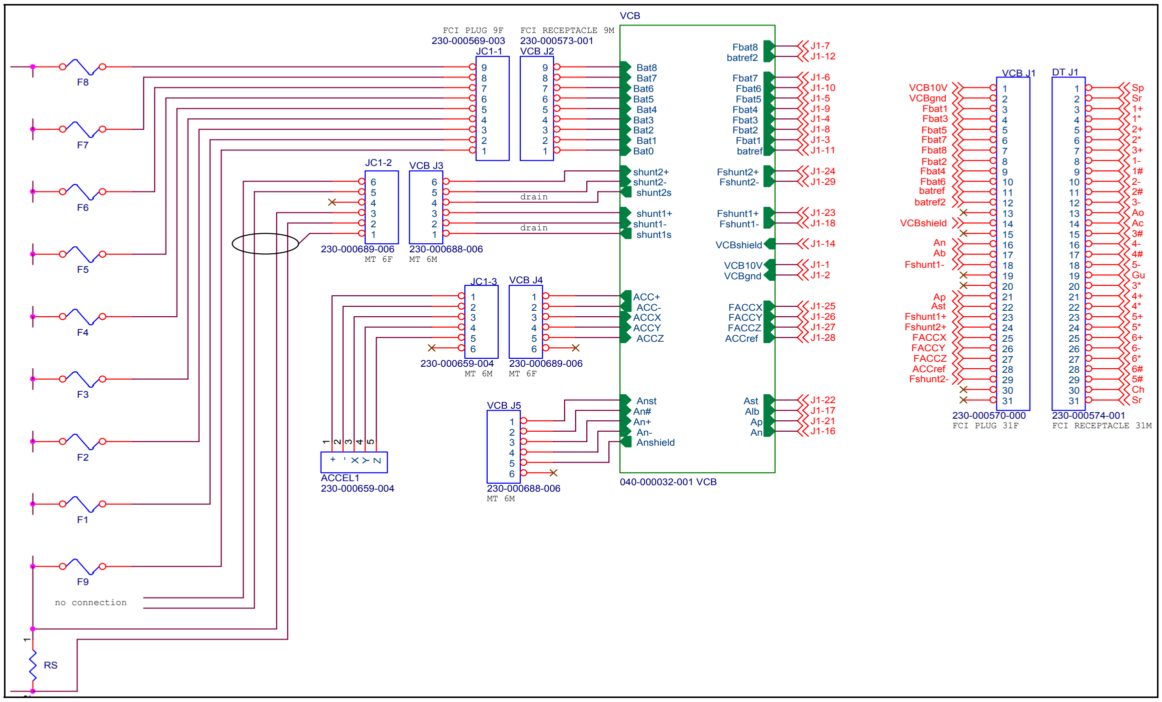
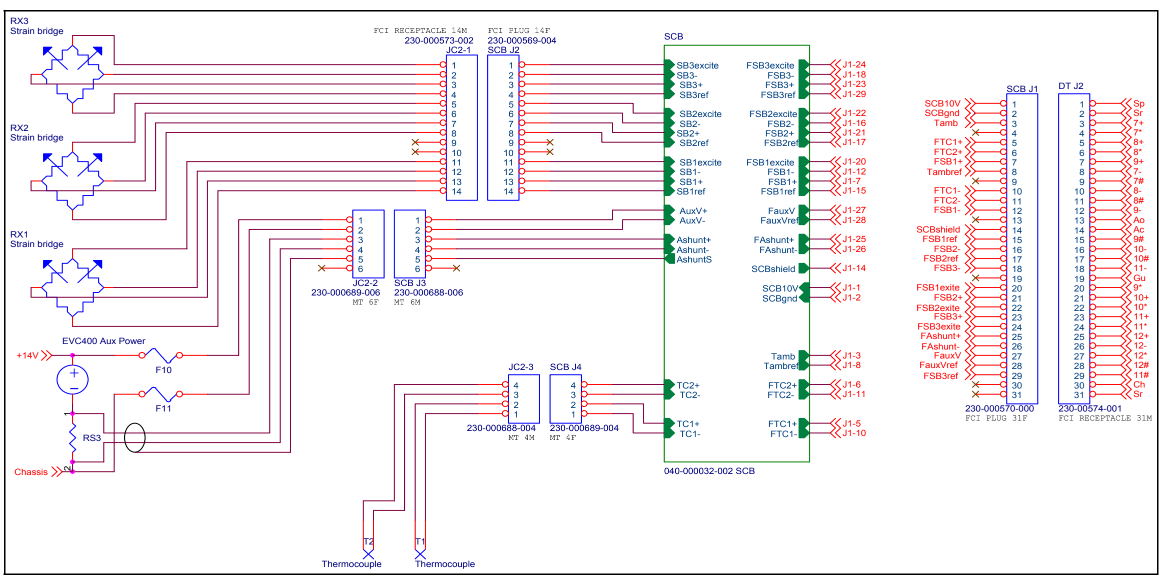
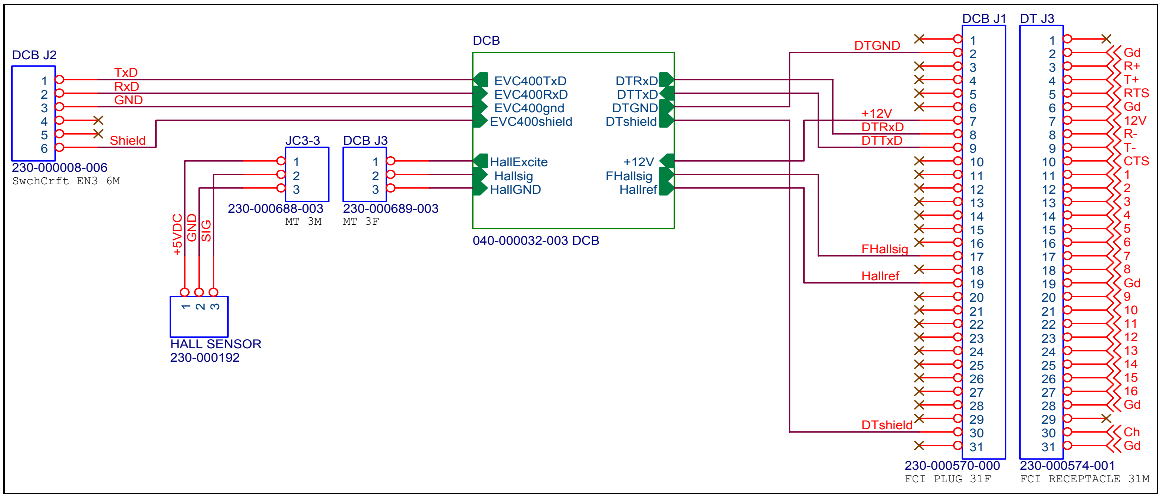


Figure 4 - SCB Connections Pin Assignment



	New Generation Motors Corporation			
	Title:	IZET DAQ On-Board Hardware Technical Specifications	Date:	21-NOV-2001
	Document #:	061-000011	Page:	23 of 23

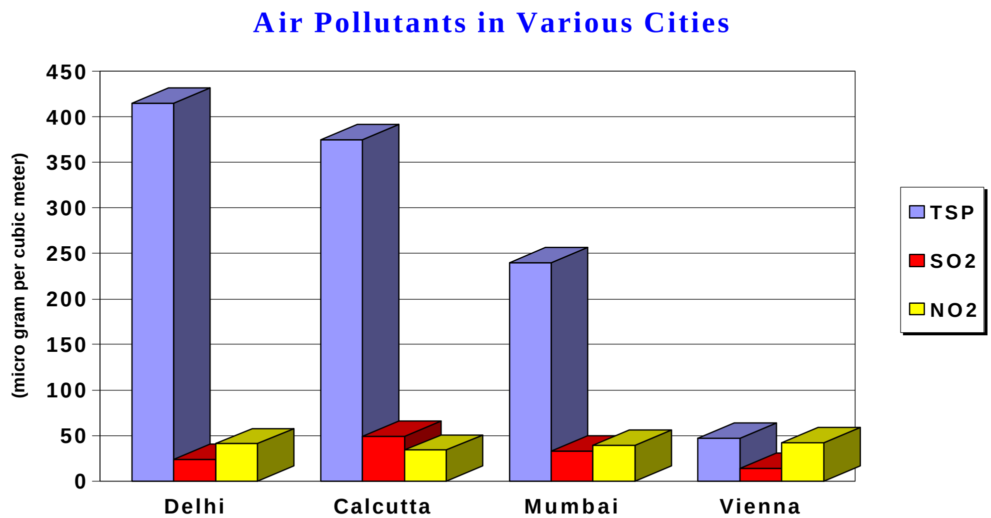
Figure 5 - DCB Connections Pin Assignment



Air Pollution Impact in Delhi

1 Introduction

Air pollution in India' is a cause for serious concern and has become a political rallying cry. Air pollution in India's urban areas is among the worst in the world (See Figure 1). Levels of particulate matter, ground level ozone and carbon monoxide, and lead are all well above the recommended World Health Organization levels. For example, the average annual concentrations of SO2 and PM in Delhi are 16.2 micrograms per cubic meter (μm/cm), and 370 μm/cm, respectively. Poor air quality is a serious drain on the country's human and capital resources. Premature mortality attributable to air pollution above the WHO standards ranges from 7,491 additional deaths in Delhi to 5,726 in Calcutta and 1,894 in Kanpur. Annual hospital admissions range from 3.99 million more in Delhi to 812 thousand in Kanpur[1].



The most significant contributor to urban air pollution is transportation and of that two and three wheeled vehicles. A recent study by the Central Pollution Control board has shown that transportation is the single greatest cause of air pollution in Delhi, accounting for 67% of total air pollution[2]. For Mumbai it has been estimated that transportation is also the single largest contributor to air pollution[3]. As a result of continued urbanization and population growth the number of two-stroke two and three wheelers (2WVs and 3WVs) in operation in cities throughout India continues to increase as well. In fact the problem is so serious that a recent GOI study recommended, "In the absence of technological breakthrough on the conventional 2-

[1] London Financial Times Special Report on Environment and India. *Environment: Capital urgently in need of fresh air*. April 1997.
[2] Source: White Paper on Pollution in Delhi with Action Plan, GOI.
[3] Urban Air Quality Management Strategy in Asia, Greater Mumbai Report, October 1996, World Bank.

stroke engine and its high pollution potential, it is for consideration that Government consider the phasing out of two-stroke two and three wheelers[4]."

Despite the need to phase out two stroke 2WV and 3WVs, it will be a political thorny issue since many of the masses depend upon this inexpensive form of transportation. Some have proffered 4-stroke engines but, in the long run 4-stroke engines may not be feasible solution since they will still be polluting, albeit at a lower level per kilometer than 2 and 3 wheel vehicles.

USAID is pioneering a potential solution to both the transport needs and pollution problems in urban India – the "technological breakthrough" recommended by the GOI – the electric two and three wheel vehicle. Working with the private sector in US and India, is exploring the possibility of introducing electric-powered vehicles (EV)s as replacements for some portion of the existing and growing population of 2 and 3-wheeled, 2-stroke engine-powered vehicles. It is the purpose of this paper to examine the net environmental impacts of replacing incremental percentages of those 2-stroke engine powered vehicles with EVs of near-equivalent function.

Our analysis of the environmental impacts of replacing two stroke 2 and 3 wheel vehicles with electric motors indicates that there will be a significant improvement in urban air quality with regard to particulate matter (PM), sulfur dioxide (SO_2), oxides of nitrogen (NO_X), carbon monoxide (CO), Ozone (0^3) and carbon dioxide (CO_2) while there will be only a minimal increase in non-urban areas in SO_2 and NO_X. Also, the introduction of this technology coupled with the improvements in the electricity sector point to an increasing positive impact on the environment over time. Moreover, the operation and supply of conventional 2WVs and 3WVs contributes to other environmental problems including noise pollution and water pollution. However, the data was lacking for a quantitative assessment of these impacts.

[4] Source: White Paper on Pollution in Delhi with Action Plan, GOI.

2 Air Quality Background, Baseline, Assumptions and Impacts

2.1 Air Quality

Background

Air pollution is a serious concern for a number of reasons ranging from the impact on human health (premature mortality and increased morbidity) to its impact on Human Welfare (such as the reduced lives of materials or increased cleaning costs or the negative impact that obstructing the view has on Indian tourism), to general ecosystem concerns (global warming). Delhi is typical of many of India's urban areas. It is heavily polluted and much of that pollution is from vehicle transport.

Air pollutants of principal interest and considered in this analysis are particulate matter (PM), sulfur dioxide (SO_2), oxides of nitrogen (NO_X), hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), ozone (O_3) and lead (Pb). CO and PM levels in Delhi (and most other Indian cities) exceeds recommended World Health Organization/ US EPA standards. Table 2.1 below shows the ambient air quality of Delhi from 1989 to 1997.

Table 2.1
Delhi Ambient Air Quality
Avg Annual Concentrations

	SOx	NOx	CO	PM
1989 (Jan-Dec)	8.7	18.5	2905	373
1990 (Jan-Dec)	10.2	22.5	2688	338
1991 (Jan-Dec)	13.3	27.2	3464	317
1992 (Jan-Dec)	18.4	30.4	3259	377
1993 (Jan-Dec)	18.5	33.2	4628	372
1994 (Jan-Dec)	19.5	33	3343	377
1995 (Jan-Dec)	19	34.1	3916	407
1996 (Jan-Dec)	19	33.7	5587	387
1997 (Jan-Aug)*	16.2	33	4847	370
WHO/USEPA Standard	50	40	1000	50

Source: White Paper on Pollution in Delhi with Action Plan, GOI. Concentrations are in micrograms per cubic meter.

* This data is not strictly comparable with earlier data for full year periods. Conversations with Delhi pollution authorities indicate that annual concentrations for 1997 are above those for earlier years.

Delhi air quality well exceeds health standards for PM and CO and is on its way to approaching standards for SOx and NOx. Table 2.2 below shows India's National Ambient Air Quality Standards as reported in the White Paper on Pollution in Delhi with Action Plan, GOI.

Table 2.2

National Ambient Air Quality Standards

Pollutant (microgrames per m3)	Time-Weighted Average	Concentration in Ambient Air		
		Industrial	Residential	Sensitive
Sulphur Dioxide (SO_2)	Annual Average	80	60	15
	24 Hours	120	80	30
Oxides of Nitrogen as NO_2	Annual Average	80	60	15
	24 Hours	120	80	30
Suspended Particulate Matter (SPM)	Annual Average	360	140	70
	4 Hours	500	200	100
Respirable Particulate Matter (Size less than 10æm)	Annual Average	120	60	50
	24 Hours	150	100	75
Lead	Annual Average	1.0	0.75	0.50
	24 hours.	1.5	1.00	0.75
Carbon Monoxide (mg/M3)	8 hours	5.0	2.00	1.00
	1 hour	10	4.00	2.00

Air quality levels of the kind exhibited in Delhi mean significant real costs to the country. Note that Carbon Monoxide and PM exceed even the Indian Standards by a factor of over two times for residential areas. By all accounts Delhi is in serious trouble.

Most of Delhi's air quality problems can be directly linked to vehicles. Over 67% of the air pollution in 1997 was attributed to vehicles and of that more than 2/3s is attributed to 2WVs and 3WVs. "Two stroke engines account for 70% of hydrocarbon and 50% of carbon monoxide emissions." Their impact is growing as rising incomes and urban growth increase the use of 2WVs and 3WVs. Table 2.3 presents sources of Delhi's pollution. Clearly, vehicles are the largest and fastest growing air quality problem in Delhi.

Table 2.3
Source of Air Pollution in Delhi

Source	1970-71	1980-81	1990-91 (projected)	2000-01
Industrial	56%	40%	29%	20%
Vehicular	23%	42%	64%	72%
Domestic	21%	18%	7%	8%

Source: Central Pollution Control Board

> "Two-wheelers account for about two thirds of the total vehicular population in Delhi. Because of inherent drawbacks in the design of 2-stroke engines, 2-wheelers emit about 20-40% of the fuel un-burnt/partially burnt. Presently, two-wheelers account for more than 70% of the hydrocarbons and nearly 50% of the carbon monoxide in Delhi. As these emissions are less visible, the general public is not aware of the role of 2-wheelers in the deteriorating air quality. The 2-stroke engine, in spite of R&D efforts towards improving its design, will continue to be a high emitter of hydrocarbons and carbon monoxide. In absence of a technological breakthrough on the conventional 2-stroke engine and its high pollution potential, it is for consideration that Government consider the phasing out of two-stroke two and three wheelers.
>
> Of the 80,000 three-wheelers in Delhi nearly 97% are petrol-driven, powered by 2-stroke engines. These vehicles are also high emitters of carbon monoxide and hydrocarbons. Pollution checks conducted by the Transport Department of Delhi Government has revealed that in some instances the levels are so high that they go beyond the measurable scale of test instruments. In addition, it is widely believed that petrol is adulterated with kerosene which results in emissions of thick black smoke. "

These statistics and findings indicate that USAID has correctly targeted this segment of the vehicle population.

Baseline Emissions

Delhi is taken as a worst-case example for air quality impacts and Delhi is also the target of the first demonstration of introduction of 2WV and 3WV EVs. Therefore, impacts are examined for the Delhi case as an example of typical urban conversion scenario. Air quality values for Delhi, are presented as Table 2.1-1. 2WVs alone account for about 70% of the total vehicular population in Delhi. Because of nature of the operation of 2-stroke engines, 2WVs emit about 20-40% of the fuel unburned or as PICs. 2WVs account for more than 70% of the hydrocarbons and nearly 50% of the CO emitted in to the atmosphere of Delhi. These emissions are less visible and therefore the general public is less aware of the role of 2WVs in the deteriorating air quality of Delhi and other cities throughout India. Regardless of future innovations it is likely that the 2-stroke engine will continue to be a high emitter of hydrocarbons and carbon monoxide.

There are over 80,000 3WVs and over 1,800.000 2WVs in Delhi, nearly 97% of which are powered by gasoline 2-stroke engines. These vehicles are also high emitters of CO and PICs. Further, pollution checks conducted by the Transport Department of Delhi Government have revealed that in some instances the levels are so high that they go beyond the measurable scale of test instruments. In addition, it is widely believed that petrol is adulterated with kerosene, which results in emissions of thick black smoke, which is comprised primarily of carbon aerosol and PIC.

Development of an accurate emissions inventory for existing 2WVs and 3WVs in Delhi is essential to accurate estimation of the proportional impacts on current air quality and estimated reductions in pollutant levels that could reasonably be attributed to substitution of 2WV and 3WV EVs. Critical components of an emissions inventory are:

- Vehicle count, by type, make, model and year
- Estimated or measured emissions for each vehicle type, model and year, at idle and under load
- VMTs, idle time and speeds

With this data one can then estimate current emissions, and subtract those emissions out in proportion to offsets obtained by substituting 2 and 3-wheeled EVs.

Assumptions

Based on available data it is reasonable to assume 400 µg PM/m^3 to be representative of urban air quality in major cities of India. Further details of emission factors for specific makes and models of 2 and 3-wheelers is pending release of data developed by the Society of Indian Automobile Manufacturers (SIAM) as a result of the public emissions testing program conducted 11 November – 02 December 1999, in Delhi. Over 66,000 vehicles were tested. Data produced will be very useful in refining estimates of emissions offsets achievable through introduction of 2WVs and 3WVs.

Impacts

Impacts are based on net reductions or increases in air pollutants emitted, i.e. emissions decrease as conventional 2WV and 3WV are off the road while there is an increase from the power sector for vehicle charging of EVs. For 2WV and 3WV emissions the current emissions must be estimated, and then 10% and 50% subtracted from each category of vehicle based on assumed replacement at those percentages. These reductions are then offset by emissions from electric power generation. Impacts of emissions from 2º Pb smelting and battery production are not added in to the “mass balance”. Table 2.4 presents estimated vehicular emissions in Delhi, based on total emissions from all sources, and prorated by the stated percent contributions of 2 and 3-wheelers. Similarly, Table 2.5 presents the same estimates for all of India, using the estimated annual emissions per vehicle as derived from the Delhi calculations.

Increased power requirements have also been calculated, based on assumed VMTs per year multiplied by kWhrs required at the electric motor. KWhrs required at the plant, taking in to account thermal, transmission and distribution, rectification and charging losses were then calculated, and emissions per kWhr estimated.

Projected net changes in emissions of PM, NOX, CO, SO2 and CO2 are presented in Tables 2.-6.

Table 2.4
2 and 3-Wheeler 2-Stroke Engine Emission Estimates in Delhi, India, 1997

Vehicle Type (1)	Delhi (2)	PM (3) (metric tpy)	NO_x (4) (metric tpy)	CO (5)(6) (metric tpy)	SO2 (7) (metric tpy)	CO2 (8) (metric tpy)
2-Wheeler	1,800,000	8,213	329	32,850	261.16	1,656,970
3-Wheeler	80,000	1,168	47	9,344	37.14	235,658
Total	1,880,000	9,381	375	42,194	298.30	1,892,628

(1) All 2-stroke engines, assumes 25 km./day for 2-Wheelers, and 80km./day for 3-Wheelers
(2) GOI statistics
(3) 0.5 grams PM/km.traveled (WB URBAIR Project, Technical Paper 381, 1997)
(4) 0.02 grams NOx/km. Traveled (WB URBAIR Project, Technical Paper 381, 1997)
(5) 2 grams CO/km. Traveled (WB URBAIR Project, Technical Paper 381, 1997)
(6) 4 grams CO/km. traveled (WB URBAIR Project, Technical Paper 381, 1997)
(7) 0.0000159 kilograms SO2/km traveled (World Bank, Environmental Manual)
(8) 0.100881 kilograms CO2/km traveled (World Bank, Environmental Manual) See Appendix 1 for detailed methodology for CO2 estimation.

Results of the calculations for load demand in Delhi and resultant emissions, at 100% EV substitution are presented in Tables 2.5. The 100% value is then prorated to 10% and 50% substitution for subsequent calculations.

Table 2.5 Power Requirements for Battery Charging and Associated Emission Increases at 100% Fleet Conversion, Delhi,

Type	Delhi (1)	Annual MWhr. Required (1)(2)	PM (3)(4)	NOX (3)(4)	CO (3)(4)	SO2(3)(4)	CO2 (3)(4)
2-Wheeler	1,800,000	2,069,041	1,601	1,201	80	5,605	967,268
3-Wheeler	80,000	928,062	718	539	36	2,514	433,865
Total	1,880,000	2,997,103	2,320	1,740	116	8,119	1,401,134

(1) Assumes 25 km./day for 25,000,000 2-wheelers, and 80 km./day for 7,500,000 3-wheelers, 365 days/year,

(2) Power requirement of 0.026 kWhr./km traveled, 2-wheelers, and 0.082 kWhr./km traveled for 3-wheelers, NGM, personal correspondence, thermal efficiency of 30% at power plant, 20% losses on transmission and 14% loss on AC to DC conversion and the battery charging process

(3) Kg. of coal fired/yr = (MWhr/yr.) X (kg. coal/22,046Btu) X (3,413,000 Btu/MWhr) [= 154.8 X MWhr/yr.]

(4) From USEPA AP-42 Emissions Factors, "Medium Volatile Bituminous Coal. All values as mg/kg coal fired

Table 2.6. Projected Net Change in Emissions of PM, NO_X, CO, SO_2 and CO_2 as a Result of Conversion of 2 and 3-Wheeled Vehicles to Electric Power in Delhi. India (1)

% Conversion to Electric, by Type	PM (metric tpy)	NOx (metric tpy)	CO (metric tpy)	SO2 (metric tpy)	CO2 (metric tpy)
2-Wheeler					
10% Conversion	-661	87	-3,277	534	-68,970
50% Conversion	-3,306	436	-16,385	2,672	-344,851
100% Conversion	-6,611	873	-32,770	5,344	-689,702
3-Wheeler					
10% Conversion	-45	49	-931	248	19,821
50% Conversion	-225	246	-4,654	1,238	99,104
100% Conversion	-450	492	-9,308	2,477	198,207
Total					
10% Conversion	-706	136	-4,208	782	-49,149
50% Conversion	-3,530	682	-21,039	3,910	-245,747
100% Conversion	-7,061	1,365	-42,078	7,821	-491,495

(1) Negative numbers indicate net decrease, positive numbers indicate net increase

Emissions caused by coal mining and transport, and oil and gas extraction, refining, transfer and storage were not considered. Thus, while electricity's contribution to air quality is examined from generation to end-use consumption, vehicular impacts are considered only at the end use. ***This means that the environmental benefits of reducing petroleum fueled vehicles is underreported.***

3 Water Quality

Background and Baseline

Water quality will be a minor issue with respect to environmental impacts of substitution of 2WV and 3WV EVs. Primary positive impacts will be from reduced discharges of gasoline, oils and lubricants to the soil, runoff and surface water as might be attributed to the vehicles replaced by the 2 and 3-wheeled EVs. No data on amounts of gasoline, oil or lubricants lost per 2WV and 3WV is readily available, nor are the pathways of run-off, assimilation, biological degradation or resultant impacts on BOD and COD of surface waters known.

There will be negative secondary impacts in the form of increased acid deposition resulting from increased sulfate and nitrate formation from power plant emissions, and increased deposition of metal known to occur in Indian coal – including mercury. Water quality impacts can also be expected as a result of reclamation and secondary of plates, grids and terminals of the battery, 2º Pb smelting, and production of new batteries. Impacts will include acid runoff from loss or outright dumping of battery acid and battery case wash water, and Pb from wet scrubber liquids, particle formation and deposition, and runoff.

Therefore, at present the net benefit to water quality cannot be estimated.

Assumptions

No assumptions were made in the case of water quality impacts as the quality of receiving waters is highly variable and the data not readily available.

Impacts

Specific impacts were not calculated.

4 Solid Waste

4.1 Background and Baseline

Assuming complete recovery of Pb and reclamation of battery electrolyte solution , sulfuric acid (H_2SO_4), the only solid waste associated with introduction and use of 2WV and 3WV EVs should be the scrap battery casings and 2º lead smelter rotary furnace slag.

In larger recycling facilities and or 2º Pb smelters (not “backyard” operations where the battery case is split using a sledge hammer) and as described in more detail in Section 2.5, the tops of drained and washed battery casings are removed by cutting across just below the top using a bandsaw. It is further assumed that the recovered casings will be washed again, sorted by color, and chipped in to pellets for bagging and recycling of the high density polyethylene (HDPE) material in non-food applications. Recyclable polyvinyl chloride (PVC) will also be present, as it is used for insulating separator plates inside the battery.

If the plastics are not recovered and reused then it will add to the already immense environmental burden posed plastic wastes, shortage of approved landfills and the impacts of unapproved disposal methods such as illegal dumping and burning. Further, if the PVC is disposed of by burning then dioxins will be formed and emitted to the atmosphere.

Citing Delhi as an example, the quantity of plastic wastes generated in Delhi is estimated to be 300 mt per day. The problem pertaining to the management of plastic wastes is its non-biodegradability. The plastic waste reprocessed is about 1,000 mt per day, a substantial amount of which comes sources outside Delhi.

Even recycling can pose environmental problems, however. For example, a fire in a plastics storage area of Jwalapuri in June 1995 and the consequent gutting of the market demonstrated the hazards of the plastic recycling industry. Subsequent to the Jwalapuri incident, the Delhi Government constituted a fact-finding committee. Consequently, it was decided that the plastics waste market be shifted from Jwalapuri to Tikri Kalan. The potential for a disaster remains if excess materials are improperly stored. The situation is similar in most other major urban areas of India as well.

Disposal of slag is more problematic as it contains a mixture of other metals, including heavy metals. Proper landfill disposal (in a landfill that does not discharge leachate) must be assured.

Assumptions

The total mass of recyclable HDPE and PVC produced per year under any given scenario can be estimated in the following manner:

$$[(EV_2 \times B_{A1} \times BP_{M1}) + (EV_3 \times B_{A2} \times BP_{M2})]/10^6 \times E_R = P_{RA}$$

Where:

EV_2 = number of 2-wheeler EVs introduced (2.5 million at 10%, 12.5 million at 50%)

EV_3 = number of 3-wheeler EVs introduced 0.75 million at 10%, 3.75 million at 50%)

BA_2 = batteries purchased per year, per 2-wheeler (7.3)

BA_3 = batteries purchased per year, per 3-wheeler (4.2)

BP_{M2} = mass of HDPE and PVC per battery, as grams (2-wheeler size)

BP_{M3} = mass of HDPE and PVC per battery, as grams (3-wheeler size)

E_R = 1 – fraction of mass of HDPE and PVC lost in recovery process

P_{RA} = MT recyclable plastic recovered per year

Estimated HDPE and PVC content per battery is still on request from the battery manufacturers.

4.2 Impacts

Impacts on solid waste loadings in India should be minimal. In fact there should be a net reduction in emissions and effluents that would otherwise be expected from the increase in HDPE and PVC production for new batteries if the recovered plastics are Recycled.

Quantities of recyclable plastics generated will be calculated and stated in an addendum to this report after receipt of necessary data from the battery manufacturers.

5 Noise

5.1 Background and Baseline

Noise from 2WVs and 3WVs is highly variable and depends on the maintenance of the vehicle as well as condition of the muffler, vehicle speed and engine revolutions per minute (rpm). Impacts will also depend on the location, acoustics of the location, number of vehicles and presence of sound reflecting, blocking or absorbing structures.

Noise limits which must be met at the time of their manufacture, by various vehicles and various other common devices, are as shown in Table 2.7. Sound levels are expressed as decibels (dB) and A-weighted decibels (dBA, a weighting scale that approximates the sensitivity of the human ear as f(octave band))

As a lower limit one can assume that all 2 and 3-wheelers will comply with the Air (Prevention and Control of Pollution) Act, 1981. These limits should be used in addition to the ambient noise standards, as promulgated under the Environment (Protection) Act, 1986, and are as follows:

The Delhi Pollution Control Committee conducted noise surveys in Delhi from August to October, 1996 in different parts of Delhi. The analysis of primary and secondary data indicate the following:

- Three wheelers, trucks and motorcycles remain the main source or noise pollution on Delhi roads followed by generators in the residential, commercial and industrial locations.
- Fifteen of the forty-six residential locations had noise levels that were within the tolerable limits for over 90% of the day.
- Noise levels in all major commercial area exceed allowable limits, with Chandni Chowk being the loudest.
- Industrial areas by and large remained within the prescribed limits.
- Sensitive locations including silence zones and hospital areas, are alarmingly noisy.
- All major traffic corridors are very noisy with peaks occasionally exceed 100 dBA. Mahipalpur Crossing on NH-8 is the noisiest throughout the day, followed closely by Andrew's Ganj Crossing on Ring Road.

Table 2.7 Noise Limits at Time of Manufacture

Noise Source	Limit (as dBA)
Scooters, Motorcycles, 3-Wheelers	80
Passenger Cars	82
Passenger Commercial Vehicles up to 4 MT	85
Passenger or Commercial Vehicles above 4 MT and up to 12 MT	89
Passenger or Commercial Vehicles exceeding 12 MT	91
Window Air Conditioners of 1 to 1.5 ton	68
Air Coolers	60
Diesel Generators for Domestic Purposes	85-90
Refrigerators	46
Compactors(rollers) Front Loaders, Concrete Mixers, Cranes (Movables) Vibrators and Saws	75

It can also be assumed that the ultimate object is to attain the ambient noise standards, as presented in Table 2.8, which follows.

While regulation of loudness and use of horns, and improved traffic management would do much to alleviate excessive noise levels, it remains a fact that 2 and 3-wheelers are the primary sources of noise in Delhi and presumably all other major urban areas.

Table 2.8 Ambient Noise Standards, Environment Act, 1986

Area Type	Daytime Limit (dBA)	Nighttime Limit (dBA)
Industrial	75	70
Commercial	65	55
Residential	55	45
Silence Zone	50	40

As regard baseline noise levels, this is highly variable depending on location, but probably ranges from 80 to 90 dBA during daytime and from 60 to 90 dBA at night.

5.2 Assumptions

The dynamics of acoustics, and the variability in the vehicle population as a function of time, day and place, are too great to perform any meaningful modeling of noise reductions at specific locations resulting form introduction of electric powered 2 and 3-wheelers.

5.3 Impacts

Reductions in noise levels will be extremely difficult to calculate in the absence of additional field measurements and experimentation with live traffic. One means of estimating impacts of varying degrees of introduction of electric 2WVs and 3WVs at intersections and street corners would be for traffic police to stop traffic for no more than two minutes, during which time noise levels (both dBA and octave band) would be recorded for one minute, and then varying percentages of randomly selected 2 and 3-wheelers would be requested to turn their engines off. The percent of 2WVs and 3WVs turned off would simulate the same percentage of EVs in that specific sample. No such sampling has been conducted to date.

In any event, unless the population of 2WVs and 3WVs increases faster than the rate of introduction of 2WV and 3WV EVs, it is intuitive that noise levels would go down.

A simplistic calculation of net reduction in noise attributable to substitution of 2WVs and 3WVs at a busy intersection can be made as follows:

Assume 50 2-wheelers and 10 3-wheelers at essentially the same location.

Assume that each is emitting sound at 80 dBA (the legal limit), measured by convention, at 1 meter from the sound source.

Resultant dB = 10 x $\log_{10}$ (60 vehicles x $\log_{10}(10^{(80\ dB/10)})$ = 97.8 dB, at 1 meter from the virtual sound source

Attenuation of sound is in accordance with the inverse square law, i.e., the sound power level (SPL) is reduced by a factor of 1/distance^2. For ease of calculation, this is equivalent to a reduction of 6 dB with every doubling of distance. Therefore, the dB levels at 8 meters is reduced by 18 dB and would be 79.8 db.

Assume 10% substitution by 2WV and 3WV EVs. Substituting 54 vehicles for 60 in the previous equation the new sound level at 1 meter is 97.5 dB, and the resulting sound level at 8 meters now becomes 79.5 dB.

Assume 50% substitution by 2WV and 3WV EVs. Substituting 30 vehicles for 60 in the previous equation the new sound level at 1 meter is 94.8 dB, and the resulting sound level at 8 meters now becomes 76.8 dB.

While the difference in resulting dB at 10% and 50% substitution seems small (3 dB), note that dBs are a logarithmic function, and therefore a reduction of 3 dB is equivalent to halving the SPL – a significant reduction.

6 Lead-Acid Battery Industry

6.1 Background and Baseline

Lead-acid battery recycling in India presents opportunities for significantly improved environmental performance, but is presently plagued by a large uncontrolled segment of the industry comprised of backyard 2º Pb smelters that operate very inefficient processes with no emissions controls and that pose serious occupational and secondary exposure hazards to Pb fumes, dust, and process residues. Even the controlled segment of the 2º Pb smelting industry, made up of seven large plants and about forty smaller facilities, employs older technology with limited emissions controls. The Government of India, through a recent battery recycling initiative, is attempting to restrict the domestic and the potential future import market for Pb-acid batteries to licensed processors meeting minimum emissions standards. In 1997, fifty-five percent of 2º Pb smelting took place in backyard-type operations. The 2º Pb smelting process can be a relatively clean manufacturing operation with appropriate emission controls, worker safety procedures, and waste disposal. Furthermore, 2º Pb smelting is the only means of suitably dealing with Pb waste from batteries and other sources.

Primary Pb is also produced in India, though domestic reserves are limited. In 1997, of 44,000 metric tons of domestic production (primary and 2º Pb smelting), about a third was primary Pb. With a domestic demand of 87,000 MT of Pb in 1997 (75 percent of which is used in the production of Pb-acid batteries), India was a net importer of Pb and Pb concentrates. Due to the Basel Convention's ban on export/import of Pb waste, secondary Pb production is limited by supply. With a projected demand of 120,000 MT in 2001, and domestic capacity and supply of Pb and Pb waste limited (domestic production is projected to increase to 80,000 MT), India is considering lifting the Pb waste portion of the Basel Convention in concert with initiatives to improve the 2º Pb smelting industry.

2º Smelting of Pb-Acid Batteries

The 2º Pb smelting process, which would necessarily be employed to Pb batteries for domestic production of new batteries consists of: (1) breaking or bandsawing the tops off of Pb-acid batteries and separating the Pb bearing materials (plates, grids and terminals) from the other materials, including the plastic case material and battery acid, (2) melting Pb metal and reducing Pb compounds to Pb metal in the smelting furnace, and (3) refining and alloying the Pb to customer specifications.

The means by which batteries are collected and pre-processed (prior to smelting) can have a significant impact on environmental releases. In the US, batteries are typically received at the 2º smelter intact; the sulfuric acid is drained and neutralized; automated crushing of the battery is carried out to separate plastics from Pb; and the operation is covered so that Pb dust is not released. When the Pb waste is stored prior to smelting, it is covered or wetted to insure that additional fugitive Pb dust is not released. Proper separation of plastics and Pb is carried out to insure that organic air releases from the plastics (including dioxins) are not generated in the smelting process. Several reports of practices in the Indian 2º smelting industry suggest that the crushing and separation process is largely manual, posing hazards to workers and presenting the potential for fugitive releases of Pb dust and organic air emissions.

The vast majority of emissions, in both primary and 2º Pb processing, come from the smelting operation itself. Smelting is performed in reverberatory, blast, rotary, or electric smelting furnaces. Reverberatory and blast furnaces, are the most common types of smelting furnaces in the US, while Indian 2º smelting primarily relies upon rotary furnaces.

Blast, rotary, and electric furnaces produce a final slag that cannot be Recycled and that must be disposed of as a solid waste. This slag typically has a high content of heavy metals and in the US must be disposed of in an approved landfill as a hazardous waste.

Hazardous air pollutants are emitted from 2º Pb smelters as: (1) Process emissions contained in the primary exhaust of smelting furnaces, (2) process fugitive emissions associated with charging and tapping of smelting furnaces, and (3) fugitive dust emissions from Pb stockpiles and battery separation. Metal emissions from process sources are produced through the volatilization of the metals contained in the feed materials. Organic emissions from smelting furnaces result from incomplete combustion of organic-containing materials (coke, plastics, and hard rubber battery case material) in the furnace charge, as well as coke and other fuels used for combustion. All smelting furnaces that process broken batteries are potential sources of hydrochloric acid and chlorine emissions. Many used Pb-acid batteries contain polyvinyl chloride (PVC) plastic separators between the battery grids, although the use of PVC plastic as a separator material has been discontinued by most battery manufacturers. Combustion of PVC can Pb to the emission of dioxins. However, metal and acid emissions can be very effectively controlled through the use of baghouses and chemical scrubbing.

Estimates of Emissions from Primary and 2º Pb Smelting in India

Table 2.9 provides an estimate of particulate, Pb, and SO_2 emissions from primary and 2º Pb smelting for 1997 and a projection for 2000. The emission factors are based upon USEPA data for controlled and uncontrolled releases of process and fugitive emissions. Pb production data is based upon the 1999-2000 Annual Report from Indian Ministry of Mines and from a paper from the National Conference on Pb & Zinc Recycling, New Delhi, December 1998. Table 2.10 provides estimates of primary and 2º Pb smelting, and an estimate of official and backyard 2º smelting production. In 1997, production between the two was split 45 and 55%, respectively. With GOI initiatives to remove supply from the backyard smelters, it is assumed that the mix will shift to 75%/25% in 2000.

EPA emission factors are applied as follows: upper bound (worst case), and emission control factors are applied to the primary and organized 2º Pb smelter emissions. (While not all of these facilities have emissions controls, it is increasingly the case that emissions controls are required by the GOI. For example, Hindustan Zinc Limited recently shut-down a primary Pb smelting operation because the addition of required emissions controls was uneconomic given current depressed world Pb prices - it was cheaper to buy refined lead (Pb) on the world market than produce clean Pb domestically at this smelter.) Upper bound controlled factors are applied to the backyard 2º Pb smelting.

It should be considered that these "upper" bound USEPA emissions factors for US based facilities serve as lower bounds on Indian production, pending additional detailed research on the state of emission control technology at Indian smelters.

Table 2.9 Primary and 2º Pb Smelting in India, 1997 and 2000

Year	Total Production (MT)	Primary	2º	Large 2º	Backyard
1997	44604	15,604	29,000	13,050	15,950
2000	78500	38700	39800	29850	9950

Table 2.10 Estimates of Current Emissions from Primary and 2º Pb Production in India, (MT)

	1997			2000		
	Particulate	Pb	SO2	Particulate	Pb	SO2
Primary Pb Smelting	3,277	6,710	358,892	8,127	16,641	890,100
2º Pb Smelting: Process	3,334,144	1,120,676	877,250	2,133,977	706,052	547,250
2º Pb Smelting: Fugitive	249,110	6,090	0	181,250	4,350	0
Total (kgs)	3,586,531	1,133,476	1,236,142	2,323,354	727,043	1,437,350

The Ministry of Environment and Forests plans to introduce legislation to control the hazard associated with backyard smelting and unauthorized reprocessing of Pb in batteries. Pb is a toxic metal and reprocessing of old/used Pb acid batteries for recovery of Pb causes its emission in particulate and gaseous forms which is harmful.

According to sources in the Ministry, the legislation on the anvil is to channel the used Pb acid batteries which are one of the major sources of Pb. The stress is on seeing that recovery of Pb from scrap is done in an environmentally sound manner and in compliance with environmental standards. Consumers may not be able to dispose of used Pb acid battery by any other satisfactory means except giving it back to the authorized agents who collect it back on behalf of the manufacturer or importer.

As backyard smelters obtained their raw material through auction of old/used Pb acid batteries, the Ministry has also taken a decision recently that traders would not be allowed to participate in such auctions. Only such units which were actual users and enlisted with the Ministry should be allowed to participate in the auction with effect from December 31,1999.

The main features of the draft Legislation, Channelisation, Reprocessing and Disposal of used Pb acid batteries are:

- All manufacturers and importers of Pb acid batteries shall collect an equal number of used batteries back for every new battery sold. A phased approach for collection has been drawn up.
- Manufacturers of batteries shall buy re-cycled Pb for manufacture of new batteries.
- Manufacturers, importers and re-cyclers shall be responsible for creating awareness among public regarding hazards of unscientific reprocessing of Pb and advantages of collection of batteries by authorized agents
- It shall be the responsibility of the manufacturer and importer to send used batteries to re-cyclers registered with the Ministry of Environment and Forests.
- Dealers shall be responsible for collecting back the used batteries against new ones and give appropriate discount to the consumers in lieu of old ones.
- Manufacturers, importers and dealers shall file a quarterly return with State Pollution Control Board /Committee of their buy-backs and sale of Pb Acid Batteries
- Manufacturers shall be responsible for safe transportation of used batteries collected by the dealers to the registered re-cyclers.
- Registered recyclers shall reprocess these batteries and dispose of the waste generated in an environmentally sound manner.
- State Pollution Control Boards shall monitor the implementation of the rules.
- An annual statement on the collection scheme shall be sent to the Central Pollution Control Board (CPCB) by all the State Pollution Control Authorities.
- The CPCB shall compile and publish annually the data received on collection of batteries.

6.2 Assumptions

Based on assumed battery demand generated by replacement of 10% or 50% of the 2 and 3-wheeled vehicle population with equivalent EVs in India, it is estimated that 2º Pb smelting capacity must increase by from approximately 55,000 to 275,000 MT ton output per year. Presumably most of the additional material input to the 2º smelting process will be as Recycled Pb-acid batteries used by the new EVs.

Pb emissions from the 2º smelting industry are going down as a result of the shift from small-scale to large-scale smelters as mandated by government, and increased compliance and enforcement action.

6.3 Impacts

Estimated increases in Pb, particulate matter and sulfur dioxide emissions resulting from increased 2º Pb smelting and increased battery production are presented in Table 2.11.

It should be noted that this data represent only mass emissions, and are likely underestimates as USEPA emission factors for Pb and PM for controlled 2º smelters were used. Actual emissions may be much higher as control efficiencies of 99% or higher are achieved by 2º Pb smelters in US. SO2 emissions are based on uncontrolled estimates, though 80-99% control can be achieved by use of venturi or other wet scrubber systems.

As the locations and capacities of smelters and battery production factories, and the respective dispersion characteristics of their plumes are not known, it is not possible to estimate resulting impacts on ambient air quality

Table 2.11 **Pb, Particulate and Sulfur Dioxide Emission Increase as a Result of Increased Battery Demand Under 10% and 50% 2 and 3-Wheeled Vehicle Replacement Scenarios**

	Vehicles	Batteries/Yr. (1)	Total Pb Required, MT/Yr. (2)	Pb Emissions, MT/Yr. (3)	PM Emissions, MT/Yr. (4)	SO2 Emissions, MT/Yr. (5)
Total 2-Wheelers	25,000,000					
10% as EVS	2,500,000	18,250,000	41,063	75	593	1,109
50% as EVs	12,500,000	91,250,000	205,313	373	2,967	5,543
Total 3-Wheelers	7,500,000					
10% as EVs	750,000	3,128,571	14,079	14	110	380
50% as EVs	3,750,000	15,642,857	70,393	69	548	1,901
Total Vehicles at 10%	3,250,000	21,378,571	55,141	88	703	1,489
Total Vehicles at 50%	16,250,000	106,892,857	275,705	442	3,516	7,444

(1) Assumes 48 VDC System, 8 batteries/vehicle, 400 charge life (days) for Hawker motorcycle battery and 700 charge life for Trojan 3-wheeler batteries
(2) Assumes 2.25 kg.Pb/Hawker battery and 4.5 kg.Pb/Trojan battery
(3) Assume 0.15 kg.Pb emitted/MT smelted (controlled) and 3.75 kg.Pb/1000 units produced (uncontrolled) (USEPA AirChief 7.0)
(4) Assume 1.12 kg.PM emitted/MT smelted (controlled) and 30 kg.Pb/1000 units produced (uncontrolled) (USEPA AirChief 7.0)
(5) Assume 27 kg.SO2 emitted/MT smelted (controlled) and 0 kg.SO2/1000 units produced (uncontrolled) ((USEPA AirChief 7.0)

7 Health Effects

7.1 Epidemiological Impacts of Vehicular Emissions

The primary and most pressing reason for controlling emissions and reducing ambient loadings of air pollutants is their effect on human health. Inhalation of, or exposure to, fine particles (PM-2.5), oxides of nitrogen (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), hydrocarbons (HC), ozone (O_3), and metals are the primary causes of adverse health effects. Such effects result from both chronic and acute exposures; the chronic exposures have a cumulative effect over time, while acute exposures typically take a heavier toll among the young, old, and ill. Adverse health effects include premature or sudden death, as well as an increased incidence of chronic respiratory, coronary, and neurological disorders. The sources and the particular health effects are discussed below.

7.1.1 CARBON MONOXIDE (CO)[5]

Health effects - Carbon monoxide weakens the contractions of the heart, reducing the amount of blood pumped in the body and the oxygen available to the muscles and various organs. Fetuses, young infants, pregnant women, elderly people, and individuals with anemia or emphysema are more susceptible to the effects of CO. For these individuals, the effects are more pronounced when exposure takes place at high altitude locations, where oxygen concentration is lower. Carbon monoxide can affect the mental function, visual activity, and alertness in healthy individuals, even at relatively low concentrations.

7.1.2 SULFUR DIOXIDE (SO_2)

Health effects - SO2 can cause impairment of respiratory function, aggravation of existing respiratory disease (especially bronchitis), and a decrease in the ability of the lungs to clear foreign particles. It can also lead to increased mortality, especially if elevated levels of particulate matter (PM) are also present. Groups that appear most sensitive to the effects of SO2 include asthmatics and other individuals with hyperactive airways, and individuals with chronic obstructive lung or cardiovascular disease. Elderly people and children are also likely to be sensitive to SO2.

The presence of PM appears to aggravate the impact of SO2 pollution. Several studies of chronic effects have found that people living in areas with high PM and SO2 levels have a higher incidence of respiratory illnesses and symptoms than people living in areas without such a synergistic combination of pollutants.

[5] http://www.deq.state.la.us/assistance/educate/readdat6.htm

7.1.3 NITROGEN DIOXIDE (NO_2)

Health effects - individuals experience respiratory problems when exposed to high levels of NO2 for short durations (less than three hours). Asthmatics are especially sensitive, and changes in airway responsiveness have been observed in studies of exercising asthmatics exposed to relatively low levels of NO2. Several studies also show that chronic exposure to relatively low NO2 pollution levels may cause structural changes in the lungs of animals. Studies suggest that chronic exposure to NO2 could lead to adverse health effects in humans, but specific levels and durations have not yet been determined.

7.1.4 PARTICULATE MATTER (PM_{10})

Health effects - Particulate Matter (PM) represents a broad class of chemically diverse particles that range in size from molecular clusters of 0.005 microns to coarse particles of 50-100 microns in diameter. Also of concern are the sulfate and nitrate particles that are formed as a by-product of SO2 and NO2 emissions, primarily from fossil fuel-burning power plants and vehicle exhausts. In the US, the NAAQS was originally based on particles up to 25-45 m in size, termed "total suspended particles" (TSP). In 1987, the U.S. EPA replaced TSP with an indicator that includes only those particles smaller than 10 microns, termed PM_{10}. These smaller particles cause most of the adverse health effects because of their ability to penetrate deeply into the lungs. Ongoing health effects research has resulted in an additional standard for even smaller particles. EPA recently revised the PM standard to include $PM_{2.5}$ -- particulates smaller than 2.5 microns. The observed human health effects of PM include breathing and respiratory distress, aggravation of existing respiratory and cardiovascular disease, alterations in the body's defense system against inhaled materials and organisms, and damage to lung tissue. Groups that appear to be most sensitive to the effects of PM include individuals with chronic lung or cardiovascular disease, individuals with influenza, asthmatics, elderly people, and children.

7.2 Background and Baseline

The primary and most pressing reason for controlling emissions and reducing ambient loadings of air pollutants is their effect on human health. For this analysis, only the PM10 was considered as sufficient data did not exist for fully investigating the health effects of other pollutants. Ongoing tabulation and analysis of epidemiology, as morbidity (sickness)and mortality (death) is of extreme importance in providing the basis and levels for environmental controls. Epidemiology also provides a baseline and time series data set against which to estimate the effects of pollution control strategies.

Human health is impacted by all air pollutants inhaled, ingested or which come in contact with sensitive tissues such as the conjunctiva of the eye. To evaluate the incremental impact of vehicular emissions one must know the total level and exposure of all pollutants. Further, pollutants may act antagonistically, or on occasion in a positive manner (scrubbing of O_3 by NO to for NO_2). Once the total exposure is known, one can then subtract estimated reductions in exposure resulting from control measures (e.g., substitution of electric vehicles for some portion of those fueled by gasoline).

To estimate the impacts of introduction of EVs on urban human health, one must establish scenarios of introduction – i.e., rates of introduction, classes of vehicles displaced, geographic distribution of displaced vehicles, and resultant reductions in pollutant levels.

PM (particulate matter), PM-10 (PM of aerodynamic diameter < 10 microns) or more appropriately the fine or respirable fraction, PM-2.5, is an air pollutant that is a primary or contributing cause of premature death due to respiratory and or cardiovascular effects. The following section presents estimated reductions in PM resulting from replacement of 10, 50 and 100% of the 3-wheeler population with EVs. There are no PM emissions from electric EVs. Secondary emissions resulting from increased fuel combustion required to satisfy the incremental demand for battery recharge, from lead smelting and from battery lead-production are not considered as emissions and impacts will typically occur elsewhere. .

7.3 Assumptions

Reduction in excess deaths due to PM is then estimated by first estimating the reduction in ambient PM, by prorating ambient concentrations to emission reductions. Percent change in mortality, per 100 µg PM/m^3 increase (or decrease) is then applied to the total population of Delhi. The relationship is simplistically assumed to be linear, with no consideration of antagonistic effects from other covarying or independently parameters (heat, humidity, age or occupation). The maximum and minimum excess deaths are estimated based on prior maximum and minimum PM values.

Examining the impacts in the test case of Delhi, PM emissions are assumed to be approximately 115,700 tons/year in 2000, again for Delhi. Vehicular emissions are assumed to be approximately 25,000 tons per year, with approximately 40% of that amount emitted by 2WVs and 3WVs. Based on the work of Cropper, et.al., the estimated percent change in mortality per 100 µg PM/m^3 increase in PM is 2.3% (total non-trauma), 4.3% (cardiovascular) and 3.1% (respiratory), for a total of 9.7% increase due to all three causes per 100ug/m3 increase in PM. The estimated reduction in PM resulting from replacement of 10, 50 and 100% of the 2WV and 3WV vehicle population with equivalent EVs is presented in Section 2s.

The work of Bart Ostro was used to develop estimates of health impacts[6]. These include restricted activity days (RADS), emergency room visits (ERI), Respiratory Hospital Admissions (RHA), Respiratory Symptom Days (RSD), chronic Bronchitis (CB) and Lower Respiratory Illness in Children (LRI). RAD includes days spent in bed, days missed from work, and other days when normal activities are restricted due to illness, even if medical attention is not required. Respiratory Hospitals Admissions (RHA) represents the number of visits to the hospitals as a result of pollution and this is on a patient basis.

[6] Source: Ostro, Bart: "The effects of air pollution and morbidity revisited", Jounral of Environmental Economics and Management 14:87-98

7.3.1 Impacts

Table 2.12 presents the estimated health impacts of reducing PM10 concentrations by 16 micrograms per cubic meter. It further assumes that only 60% of Delhi's 14.3 million population are at risk.

Table 2.12
Health Impacts of Improved Air Quality
Reductions in Morbidity Measures

Restricted Activity Days (RAD)	days	4,736,160
Emergency Room Visits (ERI)	visits	19,356
Respiratory Hospital Admissions (RHA)	visits	988
Respiratory Symptom Days (RSD)	days	15,073,344
Chronic Bronchitis (CB)	no. cases	5,041
Lower Respiratory Illness in Children (LRI)	no. cases	139,202

Assumes 10% Penetration of EVs in Delhi

Table 2.12 shows, for example, that a 16 μm/cm reduction in PM will result in 4.7 million fewer restricted activity days or 5 thousand fewer cases of chronic bronchitis on an annual basis. Note that this does not include the health impacts of reduced SO2, NOx, or CO. Delhi is cited has having 12 times the national average of respiratory disease, so this reduction is significant.

Estimated number of premature deaths avoided, by age group, as a result of replacement of 10, 50 and 100%of the 2WV and 3WV fleet by EVs is presented as Table 2.13. This clearly shows the link between air quality and premature mortality. Even at a 10% reduction in ambient PM translates into 1,385 fewer premature deaths.

Table 2.13 Estimated Reduction in Number of Premature Deaths in Delhi, by Age Group, as a Result of Replacing 10%, 50% and 100% of the 2-Cycle 2-Wheeler and 3-Wheeler Fleet with Electric-Powered Equivalents

Age Group	Reduction in Deaths/Year, per 100mg/m^3 Reduction in Ambient PM (1)	Reduction in Deaths/Year at 10% Substitution by EVs (2) (3) (16 mg/m^3 reduction)	Reduction in Deaths/Year at 50% Substitution by EVs (2) (3) (80 mg/m^3 reduction)	Reduction in Deaths/Year at 100% Substitution by EVs (2) (3) (160 mg/m^3 reduction)
0-4	278	44	220	440
5-14	63	10	50	100
15-44	651	104	520	1,040
45-64	268	43	215	430
65 and over	125	20	100	200
Total	1,385	221	1,105	2,210

But the Based on Table 8., and 1991 population figures "The Health Effects of Air Pollution in Delhi, India", World Bank PRD Working Paper 1860, M. Cropper, et. al., 12/97.

Assumes 40% of PM emissions are from 2-wheelers and 3-wheelers, "Emissions and Control Options for Two-Stroke Engines in India", N.V. Iyer, et. al., Workshop on Pollution form Motorcycles: Issues and Options, The World Bank, 3/9/2000

(1) Prorated against assumed ambient loading of 400 μg PM/m^3

8 Conclusions

India's urban areas are suffering increasing degradation of air quality and it is mostly due to the phenomenal growth in vehicles. Urban India is desperate for cleaner means of transport. USAID's EV project can provide the catalyst and prototype for this. Our analysis indicates that there will be a significant improvement in urban environmental quality as a result of conversions. A 10% conversion of Delhi's 2WVs and 3WVs would reduce all air borne pollutants in the urban airshed with only a minor increase in SOx and NOx pollution in rural areas. Even if conversion is limited to 10%, this is equivalent to a reduction of 16 micrograms of PM which translates significant health impacts as shown above.

This environmental analysis does not investigate the economic viability of 10%, 50% or 100% penetration of EVs. Environment and economics are not wholly separable. Even a slight penetration of Evs demonstrated significant environmental gains and these environmental gains translate into economic gains as less resources are diverted to health care and formally sick people do not withdraw from the workforce but continue to contribute to economic activity. Thus, the environmental impacts will have a positive impact on the economics of EVs.

9 Recommendations

The environmental impacts of EVs are both greater and more positive than has been demonstrated in this study. This is due to data limitations in performing the analysis. It is recommended that additional effort be place in gathering local economic data so that health effects can be monetized and that additional data be collected in the environmental pollution from gasoline service stations and bulk storage facilities. Other recommendations include:

- Improve the quality and accessibility of data required to continue and improve estimates of net changes in environment and health effects.
- Specify indicators that should be tracked in determining net results of introduction of EVs. Perform a realistic ground-truthing of (a) the interest of the affected sector of the public in such technology and more importantly, (b) the affected, and presumably targeted, sector's ability and willingness to pay.
- Also examine the reality of infrastructure required to manage the volume of batteries required, exchange of batteries and the demands and logistics of recharging.

10 APPENDIX 1

10.1 Estimating CO2 Emissions

Estimates of MT CO_2 /year are based on the assumption that almost all C in the coal is converted to CO_2. For the purpose of estimation it is also assumed that one pound of bituminous coal has a C content of 80%, and a heat content of 12,500 Btu. Tons of coal required for the total power output stated, CO2/lb coal, and finally MT CO2/year at 100% conversion to EV are then calculated by the following equation:

Tons coal/year = (X kWhr/year)x(3413 Btu/kWhr)x(lb. Coal/12,500 Btu)x(ton/2,000 lb)

Lb CO_2/ton coal burned = %C x 72.6 (USEPA)

Then, lb CO_2/ton coal is multiplied by tons coal burned/year to arrive at tons CO_2 emitted per year.

The calculation, which can be reduced to (X kWhr/yr) x (3.5966×10^{-4}) = MT CO2/year, is then repeated for the different kWhr/year requirements. A very slight difference in calculated results occurs due to round off error in the reduced conversion factor.

Estimation of Emissions (GHG) for Two and Three –Wheelers in Delhi

Introduction
India has an opportunity to make a positive contribution to the country's environment and, what might seem counterintuitive to some, climate change by replacing liquid fueled rickshaws (three-wheelers) and scooters (two-wheelers) with electric ones. The purpose of this brief is to report the results of modeling the life cycle of both alternatives. Lifecycle emissions modeling considers the full chain of resource and energy use from when the energy resource is mined, transported, transformed and finally consumed.

The estimation of GHG emissions from two & three-wheelers is based on an assumption that all two & three wheelers in Delhi are converted to electric powered vehicles. Lifecycle GHG emissions from all of the conventional vehicles including two and three-wheelers and the resulting emissions from conversion of all conventional vehicles to electricity are calculated using the EM Model[1]. In Delhi alone, there are approximately 1.8 million scooters (mostly 2 stroke) and 80 thousand rickshaws. Significant sources of GHG emissions, the conventional vehicles are also major contributors to deteriorating urban air and noise pollution in Delhi. To address these issues USAID has embarked on a technology transfer and commercialization project that will replace these vehicles with electric ones. This program has the potential of reducing significant vehicular pollution in urban areas since electric vehicles have zero tailpipe emissions.

The EM Model (EM)

This analysis uses the World Bank's Environmental Manual (EM).

> *"The 'Environmental Manual for Power Development' (EM in short) is a WINDOWS-based computerized tool for the inclusion of environmental and cost data into the decision-making process of Development Agencies regarding energy projects.*
>
> *The software was developed by GTZ with scientific support from Oeko-Institut. It is part of a multilateral project on environmental management, coordinated by the World Bank with contribution from BMZ, BAWI, DGIS, GTZ, ODA, World Bank.*
>
> *The EM software can analyze and compare airborne and greenhouse gas emissions, solid wastes, and land use, as well as internal and external costs associated with the investment and operation of all kinds of energy technologies, including their life-cycles*
>
> *The EM comes with a generic database for energy technologies in developing countries, and covers*
> ** all fossil-fueled electricity generation and heating systems,*
> ** cogenerators,*
> ** renewable energies (for electricity and/or heat),*
> ** energy efficiency (demand-side management) technologies,*

[1] GTZ-World Bank

** and nuclear power systems, as well as*
** data for 'upstream' activities like mining, fuel benefication, transport, and*
** for emission control systems like flue-gas desulfurization, ESP, SCR, etc.”*[2]

At each possible step, the EM model has been altered to reflect actual Indian conditions. For example, the coal power plant has been given an efficiency of 27%, reflecting that of the Badarpur plant.[3] Transmission & Distribution (T&D) loses have been set to 22.8 percent. Indian data came from two sources – the EM Indian database and our own research and data gathering. All the assumptions including emission factors for conventional vehicles are provided in Appendix. Table 1 represents the primary basis for determining the emission results from each process.

Table 1. Vehicle Operating Characteristics

	2-Wheeler	3-Wheeler
No. of vehicles in Delhi	1,800,000	80,000
No. of days per year of driving	330	300
Travel (km/day)	25	80
Electricity consumption for an EV (KWh/km)	0.026	0.065
Energy consumption for 2-Stroke vehicles (mj/km)	0.906	1.39
Average annual distance traveled per vehicle (km)	8,250	24,000
Total distance traveled for all vehicles per year (million km)	14,850	1,920
Total Electricity required to operate all vehicles per year (‘000 MWh)	386.1	124.8
Total petrol consumption for all vehicles (million liters)	386.72	76.8

Electric Powered Scooters and Rickshaws

There are various processes during the generation, transmission and distribution of electricity to power each electric vehicle. Each process has its own link of resource and energy use. Thus, CO_2 equivalent emissions at the end of each process are calculated to obtain the aggregate emissions for electric vehicles. The process linking the mining of coal to supply of power to electric vehicles is partially illustrated in **Figure 1**. The following section provides specific information regarding Delhi’s electric power supply.

- **Delhi’s Power Supply for Electric Vehicles**

Majority of Delhi’s power need comes from coal-fired power plants. While Delhi’s generation mix varies (Table 2), to be conservative it is assumed that all the power for electric driven vehicles are supplied from a marginal coal fired power plant. The assumption is based on conservative estimates since the majority of CO2 emissions is generated from coal fired power plants. The Badarpur plant in Delhi is used as a representative marginal for Delhi’s power supply for this study because of its sheer size and readily available data. The Badarpur plant has

[2] http://www.oeko.de/service/em/
[3] Badarpur Plant is owned by NTPC and is located approximately 50km outside of Delhi.

720MW of generating capacity with an average thermal efficiency of 27%. Coal for the power plant is transported from Jharia Coal field in Jharkhand (formerly the state of Bihar), which lies 1200 km east of Delhi. The plant uses E and F type coal for its power supply. The characteristics of Jaharia coal are given in Table 3 below. Based on information provided by Indian Railway, it is assumed coal is transported using diesel locomotives from the coalmine to the power plant. For this specific plant, the coal is washed before transport.[4] The emissions rates of diesel locomotives for transportation of coal are based on EM India data provided by TATA Energy Research Institute.

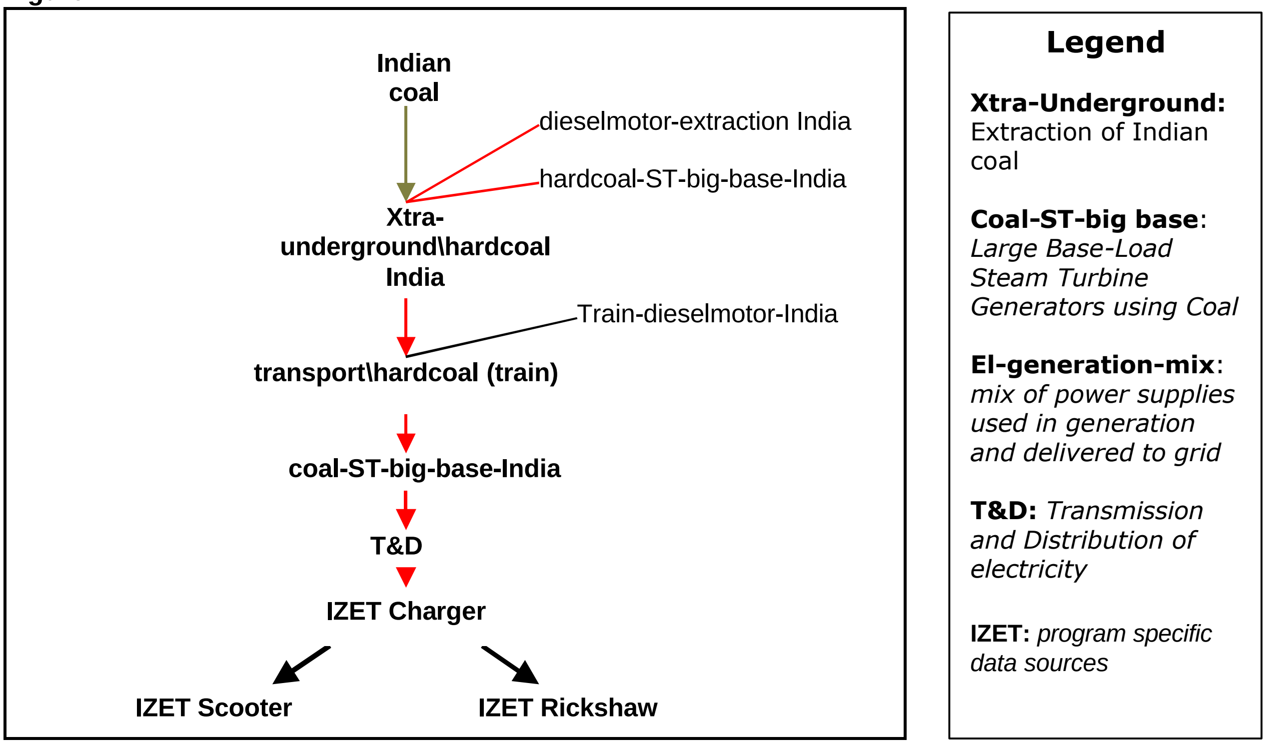
Table 2: Generation Mix for Delhi

Power Source	%
Coal	71
Natural Gas	15
Hydro	10
Nuclear	4

Source: Delhi Vidyut Board, 2001

It is assumed that there is 22.8% loss of power during transmission and distribution (T&D) process from the power plant to a battery charging station.[5] Apart from T&D losses, EV industry assesses an additional 32-34% loss of power during charging and AC to DC conversion process, which is factored in this study.[6]

Figure 1



[4] The resulting emission from energy use of the coal washing process is not factored into the study.
[5] EM India Database
[6] Personal interview with design engineers from New Generation Motors (NGM).

Table 3. Chemical Composition of Jaharia Coal (%)

Coal Type (Grade)	Carbon	Hydrogen	Sulfur	Nitrogen	Ash Content	Moisture
E	37.9	2.4	0.53	0.8	41.7	7.5
F	44.47	3.37	0.35	0.99	32.9	8.4
Average	**41.185**	**2.885**	**0.44**	**0.895**	**37.3**	**7.95**

Source: Ohio Supercomputing Center
Note: The numbers do not add up to 100% due to small presence of other chemicals/materials

The annual emissions of GHG that would result from converting all of Delhi's 1.8 million two-wheelers and 80,000 three – wheelers are given in Table 4.

Table 4 Annual Emissions Resulting from the use of Electric Powered Vehicles

	CO_2 Tons	CH_4 Tons	N_2O Tons	CO_2 Equivalent Tons (1)	CO2 Equivalent g/Km
Electricity – Scooter					
Vehicles	439,200	26	17	444,900	
Other Processes	23,220	2,101	1	67,555	
Total	462,420	2,127	18	512,455	**32**
Electricity – Rickshaw					
Vehicles	121,200	11	6.49	123,400	
Other Processes	6618	578	0.19	18,817	
Total	127,800	589	7	142,200	**67**
Total from Scooters and Rickshaws					
Vehicles	577,700	36	24	585,900	
Other Process	30,784	2,763	2	89,083	
Total	608,484	2,799	26	674,983	

Source: EM IZET Analysis

(1) Greenhouse gases are not all equal in terms of their radiative forcing and lifetime in the atmosphere, meaning that some gases are stronger than others. "To calculate the sum of the effects to the global warming, one can define mass-based weighting factors which describe the equivalent amount of CO2 which has the same radiative forcing effect over the same time horizon[7]." The 100 year CO2 equivalence factors for methane and N2O are 21 and 310 respectively.

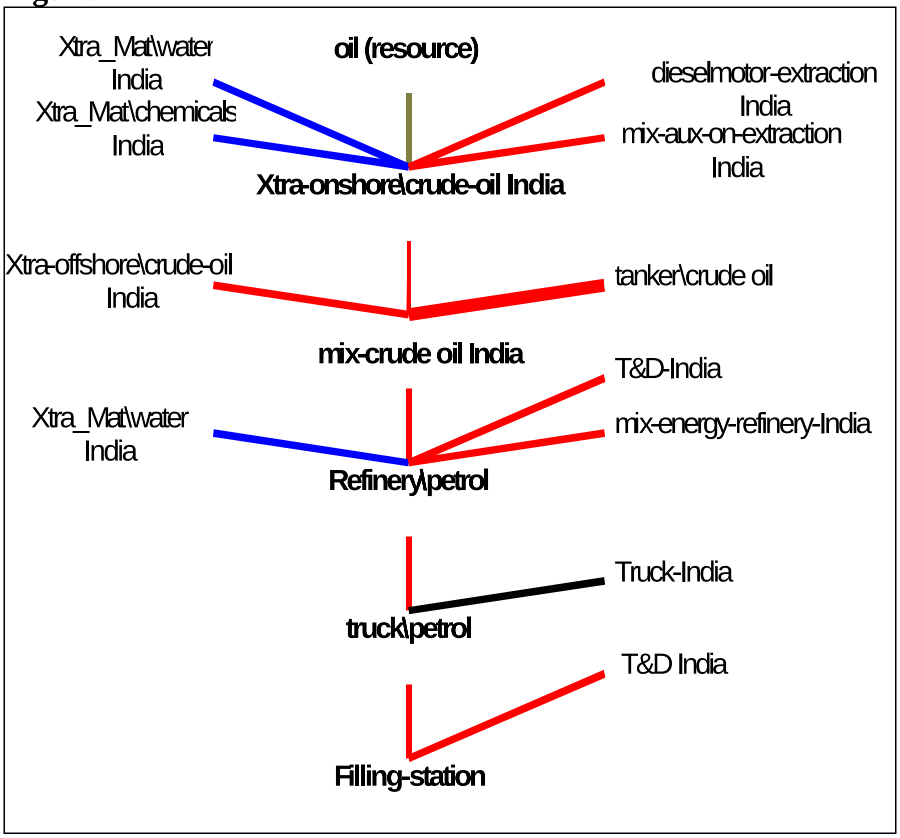
Liquid Fueled Scooters and Rickshaws

Emissions and environmental impacts of these vehicles are not limited to what escapes from the tailpipes of these vehicles. Figure 2 graphically portrays the "energy chain" for liquid fueled vehicles. The most immediate link in the chain is the local service station. Energy is consumed to run the pumps and light the station. Petroleum leaks from underground storage tanks and evaporates during fueling. These sources plus on-board evaporation amount to losses of up to 5

[7] Quoted from the EM Model Documentation (c) by GTZ + Oeko-Institut 1995

percent[8]. Fuel is brought to stations on trucks from bulk storage. Again, energy is used and pollution is emitted. The bulk storage is served by pipeline from the refinery, which is itself, supplied crude oil by a pipeline.

Figure 2



Legends

diesel motor auxiliary: *On-site diesel power generators* (used in extraction)
coal-ST-big base: *coal-derived electric power plants*
Xtra-onshore crude-oil: *Extraction of onshore crude oil*
Xtra_Mat\water: Materials and water used during *Extraction of oil*
train-diesel motor: *train transport powered by diesel motor*
nix-aux-on-extraction: *Auxiliary power used during extraction process*
Xtra-offshore crude-oil: *Extraction of offshore crude oil*
T&D India: *Electricity Transmission and Distribution process*

- **Delhi's Fuel Supply for Conventional Vehicles**

Various reports suggest that the majority of crude oil for petrol consumed in Delhi is supplied from Salaya Port (mother station) in western state of Gujarat. The fuel is then transported via pipelines to refineries (Mathura and Panipat) that supply petrol to Delhi. Both refineries are located within 90 km of Delhi. Table 5 provides additional information on refineries and processed fuel. The distance between the mother station and the refineries are approximately 1,350 km. The processed fuel is transported to bulk terminals via tanker trucks and freight trains, which is then transported to Delhi's 241 service stations via tanker trucks.

Table 5 Characteristics of Refineries

Operating Efficiency (%)	95%
Total Capacity (MMT)	27
Operating Time	8000 hours/year
Process Petrol Type	Octane 87

Source: Reliance India, Indian Oil and EM Data for India

[8] While an important source of emissions, they have not been included in our calculation.

The Results:
The annual CO_2 equivalent emissions from the liquid fuel processes of the conventional two and three-wheelers are presented in Table 6.

Table 6. Annual Emissions Resulting from the use of Conventional Vehicles

	CO2 Tons	CH_4 Tons	N_2O Tons	CO_2 Equivalents Tons (2)	CO2 Equivalent g/Km
Liquid Fuels – Scooters					
Vehicles	960,600	11,178	30	1,205,000	
Other process	158,100	1,361	3	187,600	
Total	1,118,700	12,539	33	1,392,600	**85**
Liquid Fuels – Rickshaws					
Vehicles	187,700	1,426	4	218,800	
Other process	31,484	271	1	3,736	
Total	219,184	1,697	5	222,136	**105**
Total from Scooters and Rickshaws					
Vehicles	1,148,300	12604	34	1,423,800	
Other process	189,584	1632	4	191,336	
Total	1,337,884	14236	38	1,615,136	

Source: EM IZET Analysis

(2) Greenhouse gases are not all equal in terms of their radiative forcing and lifetime in the atmosphere, meaning that some gases are stronger than others. "To calculate the sum of the effects to the global warming, one can define mass-based weighting factors which describe the equivalent amount of CO_2 which has the same radiative forcing effect over the same time horizon[9]." The 100-year CO_2 equivalence factors for methane and N_2O are 21 and 310 respectively.

Future Emissions Scenario

Table 7 provides the overall emissions avoided each year by replacing conventional two & three -wheelers with electric vehicles. The table also provides total CO_2 equivalent emissions avoided for next 10 years from Delhi's transport sector. However, the table does not assume growth in number of vehicles or technology/efficiency improvement over the years on either side of the fuel chain.

[9] Quoted from the EM Model Documentation (c) by GTZ + Oeko-Institut 1995

Table 7. CO_2 Emissions Equivalent/Platform/Energy Source (Tons)

	Emissions from Petrol		Emissions from Coal		Difference due to EVs	
	2-W [(a)]	3-W [(b)]	2-W [(c)]	3-W [(d)]	2-W [(a-c)]	3-W [(b-d)]
From Vehicles	1,205,000	218,800	444,900	123,400	760,100	95,400
From Other Processes	187,600	3,736	67,555	18,817	120,045	(15,018)
Total	1,392,600	222,536	512,455	142,200	880,145	80,336
Total CO_2 equivalent emissions avoided each year by converting all the conventional scooters and rickshaws to electric powered ones in Delhi					**960,481**	
Total /CO_2 emission avoided in next ten years (x10) (The model does not assume growth in number of vehicles and technology improvement over the years on either side of the fuel chain)					**9,604,810**	

Validating IZET Results

Above results indicate that converting all of Delhi's conventional two and three – wheelers will avoid approximately 1 million tons of CO_2 equivalent GHG emissions each year. In order to validate the above findings, the results (g/km) have been compared with similar studies recently carried out by various entities. Table 8 compares the results of this effort with a study carried out by the Pew Center[10] and Bajaj Auto Limited for two & three wheelers respectively.

Table 8 Emissions of CO2 Equivalent in g/km

	Pew Center [1]	Bajaj[1]	USAID/IZET
Petrol Scooter	**118**	**N/A**	**85**
Electric Scooter	**51**	**N/A**	**32**
Petrol Rickshaw	**N/A**	**118**	**105**
Electric Rickshaw	**N/A**	**90**	**67**

[1] Pew Center assumes average driving distance of 9,438 km/vehicle for 1,568,000 2-wheelers in Delhi. Pew Center results are based on the Lifecycle Environmental Model (LEM) developed by Dr. Mark Delluchi of University of California, Davis. Bajaj numbers are calculated using the GREET model developed by US DOE. Bajaj assumes an average driving distance of 42,000 km/year/vehicle for Delhi's 80,000 3-wheelers.

[10] Transportation in Developing Countries -Greenhouse Gas Scenario for Delhi, India, Pew Center on Global Climate Change, May 2001

Conclusion:

Considering the annual emissions of GHG avoided from converting Delhi's two-stroke two & three – wheelers to electric powered vehicles, India will be taking a major step towards significant GHG emissions reduction. Similarly, the conversion of conventional vehicles to electric powered vehicles will also contribute towards the reduction of urban air pollution, which is costing India billion's of U.S. dollars per year due to the deteriorating human health of its citizens from respiratory diseases. In conclusion, the electric two & three-wheelers in Delhi seem to be an environmentally win-win proposition for India.

Appendix 1

Fuel and Refinery Data	
Gasoline demand for 2 & 3 Wheelers in Delhi (gallons)	137679704.3
Delhi's overall demand (gallons)	121750000
No of filling stations in Delhi (1997)	241
Average loss at filling stations (evaporation, fugitive emissions, loading, leakage, etc.) %	5
Average efficiency of Indian refineries	93
No. of refineries serving Delhi	2
Mathura Refinery is located northeast of Delhi	
Panipat Refinery is located southwest of Delhi	
Distance to Mathura Refinery form Delhi (Km)	90
Distance to Panipat Refinery form Delhi (Km)	60
The crude oil is transported from Salaya station in Gujrat using pipelines	
Distance from Salaya to Mathura (Km)	1350
Distance from Salaya to Panipat (Km)	1180
Chemical Composition of Indian Gasoline (%)	
Carbon	91
Benzene	0.9
Sulfur	1
Hydrogen	3
Lead	0.001
Phosphorus	0.1
Others	
Electricity Data	
Total Capacity of Delhi (MW)	648
Access to total installed capacity (MW)	3109
(Delhi obtains 81% of its demand from outside source)	
Electricity source 71% Coal, 15% Gas, 10% Hydro, 4% Nuclear	
Electricity supply 400 KV lines (Km)	72
T&D Loss (technical only)	22.8%
Average power plant efficiency (since 81% of Delhi's electricity demand is out sourced)	30%
Types of Power Plants in Delhi	
1 Gas Turbine (MW)	265
2 Coal (MW) (IP Station and Rajghat Power Plants)	382.5
Coal per unit of electricity (Kg/Kwh)	0.77
Badarpur Power Station (NTPC) - *used as representative power plant for Delhi's coal based power source*	
Capacity (MW)	720
Energy Source 100% Coal from Jharia Coal Field*	
Power Plant Efficiency (%)	27
Distance between Jharia Coal Field and the Badarpur plant (Km)	1200
Fuel consumption of diesel locomotive per ton of load (mj/tons-km)	0.43

Emission of diesel locomotive (g/km) based upon capacity for 100t of freight and lifetime of 15 years of driving distance of 200,000 km/year. Approximate weight of 3 tons of steel per tons of transport capacity.	
CO	15.00
PM	3.00
CH4	0.50
NOx	0.05
NO2	10.00
VOC	2.10
Fuel Consumption of Diesel Trucks in (mj/km) - for transport of fuel	2.10
Emission of diesel trucks (g/km)	
NOx	3.00
PM	0.14
CO	1.00
CH4	0.00
VOC	0.60
Chemical Composition of Average Indian Coal	
Ash (%)	47
Carbon (%)	37.69
Hydrogen (%)	2.66
Nitrogen (%)	1.07
Oxygen (%)	5.78
Sulfur (%)	0.8

Emissions from Conventional Vehicles (two-stroke)	**2-W**	**3-W**
PM g/Km	0.5	0.5
CO g/km	2	4
SO2 g/km	0.0159	0.0159
NOx g/km	0.02	0.02

Source: WB URBAIR Project.

References:

India State Electricity Board Report, New Delhi, India 2001

Ministry of Environment and Forest, New Delhi, India

Modeling Anthropogenic Emissions from Energy Activities in India: Generation and Source Characterization, Ohio Supercomputing Center, Columbus, Ohio (***www.osc.edu/research//pcrm/emissions/index.shtml***)

Bajaj Auto Limited, Pune, India

New Generation Motors, Ashburn, VA

Air Emissions Impacts - Electric Vehicles

A collaborative effort between Ahmedabad Electricity Company

and

USAID/India

June 2002

Contract: LAG-I-00-98-00006-00, Task Order 7
Prime Contractor: Nexant, Inc

Introduction

Ahmedabad Electric Corporation (AEC) and USAID/India agreed to collaborate on assessing the emissions impact of replacing conventional two and three wheelers with electric driven vehicles in AEC's service area. AEC is currently operating a fleet of electric three-wheelers for their internal use. They have an interest in determining the effect on the ambient air quality by replacing conventional vehicles with electric driven units. USAID/India has an interest in alternative technology transport options and also in measuring the effect on air emissions by replacing conventional vehicles with electric driven units. In addition, AEC requested USAID to carry out the air emissions analysis of its electricity generating units (C, DEF and G) using different fuel types using existing operating condition. The purpose of this exercise is to assist AEC in determining cleaner fuel for its generating units. The results from Units C and DEF are provided in Appendix 3. Similarly, the results from the Unit G are included in Appendix 4.

AEC provided the operational characteristics of their generation system and the conventional two and three-wheeler use profile in Ahmedabad to analyze air emissions from recharging of electric vehicles and driving two-stroke two & three-wheeler conventional vehicles in Ahmedabad. Similarly, USAID/India provided the information obtained from an on-going effort, Indian Zero Emissions Transportation Program, and made arrangements for the data to be assessed.

This study is carried out using lifecycle emissions modeling. Lifecycle emissions modeling considers the full chain of resource and energy use - when the energy resource is mined, transported, transformed, and finally consumed. Lifecycle emissions from conventional two and three-wheelers and the resulting emissions from converting conventional vehicles to electric driven vehicles are calculated using the World Bank's Environmental Manual (EM) Model[1]. Using the information provided by AEC, baselines for air emissions from conventional vehicles and AEC's generation system have been developed. The baseline represents what would occur in the absence of electric vehicles (EV). To quantify EV impacts, two scenarios of EV market penetration are modeled, with market shares of 10% and 40% for three and two-wheel vehicles. In each scenario there is a net reduction in air emissions from per unit of electricity generation at AEC's Unit C.

Air Emissions Per unit of MWH generation and percentage change

	SO2		NOx		PM		CO		CO2 Equivalent	
	Tons	% Change	Tons	% Change	Tons	% Change	Tons	% Change	Tons	% Change
Baseline	0.0059	NA	0.0070	NA	0.0053	NA	0.0019	NA	0.0950	NA
Additional load of 10% EVs	0.0052	10.6330	0.0062	10.6310	0.0047	10.6350	0.0017	10.4456	0.0851	10.4131

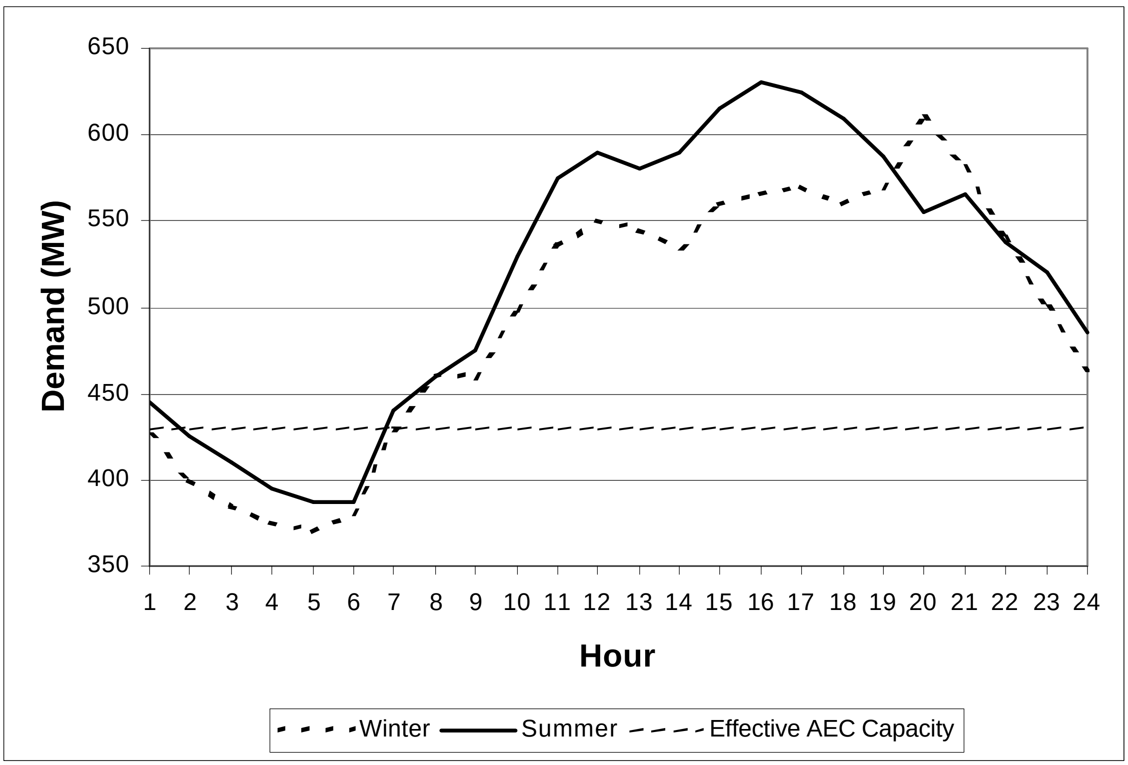
[1] GTZ-World Bank

	SO2		NOx		PM		CO		CO2 Equivalent	
	Tons	% Change	Tons	% Change	Tons	% Change	Tons	% Change	Tons	% Change
Additional load of 40% EVs	0.0050	15.1567	0.0059	15.1590	0.0045	15.1549	0.0016	15.3424	0.0804	15.3742

Characteristics of AEC's System

AEC provided typical daily system demand curves for the summer and winter seasons in 2000. These curves are shown in **Figure 1**.

Figure 1: Typical Daily Demand Curves, 2000



Source: Ahmedabad Electricity Company

AEC operates five generating stations: three 110-MW coal plants, one 60-MW coal plant, and a 100-MW combined cycle combustion turbine plant that can operate on either natural gas or fuel oil. Currently, the turbine is operated at 40 MW of capacity due to limited fuel availability. AEC's total installed capacity is 490 MW, and its effective operating capacity is 430 MW. AEC is operating near its maximum output currently. As shown in the demand curves in Figure 1, there are parts of the day when the system demand exceeds AEC's capacity. During these times, AEC purchases additional power from the Gujarat Electricity Board (GEB).

The following table presents generation and fuel consumption statistics for AEC's plants in 2000. Note that the generation values shown represent net generation, which equals total generation minus on-site auxiliary consumption. Capacity factors and heat rates are based on this net generation.

Table 1: AEC System Generation and Fuel Consumption, 2000

	Station C	Station D	Station E	Station F	Station G	Total
Fuel	Coal	Coal	Coal	Coal	Gas/oil	
Installed capacity (MW)	60	110	110	110	100	490
Net generation (GWh)	357	696	713	768	581	3,115
Capacity factor	68%	72%	74%	80%	66%	73%
Fuel consumption						
Coal (1000s metric ton)	284	364	378	404	N/A	1,430
Gas (1000s m^3)	N/A	N/A	N/A	N/A	86,300	86,300
HSD/SKO (kL)	N/A	N/A	N/A	N/A	48,600	48,600
Avg. heat rate (kcal/kWh)	4,301	2,998	2,979	2,956	2,119	2,969

Source: Ahmedabad Electricity Company

AEC advises the final plant to be dispatched in the their system is Station C. When the system demand falls below the effective system capacity of 430 MW, Station C's operation is modulated. Station C is therefore the marginal generating asset in the AEC system and is used for determining the emissions impact for this effort. When system demand exceeds 430 MW, AEC purchases power from the GEB to meet demand, so the GEB acts as the marginal generating asset at system demand levels above 430 MW. The characteristics of GEB's Wanakbori unit, 210 MW coal-fired power plant, are used as an input to EM for determining emissions impact for the 100% EV penetration scenario; power needed in this scenario exceeds the available capacity of AEC's Station C. Finally, to remain conservative from an emissions perspective, the impact of improvement to AEC's system is not considered and the assessment assumes recharging takes place during AEC's off-peak hours.

Historically, AEC's losses in transmission and distribution of power from the generating plants to the end user have been approximately 18%. This figure includes both technical and commercial losses. These losses will increase the amount of generation required to serve the potential additional load and have been taken into account in the study.

Since the projected new loads imposed by EV battery chargers are expected to occur during off-peak periods, it is anticipated that the existing transmission and distribution systems will not experience constraints in their ability to serve these loads.

Apart from T&D losses, the EV industry estimates an additional 32-34% loss of power during the charging of EVs and the AC to DC conversion process, which is factored in this study.[2]

This study assesses the current condition of AECs generating system and does not consider potential improvements or degradation.

Characteristics of Conventional Two and Three-Wheelers

There are approximately 488,500 conventional two-wheelers and 35,000 conventional three-wheelers in Ahmedabad. AEC estimates approximately 10% of the current vehicles are 0-2 years old, 50% are 3-7 years old, and 40% are over 7 years old.

The three-wheeler vehicles are typically used for taxi service or freight transport, and thus have a relatively heavy use. Daily range is held at 80 kilometers for the purposes of modeling since this coincides with the guaranteed range for the electric driven three-wheelers. It is further assumed the vehicle is in operation for 330 days per year.

The two-wheelers primarily provide personal transportation, and thus have lower usage. A typical two-wheeler vehicle travels 25 km/day and 8,250 km/year, according to USAID's recent study of urban driving profiles in India.

The fuel economy of the vehicles in the current fleet varies based on age and specific vehicle type. This effort assesses current technology and does not consider potential improvements for conventional or electric driven vehicles. It is assumed two-stroke internal combustion engines power conventional vehicles.

Table 4 represents the key inputs into the EM for conventional and electric vehicles.

Table 4. Vehicle Operating Characteristics

Characteristics	Two-Wheelers	Three-Wheelers	Sources
Daily Range (Km)	25.	80	Bajaj Auto
Annual distance traveled (Km)	8250	26,400	"
Number of vehicles	488,545	35,176	SIAM, India
Electric Vehicles			
kWh/Km *(with 34% battery charging loss)*	0.035	0.087	New Generation Motors/Bajaj Auto
Annual kWh/vehicle	289	2,297	
Total MWh required for vehicles:			
10%	14,107	8,079	
40%	56,427	32,317	
100%	141,067	80,792	

[2] Personal interview with design engineers from New Generation Motors (NGM).

Characteristics	Two-Wheelers	Three-Wheelers	Sources
Total Distance Traveled for 10% of vehicles (Km)	4.E+08	9.E+07	
Total Distance Traveled for 40% of vehicles (Km)	2.E+09	4.E+08	
Total Distance Traveled for 100% of vehicles (Km)	4.E+09	9.E+08	
Conventional Vehicles			EIC and AEC field research
Fuel Consumption:			
0-2 years old (l/Km) 10% of total vehicle Population	0.02	0.03	
(mj/Km)	0.75	1.16	
3-7 years old (l/km) 50% of total vehicle population	0.02	0.04	
(mj/Km)	0.85	1.39	
8+ years old (l/km) 40% of total vehicle population	0.03	0.05	
(mj/Km)	0.96	1.58	
Total fuel consumption for a 0-2 years old vehicle/year (gallons)	44.48	232.50	
Total energy consumption for all 0-2 years old vehicles (BTU)	2.72E+11	1.02E+11	
Total Distance Traveled for all 0-2 years old vehicles (Km)	4.03E+08	9.29E+07	
Total fuel consumption for a 3-7years old vehicle/year (gallons)	53.16	279.00	
Total energy consumption for all 3-7 years old vehicles (BTU)	1.62E+12	6.13E+11	
Total Distance Traveled for all 3-7 years vehicles (Km)	2.02E+09	4.64E+08	
Total fuel consumption for a 8+years old vehicle/year (gallons)	61	317	
Total energy consumption for all 8+ years old vehicle (BTU)	1.48E+12	5.58E+11	
Total Distance Traveled for all 3-7 years vehicles (Km)	1.61E+09	3.71E+08	

Electric Vehicle Characteristics

The three-wheeler market is dominated by the autorickshaw. Consequently, Baja Auto/New Generation Motors' design is used as the basis for this assessment. The basis for the two-wheeler is also Baja Auto/New Generation Motors' design since this is the only electric driven vehicle in India with reliable data.

Word Bank's EM

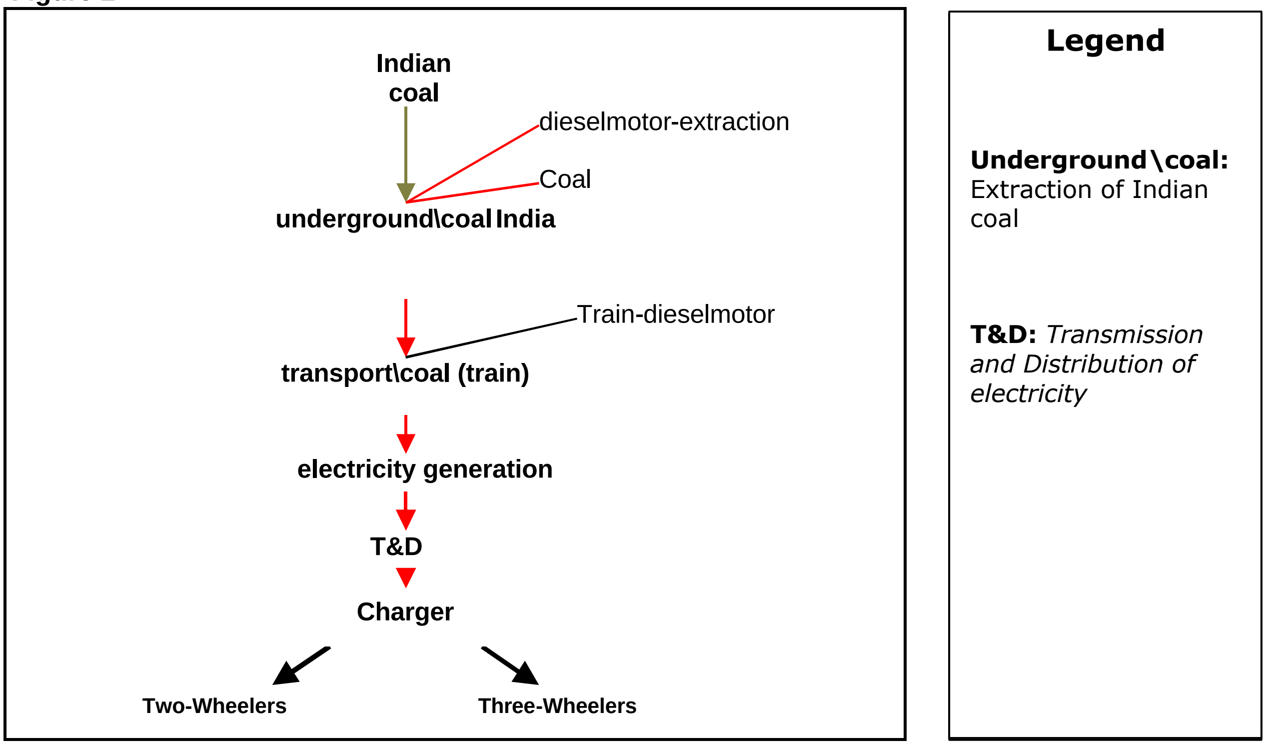
This analysis uses the World Bank's Environmental Manual (EM).

> *"The 'Environmental Manual for Power Development' (EM in short) is a WINDOWS-based computerized tool for the inclusion of environmental and cost data into the decision-making process of Development Agencies regarding energy projects.*
>
> *The software was developed by GTZ with scientific support from Oeko-Institut. It is part of a multilateral project on environmental management, coordinated by the World Bank with contribution from BMZ, BAWI, DGIS, GTZ, ODA, World Bank.*
>
> *The EM software can analyze and compare airborne and greenhouse gas emissions, solid wastes, and land use, as well as internal and external costs associated with the investment and operation of all kinds of energy technologies, including their life-cycles*
>
> *The EM comes with a generic database for energy technologies in developing countries, and covers:*
> ** all fossil-fueled electricity generation and heating systems,*
> ** cogenerators,*
> ** renewable energies (for electricity and/or heat),*
> ** energy efficiency (demand-side management) technologies,*
> ** and nuclear power systems, as well as*
> ** data for 'upstream' activities like mining, fuel benefication, transport, and*
> ** for emission control systems like flue-gas desulfurization, ESP, SCR, etc."*[3]

There are various processes during the generation, transmission and distribution of electricity to power each electric vehicle. Each process has its own link of resource and energy use. Thus, CO_2 equivalent emissions at the end of each process, for example, are calculated to obtain the aggregate emissions for electric vehicles. **Figure 2** partially illustrates the process linking the mining of coal to the supply of power to electric vehicles.

[3] http://www.oeko.de/service/em/

Figure 2



During 2000-2001, AEC used 100% Indian coal for its coal fired power plants. It is assumed that Indian coal for the power plant is transported from coalfields in Bihar, which lies approximately 1500 km east of Ahmedabad. The characteristics the coal used by AEC is given in **Table 3**. Based on information provided by Indian Railway, coal is transported using diesel locomotives from the coalmine to the power plant. The emissions rates of diesel locomotives are based on data provided by TATA Energy Research Institute.

Table 3 Chemical Composition of Indian Coal (%)

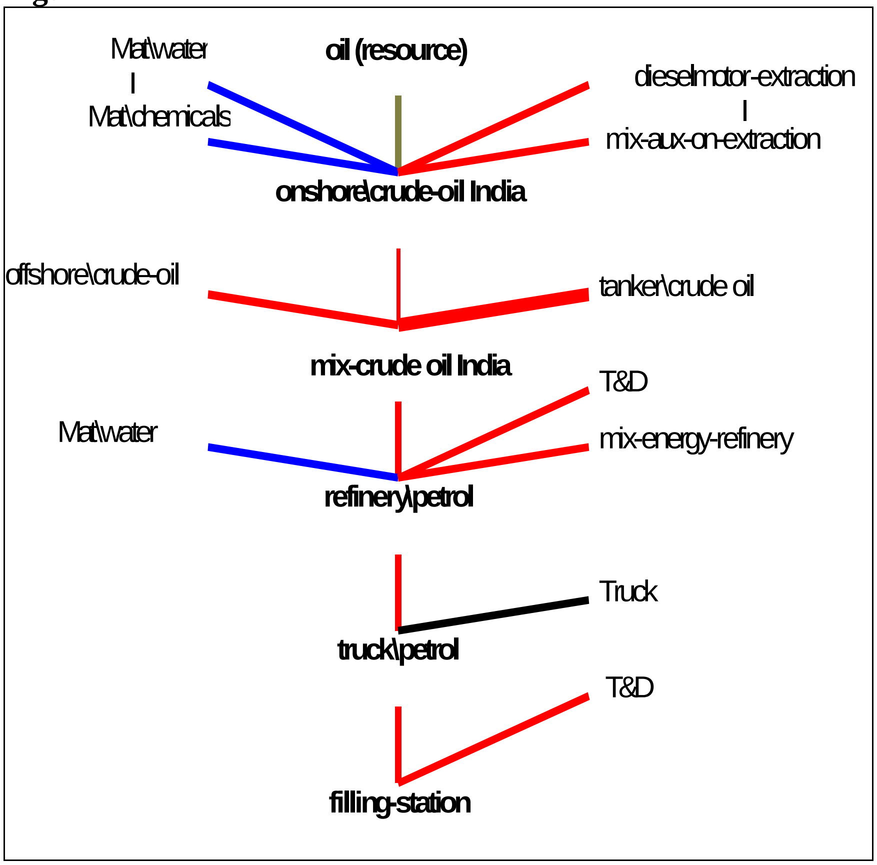
Carbon	Hydrogen	Sulfur	Nitrogen	Ash Content	Moisture	Heating Value (KWh/Kg)
60.0	4.0	0.4	1.1	18.8	8.9	7.107

Source: AEC
Note: The numbers do not add up to 100% due to presence of other chemicals/materials

Air Emissions from Conventional Two and Three-Wheelers

Emissions and environmental impacts of these vehicles are not limited to what escapes from the tailpipes of these vehicles. **Figure 3** graphically portrays the "energy chain" for liquid fueled vehicles. The most immediate link in the chain is the local service station. Energy is consumed to run the pumps and light the station. Petroleum leaks from underground storage tanks and evaporates during fueling. These sources plus on-board evaporation amount to losses of up to 5 percent[4]. Fuel is brought to stations on trucks from bulk storage. Again, energy is used and pollution is emitted. The bulk storage is served by pipeline from the refinery.

Figure 3



Legend

diesel motor auxiliary: *On-site diesel power generators* (used in extraction)

onshore crude- oil: Extraction of *onshore crude oil*

Mat\water: Materials and water used during Extraction *of oil*

Mat\chemicals: Materials and chemicalsr used during E*xtraction of oil*

train-diesel motor: *train transport powered by diesel motor*

nix-aux-on-extraction: *Auxiliary power used during extraction process*

offshore crude- oil: *Extraction of offshore crude oil*

T&D India: *Electricity Transmission and Distribution process for electricity use at service stations*

Ahmedabad's Fuel Supply for Conventional Vehicles

Majority of crude oil for petrol consumed in Ahmedabad is supplied from the Salaya Port in the western state of Gujarat. The fuel is then transported via pipelines to a nearest refinery that supplies petrol to Ahmedabad. Jamnagar refinery is located approximately 300 km from Ahmedabad. **Table 5** provides additional information on the refinery and processed fuel. The distance between the port and the refinery is approximately 7.5km. The processed fuel is transported to bulk terminals via tanker trucks and freight trains, which is then transported to service stations in Ahmedabad via tanker trucks.

[4] While an important source of emissions, they have not been included in our calculation.

Table 5 Characteristics of Jamnagar Refinery

Operating Efficiency (%)	93%
Total Capacity (MMT)	27
Operating Time	8000 hours/year
Process Petrol Type	Octane 87

Source: Reliance India, Indian Oil and EM Data for India

Results of EM Assessment

The annual emissions from the liquid fuel processes (extraction-refinery-tailpipe) of the conventional two and three-wheelers in Ahmedabad are:

Table 6 Annual Air Emissions from Conventional Vehicles (tons)

	SO_2	NOx	Particulates	CO	CO_2 Equivalent
3-wheelers	**235**	**190**	**489**	**4,118**	**178,602**
2-wheelers	**650**	**584**	**1,400**	**11,956**	**547,420**
Total	**885**	**774.**	**1,889**	**16,074**	**726,022**

Source: EM IZET Analysis

Note: Greenhouse gases are not all equal in terms of their radiative forcing and lifetime in the atmosphere, meaning that some gases are stronger than others. CO_2 equivalent is derived from emissions of CH_4, N_20 and CO_2. "To calculate the sum of the effects to the global warming, one can define mass-based weighting factors which describe the equivalent amount of CO_2 which has the same radiative forcing effect over the same time horizon[5]."

The contribution of annual emissions for each platform by age distribution is contained in Appendix 2.

The annual air emissions from AEC Unit C power station at various loads reflecting that of EV penetration scenarios are presented in **Table 7**. The 0% scenario is based upon AEC's Unit C operation in the absence of additional load from EVs. Net emissions reduction in per unit of electricity generation at AEC's Unit C is provided in **Table 8**.

Table 7 Annual Emissions Impact due to Efficiency Gains for AEC's Unit C (tons)

EV Conversion Scenario	Efficiency*	SO_2	NOx	Particulate Matter	CO	CO_2 Equivalent
0% EVs	21%	2,095	2,492	1,891	670	33,935
Load equivalent of 10% EVs	23.5%	1,988	2,366	1,795	638	32,289
Load equivalent of 40% EVs	24.7%	2,219	2,640	2,003	709	35,849

[5] EM Model Documentation (c) by GTZ + Oeko-Institut 1995

*Efficiency gains were extrapolated based on 0%EVs from increased generation (output) and fuel consumption (output) due to additional load due to EVs.

Table 8 Emissions Per unit of MWh Generation and Percentage Change at Unit C

	SO2		NOx		PM		CO		CO2 Equivalent	
	Tons	% Change	Tons	% Change	Tons	% Change	Tons	% Change	Tons	% Change
Baseline	0.0059	NA	0.0070	NA	0.0053	NA	0.0019	NA	0.0950	NA
Additional load of 10% EVs	0.0052	10.6330	0.0062	10.6310	0.0047	10.6350	0.0017	10.4456	0.0851	10.4131
Additional load of 40% EVs	0.0050	15.1567	0.0059	15.1590	0.0045	15.1549	0.0016	15.3424	0.0804	15.3742

The total annual emissions from all processes (well-wheel and coal mine-wheel) at the two EV penetration scenarios are presented in **Table 9**.

Table 9. Total Annual Emissions from All Processes (tons)

EV Conversion Scenario	SO_2	NOx	Particulate Matter	CO	CO_2 Equivalent
0% EVs	2,980	3,266	3,779	17,931	759,957
10% EVs	2,647	2,791	3,369	16,179	683,192
40% EVs	2,232	2,205	2,651	11,444	462,964

Note: detail analysis for each pollutant is provided in Appendix 2**.**

The annual net emissions for the two EV penetration scenarios from all processes are presented in **Table 10**.

Table 10. Annual Net Emissions Change in Ahmedabad from replacing 10% and 40% of from All Processes (tons)

Scenario	10%		40%	
Pollutant	**Change in annual average emissions**	**% Change**	**Change in annual average emissions**	**% Change**
CO_2 Equivalent	76,766	10.10	296,993	39.08
SO_2	333	11.16	748	25.11
NOx	209	6.97	796	26.52
Particulate Matter	410	10.85	1,128	29.85
CO	1,752	9.77	6,487	36.18

Conclusion:

Increasing the demand upon AEC's generation system by replacing conventional two and three-wheelers with electric driven versions results in significant net reductions in air emissions.

References:

Modeling Anthropogenic Emissions from Energy Activities in India: Generation and Source Characterization, Ohio Supercomputing Center, Columbus, Ohio (***www.osc.edu/research//pcrm/emissions/index.shtml***)

Bajaj Auto Limited, Pune, India

New Generation Motors, Ashburn, VA

Econergy International, Boulder, CO

Appendix 1

Vehicles	2-W	3-W	Sources
Conventional Vehicles (Emissions Factors)			WB URBAIR and Oak Ridge National Lab
PM g/km	0.3	0.05	"
CO g/km	2.6	4.0	"
NOx g/km	0.013	0.02	"
SO_2 g/Km	0.01	0.016	"
Power Plants			
AEC Marginal Plant			
Station C (MW)		60	AEC
Fuel		Coal	
Base Efficiency (%)		21%	Calculated based on heat rate provided from AEC for year 2000-01
improved efficiency at 10% EV charging (Fuel input/energy output*100)		23.5%	"
improved efficiency at 40% EV charging (Fuel input/energy output*100)		24.7%	'
improved efficiency at 100% EV charging (Fuel input/energy output*100)		27%	"
Baseline Heat Rate (Kcal/KWh)		4,301	AEC/EIC
GEB Marginal Plant			
Wanakbori TPS (MW)		1470	Ohio Super Computing Center (OSC)
Fuel		Coal	"
Efficiency (%) (Held constant)		35	Information from a knowledgeable person
Coal Supply for GEB	Indian Coal		AEC
Approximate distance from coal mine to GEB plant (assumed GEB coal comes from Jaharia coalmine (km)		1,500	Computed based on distance provided by the Indian Railway
Coal is transported using diesel locomotives			EM date from TERI
Coal Supply for AEC			AEC/EIC
Approximate distance from coalmine to AEC (Km)		1500	"
T&D Losses (%) in Ahmedabad for year 2000- 2001		18.1	AEC

Fuel Transport Vehicles		EM Data based on TERI/GTZ numbers
Emissions of diesel locomotive (g/km) based upon capacity for 100t of freight and driving distance of 200,000 km/year.		
CO	15.00	
PM	3.00	
CH4	0.50	
Nox	50.00	
NO_2	0.05	
VOC	10.00	
Fuel Consumption of Diesel Trucks in (mj/km) - for transport of fuel	2.10	
Emissions of diesel trucks (g/km)		
NOx	3.00	
PM	0.14	
CO	1.00	
CH4	0.00	
VOC	0.60	
Refinery (Jamnagar)		
Capacity (MMT)	27	Reliance Website
Distance from port (Km)	7.5	Approximation based on Indian Map
Annual hours of operation	5,000	Reliance Website
Efficiency (%)	93	Reliance Website
Fuel Distribution System	Tanker Trucks	Indian Oil Corporation
Chemical Composition of Indian Gasoline (%)		Ministry of Forestry and Environment, and other GOI sources (1999 data)
Carbon	91	
Benzene	0.9	
Sulfur	1	
Hydrogen	3	
Lead	0.001	
Phosphorus	0.1	
Others	5	

Appendix 2

CO_2 Equivalent Annual Measurements (tons)

Power Output MWH	[a] Load	[b] Air Emissions per power output	[c] Air Emissions at GEB	[d] Air Emissions from Liquid Vehicles	[e] Air Emissions at Unit C	[f] Total Air Emissions
357,400	**Baseline for Unit C**	33,935	NA	726,022	NA	759,957
379,586	**10% EVs**	32,289	NA	653,420	2,517	683,192
446,144	**40% EVs**	35,849	NA	435,613	8,498	462,964
668,003	**100% EVs***	273,329	93,422	NA	8,498	171,409

[f] = (b+d)-(c+e)

*With existing capacity, AEC can supply electricity to power 40% of vehicles and the remaining is purchased from GEB. Thus, total number in column e for 100% EV scenario reflects 40% from AEC and remaining from GEB.

SO_2 Annual Measurements (tons)

Power Output MWH	[a] Load	[b] Air Emissions per power output	[c] Air Emissions at GEB	[d] Air Emissions from Liquid Vehicles	[e] Air Emissions at Unit C	[f] Total Air Emissions
357,400	**Baseline for Unit C**	2,095	NA	885	NA	2,980
379,586	**10% EVs**	1,988	NA	797	138	2,647
446,144	**40% EVs**	2,219	NA	531	518	2,232
668,003	**100% EVs***	4,223	756	NA	518	2,950

[f] =(b+d)-(c+e)

*With existing capacity, AEC can supply electricity to power 40% of vehicles and the remaining is purchased from GEB. Thus, total number in column e for 100% EV scenario reflects 40% from AEC and remaining from GEB.

NO_x Annual Measurements (tons)

Power Output MWH	[a] Load	[b] Air Emissions per power output	[c] Air Emissions at GEB	[d] Air Emissions from Liquid Vehicles	[e] Air Emissions at Unit C	[f] Total Air Emissions
357,400	**Baseline for unit C**	2,492	NA	774	NA	3,266
379,586	**10% EVs**	**2,113**	NA	697	19	2,791
446,144	**40% EVs**	**2,358**	NA	464	617	2,205
668,003	**100% EVs***	3,375	391	NA	617	2,367

[f] = (b+d)-(c+e)

*With existing capacity, AEC can supply electricity to power 40% of vehicles and the remaining is purchased from GEB. Thus, total number in column e for 100% EV scenario reflects 40% from AEC and remaining from GEB.

Particulates Annual Measurements (tons)

Power Output MWH	[a] Load	[b] Air Emissions per power output	[c] Air Emissions at GEB	[d] Air Emissions from Liquid Vehicles	[e] Air Emissions at Unit C	[f] Total Air Emissions
357,400	Baseline for Unit C	1,891	NA	1,888	NA	3,779
379,586	10% EVs	1,795	NA	1,699	125	3,369
446,144	40% EVs	2,003	NA	1,087	439	2,651
668,003	100% EVs*	2,565	304	NA	439	1,822

[f =] (b+d)-(c+e)

*With existing capacity, AEC can supply electricity to power 40% of vehicles and the remaining is purchased from GEB. Thus, total number in column e for 100% EV scenario reflects 40% from AEC and remaining from GEB.

CO Annual Measurements (tons)

Power Output MWH	[a] Load	[b] Air Emissions per power output	[c] Air Emissions at GEB	[d] Air Emissions from Liquid Vehicles	[e] Air Emissions at Unit C	[f] Total Air Emissions
357,400	Baseline for Unit C	1,858	NA	16,073	NA	17,931
379,586	10% EVs	1,763	NA	14,465	49	16,179
446,144	40% EVs	1,968	NA	9,643	167	11,444
668,003	100% EVs*	2,161	162	NA	167	1,833

[f =] (b+d)-(c+e)

*With existing capacity, AEC can supply electricity to power 40% of vehicles and the remaining is purchased from GEB. Thus, total number in column e for 100% EV scenario reflects 40% from AEC and remaining from GEB.

Annual Emissions from Conventional Vehicles (tons)

	SO2	NOx	Particulates	CO	CO2	CO2 Equivalent
0-2 years old 3-wheelers	18.91	16.43	7.00	384.47	13,689.81	14,397.28
3-7 years old 3-wheelers	113.32	91.35	267.19	2,073.24	82,009.79	86,064.09
8+ years old 3-wheelers	103.00	82.47	214.95	1,660.84	74,557.73	78,140.70
Total 3-wheelers	**235.23**	**190.25**	**489.14**	**4,118.55**	**170257.33**	**178,602.07**
0-2 years old 2-wheelers	65.36	60.09	140.53	1,196.63	40,993.17	47,220.47
3-7 years old 2-wheelers	306.92	263.85	697.87	5,973.70	2.202E+5	2.648E+5
8+ years old 2-wheelers	277.35	260.45	561.49	4,785.28	1.988E+5	2.354E+5
Total	**649.63**	**584.39**	**1,399.89**	**11,955.61**	**459,993.17**	**547,420.47**

2-wheelers						
Total from all Vehicles	**884.86**	**774.64**	**1,889.03**	**16,074.16**	**630,250.5**	**726,022.54**

Source: EM IZET Analysis

Air Emissions Associated with Recharging of 10, 40 and 100% Penetration of EVs

	SO2	NOx	Particulates	CO	CO2-Equivalent
10% 3-wheelers	50	7	45	18	904
10% 2-wheelers	88	12	79	31	1,613
Total 10%	138	19	124	49	2,517
40% 3-wheelers	189	225	170	62	3,167
40% 2-wheelers	329	392	269	105	5,331
Total 40%	518	617	439	167	8,498
100% 3-wheelers*	418	345	281	120	31,909
100% 2-wheelers*	856	664	461	209	70,011
Total 100%	1,274	1,008	743	329	101,920

* Power required to charge 100% electric vehicles comes 40% from AEC and 60% from GEB.

Power Required to Charge 100% EVS

	100% 2W EV	100% 3W EV
GEB MWh	84,640	48,475
AEC MWh	56,427	32,317
Total	141,067	80,792

GEB Baselines Emissions and Emissions from Load Associated with Penetration of 100% EVs*

	SO2	NOx	PM	CO	CO2-Equivalent
baseline (based on power output)	3,253.71	1,443.1	898.84	242.11	32,700
60% vehicles[1] (as AEC can only supply electricity for 40% EVs)	755.94	391.458	303.642	161.88	93422.22

*These results do not indicate the entire emissions at GEB unit. It only represents the emissions associated with 310,000 MWH of power, which AEC purchases from GEB.

[1] EV related emissions only

Appendix 3

Assessment of Air Emissions at AEC Units C & DEF

AEC requested USAID to perform an assessment of air emissions at their C & DEF Units using different coal types.

Objective: Assess the air emission contribution of AEC's generating systems from using 100% domestic coal compared to 100% imported (Enviro) coal for the past three years (1999-2001).

Analysis: The assessment was performed using the World Bank's EM Model (Environmental Manual). The model performed the lifecycle assessment of air emissions form AEC's generating units using 100% domestic coal, 100% imported coal and from the actual operating conditions for the past three years. The purpose of this brief is to report the air emissions resulting from all three alternatives. Lifecycle emissions modeling considers the full chain of resource and energy use from when the energy resource is mined, transported, transformed and finally consumed. For the purpose of this study, it is assumed that the coal is mined, transported and consumed and pollutants were released during each process.

Based on the information provided by AEC, the Enviro coal is imported from Indonesia and is transported to the Indian port by ship. The coal is then transported to AEC's power plants by diesel locomotives. Similarly, the domestic coal is transported from a coalmine in Bihar to AEC's plants by diesel locomotives. The coalmining process consumes energy and emits certain pollutants during the process. During the coalmining, a large amount of GHG is emitted, which is also factored into this study. The diesel locomotive consumes diesel fuel and emits pollutants during its journey from the mine to the power plants. The fuel is consumed at the power plants. Finally, air emissions were determined based on energy use at each process of the fuel chain.

The consumption of coal, however; depends upon the efficiency of the power plants, which in turn depends upon the calorific value of the coal used. The more efficient the power plant the less energy is consumed and the less pollutants are released. The air emissions from AEC's generating Units (C and DEF) are based on three fuel scenarios. The first scenario considers 100% domestic coal. The second scenario is based on 100% Enviro coal. The third scenario analyzes the air emissions based on actual operating conditions of the generating units for the given periods or baseline. The results are determined and compared. The characteristics of AEC's generating units (C and DEF) for periods 1999-00, 2000-01, 2001-02 are provided in Table 1. The chemical composition of domestic and Enviro coal are given in Table 2.

Table 1 Characteristics of AEC Generation System

Unit	1999-00		2000-01		2001-02	
	C	DEF	C	DEF	C	DEF
Installed capacity (MW)	60	330	60	330	60	330
Installed Generation (GWh)	525.6	2891	525.6	2891	525.6	2891
Plant load factor	76%	83%	81%	83%	72%	84%
Units Generated (GWh)	397.33	2,399	424	2,401	377.2	2,439
Calorific Value (Kcal/Kg)						
Domestic Coal	5389		5560		5436	
Imported Coal	6103		5680		5126	
Fuel Consumption (MT)						
Domestic Coal (MT)	276,409	723,827	300,391	613,077	154,022	543,934
Imported Coal (MT)	7,572	422,777	0	582,402	0	641,302

Source: AEC

Table 2: Chemical Composition of Domestic and Enviro Coal.

	Domestic Coal	Enviro Coal
Carbon	60%	64.46%
Hydrogen	4%	5.84%
Nitrogen	1.10%	1.31%
Sulfur	0.3 to 0.5%	0.14%
Total Moisture	8.9%	20.9%
Ash	18.8%	1.5%

To determine the air emissions at the power plant using 100% domestic and 100% imported coal, the total consumption of both coals were converted based on the calorific value provided in the Table1 for each year. The efficiency of the power plant was determined based on this converted value, while keeping the output (generation) constant. The efficiency and the coal uses for each year for each fuel type is provided in Appendix. A.

Results

Annual emissions from using 100% Enviro coal, 100% domestic coal and the emissions from current operation of Units DEF for each period is presented in Table 3. Similarly, the air emissions resulting from Unit C are presented in Table 4. Emission from current operating practice is used as a base case scenario for this study. The results of the full analysis including air emissions per unit of electricity generation for all three cases are provided in Appendix B.

Table 3 Total Annual Emissions at AEC's UNIT DEF from using various Coal types (Tons)[1]

Years	SOx			Nox			PM			CO			CO2 Equivalent		
	Baseline	100% Domestic coal	100% Enviro Coal	Baseline	100% Domestic coal	100% Enviro Coal	Baseline	100% Domestic coal	100% Enviro Coal	Baseline	100% Domestic coal	100% Enviro Coal	Baseline	100% Domestic coal	100% Enviro Coal
99-'00	7,325	10,127	4,033	13,521	13,931	14,378	3,052	4,714	845	2,082	2,059	2,474	3,040,000	3,362,000	2,766,000
00-'01	5,965	10,075	4,448	12,314	13,861	15,859	2,776	4,690	931	1,956	2,049	2,718	2,686,000	3,345,000	3,051,000
01-'02	6,248	8,563	4,299	13,448	11,781	15,327	2,402	3,986	900	2,099	1,756	2,630	2,926,000	2,844,000	2,949,000

[1] Baseline represents the actual power plant operation for the given periods as provided by AEC.

Table 4 Total Annual Emissions at AEC's UNIT C from Using Various Coal Types (Tons)[1]

Years	SOx			Nox			PM			CO			CO2 Equivalent		
	Baseline	100% Domestic coal	100% Enviro Coal	Baseline	100% Domestic coal	100% Enviro Coal	Baseline	100% Domestic coal	100% Enviro Coal	Baseline	100% Domestic coal	100% Enviro Coal	Baseline	100% Domestic coal	100% Enviro Coal
99-'00	2,211	2,289	910	2,637	2,669	2,812	1,980	2,069	223	703	710	779	749,500	764,000	627,000
00-'01*	2,479	2,479	1,094	2,890	2,890	3,382	2,241	2,241	268	767	767	931	827,000	827,000	754,000
01-'02*	1,244	1,244	596	1,451	1,451	1,839	1,124	1,124	146	398	398	518	415,000	415,000	410,000

[1] Baseline represents the actual power plant operation for the given periods as provided by AEC.

* During the period 2000-01and 20001-02 AEC's Unit C used domestic coal only. Therefore, the baseline and the 100% domestic coal yields the same results.

Conclusion:

The study shows that using Enviro coal for power generation yields a net benefit in SO_2, PM and GHGs.

Appendix A

Unit C efficiency Using 100% Enviro Coal

Indian Coal is substituted for Enviro coal

	Input		Output		Efficiency
	Tons/year	Kcal/year	MWh/yr	Kcal/yr	
	99-00				
Indian Coal	269,014	1.3152E+12			
Enviro Coal	8,346	4.6211E+10			
Total	277,360	1.3614E+12	397,000	3.42E+11	**25.1**
	00-01				
Indian Coal	0	0			
Enviro Coal	324,124	1.6349E+12			
Total	324,124	1.6349E+12	408,000	3.51E+11	**21.5**
	01—02				
Indian Coal	180,046	8.8789E+11			
Enviro Coal	0	0			
Total	180,046	8.8789E+11	377,200	3.25E+11	**36.6**

Unit C Efficiency Using 100% Domestic Coal

Enviro Coal is substituted for Indian coal

	Input		Output		Efficiency
	Year/year	Kcal/year	MWh/yr	Kcal/yr	
	99--00				
Indian Coal	304,685	1.49E+12			
Enviro Coal	9,453	5.23E+10			
Total	314,138	1.54E+12	397,000	3.42E+11	**22.2**
	00-01				
Indian Coal	331,120	1.67E+12			
Enviro Coal	0	0			
Total	331,120	1.67E+12	408,000	3.51E+11	**21.0**
	01--02				
Indian Coal	169,778	8.37E+11			
Enviro Coal	0	0			
Total	169,778	8.37E+11	377,200	3.25E+11	**38.8**

Unit DEF Efficiency Using 100% Enviro Coal

Indian Coal is substituted for Enviro coal

	Input		Output		Efficiency
	Tons/year	Kcal/year	MWh/yr	Kcal/yr	
	99-00				
Indian Coal	704,462	3.444E+12			
Enviro Coal	466,027	2.5802E+12			
Total	1,170,489	6.0241E+12	2,399,000	2.07E+12	**34.3**
	00-01				
Indian Coal	661,516	3.3366E+12			
Enviro Coal	641,981	3.308E+12			
Total	1,303,498	6.6446E+12	2,401,000	2.07E+12	**31.1**
	01—02				
Indian Coal	635,838	3.1356E+12			
Enviro Coal	706,907	3.2873E+12			
Total	1,342,745	6.4229E+12	2,439,000	2.1E+12	**32.7**

Unit DEF Efficiency Using 100% Domestic Coal

Enviro Coal is substituted for Indian coal

	Input		Output		Efficiency
	Tons/year	Kcal/year	MWh/yr	Kcal/yr	
	99-00				
Indian Coal	797,874	3.9E+12			
Enviro Coal	527,820	2.92E+12			
Total	1,325,695	6.82E+12	2,399,000	2.07E+12	**30.3**
	00-01				
Indian Coal	675,794	3.41E+12			
Enviro Coal	655,836	3.38E+12			
Total	133,1631	6.79E+12	2,401,000	2.07E+12	**30.5**
	01—02				
Indian Coal	599,578	2.96E+12			
Enviro Coal	604,730	2.81E+12			
Total	1,204,308	5.77E+12	2,439,000	2.1E+12	**36.4**

Appendix B
Air Emissions from Unit C (Includes Emissions Per Unit of Power Generation)

Years	Coal Use (Tons)	Efficiency as reported by AEC	Unit Generation (MWh)	Total SO2 (Tons)	SOx Per unit of MWh (Kg)	NOx (Tons)	NOx Per unit of MWh (Kg)	Particulates (Tons)	PM Per unit of MWh (Kg)	CO (Tons)	CO Per unit of MWh (Kg)	CO2-Equivalent (Tons)	CO2 Equivalent Per unit of MWh (Kg)
Indian Coal (100%)													
From Power Plan (from stack)													
99-'00	314,139	22.17	397,000	2,169	4.96	2,406	5.50	2,008	4.59	627	1.43	6.40E+05	1,462
00-'01	331,120	21.04	408,000	2,348	5.22	2,605	5.79	2,174	4.83	677	1.51	6.93E+05	1,540
01-'02	169,778	38.8	377,200	1,178	2.83	1,308	3.15	3,756	9.03	1,446	3.48	3.48E+05	837
All other processes (including production and transportation of fuel)													
99-'00				121		264		61		83		1.24E+05	
00-'01				131		286		67		90		1.34E+05	
01-'02				65		143		33		45		6.72E+04	
Total													
99-'00				2,289		2,669		2,069		710		7.64E+05	
00-'01				2,479		2,890		2,241		767		8.27E+05	
01-'02				1,244		1,451		1,124		398		4.15E+05	
Enviro Coal (100%)													
From Power Plant (from stack)													
99-'00	277,361	25.16	397,000	867.98	1.98	2,621	5.99	211	0.48	717	1.59	6.14E+05	1,404
00-'01	324,125	21.49	408,000	1043.41	2.32	3,151	7.01	253	0.56	857	2.06	7.39E+05	1,642
01-'02	180,046	36.59	377,200	567.91	1.37	1,714	4.12	138	0.33	478	1.15	4.02E+05	967
All other processes (including production and transportation of fuel)													
99-'00				42.34		192		12		62		13000.23	
00-'01				50.92		231		15		75		15634.82	
01-'02				27.66		125		8		41		8493.84	
Total													
99-'00				910.32		2,812		223		779		6.27E+05	
00-'01				1094.33		3,382		268		931		7.54E+05	
01-'02				595.57		1,839		146		518		4.10E+05	
From Baseline (as reported by AEC)													
99-'00	169,778	22.3	397,000	2,093	4.78	2,376	5.43	1,920	4.39	621.0	1.42	629,300	1,438
All other processes (including production and transportation of fuel)													
99-'00				118		261		60		81.8		120,200	
Total													
99-'00				2,211		2,637		1,980		703.0		749,500	

Air Emissions from Unit DEF (Includes Emissions Per Unit of Power Generation)

Years	Coal Use (Tons)	Efficiency as reported by AEC	Unit Generation (MWh)	Total SO2 (Tons)	SOx Per unit of MWh (Kg)	NOx (Tons)	NOx Per unit of MWh (Kg)	Particulates (Tons)	PM Per unit of MWh (Kg)	CO (Tons)	CO Per unit of MWh (Kg)	CO2-Equivalent (Tons)	CO2 Equivalent Per unit of MWh (Kg)
Indian Coal (100%)													
From Power Plant (stack emission)													
99-'00	1.33E+06	30.28	2.40E+06	9,593	3.63	12,764.33	4.83	4,442	1.68	1,692.62	0.64	2.82E+06	1,064
00-'01	1.33E+06	30.46	2.40E+06	9,544	3.61	12,699.54	4.80	4,419	1.67	1,684.52	0.64	2.80E+06	1,058
01-'02	1.35E+06	36.41	2.44E+06	8,112	3.02	10,794.20	4.01	4,195	1.56	1,603.86	0.60	2.38E+06	886
All other processes (including production and transportation of fuel)													
99-'00				534		1,166.97		272		366.14		5.47E+05	
00-'01				531		1,161.04		270		364.28		5.45E+05	
01-'02				451		986.60		230		309.57		4.63E+05	
Total													
99-'00				10,127		13,931.30		4,714		2,058.75		3.36E+06	
00-'01				10,075		13,860.58		4,690		2,048.79		3.35E+06	
01-'02				8,563		11,780.90		3,986		1,755.91		2.84E+06	
Enviro Coal (100%)													
From Power Plant (stack emission)													
99-'00	1.17E+06	34.297	2.40E+06	3,845.23	1.45	1,3528.62	5.12	790.9	0.30	2,198.13	0.83	2.71E+06	1,024
00-'01	1.30E+06	31.12	2.40E+06	4,240.63	1.60	1,4921.32	5.64	871.96	0.33	2,414.48	0.90	2.99E+06	1,129
01-'02	1.27E+06	32.7	2.44E+06	4,098.61	1.52	1,4421.11	5.36	842.84	0.31	2,336.77	0.87	2.89E+06	1,074
All other processes (including production and transportation of fuel)													
99-'00				187.69		849.7		53.81		275.42		5.76E+04	
00-'01				207.03		937.25		59.35		303.8		6.36E+04	
01-'02				200.08		905.8		57.36		293.6		6.14E+04	
Total													
99-'00				4,032.92		14,378.32		844.71		2473.55		2.77E+06	
00-'01				4,447.66		15,858.57		931.31		2718.27		3.05E+06	
01-'02				4,298.7		15,326.91		900.21		2,630.38		2.95E+06	
Baseline (as reported by AEC)													
From Power Plant (from stack)													
'99-'00	1.26E+06	31.88	2.40E+06	7,002	2.65	12,808	4.84	2,888	1.09	1,858	0.70	2,711,000	1,025
'00-'01	1.32E+06	30.79	2.40E+06	5,732	2.17	11,800	4.46	2,658	1.00	1,795	0.68	2,449,000	925
'01-'02	1.31E+06	33.64	2.44E+06	6,022	2.24	12,949	4.82	2,288	0.85	1,942	0.72	2,695,000	1,002
All other processes (including production and transportation of fuel)													
'99-'00				323		714		164		224		329,200	

Years	Coal Use (Tons)	Efficiency as reported by AEC	Unit Generation (MWh)	Total SO2 (Tons)	SOx Per unit of MWh (Kg)	NOx (Tons)	NOx Per unit of MWh (Kg)	Particulates (Tons)	PM Per unit of MWh (Kg)	CO (Tons)	CO Per unit of MWh (Kg)	CO2-Equivalent (Tons)	CO2 Equivalent Per unit of MWh (Kg)
'00-'01				233		514		118		161		237,000	
'01-'02				226		500		115		157		230,600	
Total													
'99-'00				7,325		13,521		3,052		2,082		3,040,000	
'00-'01				5,965		12,314		2,776		1,956		2,686,000	
'01-'02				6,248		13,448		2,402		2,099		2,926,000	

Appendix 4

Assessment of Air Emissions at AEC Unit G

AEC requested USAID to carry out lifecycle analysis of air emissions from station G using 100% natural gas as a fuel source for the past three years (1999-2002). The station G currently burns both natural gas and diesel. However, for the year 2001-02 the unit was running only on diesel as supply of natural gas was limited.

Objective: Assess the air emission contribution of AEC's Unit G using only natural gas as a fuel source for the given periods.

Analysis: The assessment was performed using the World Bank's EM Model (Environmental Manual). The model performed the lifecycle assessment of air emissions form station G running on 100% natural gas. For the purpose of this study, it is assumed that the diesel fuel is substituted with natural gas based on total calorific value of the diesel fuel used. Thus, the purpose of this brief is to report the air emissions of the given scenario. Lifecycle emissions modeling considers the full chain of resource and energy use from when the energy resource is mined, transported, transformed and finally consumed. It is assumed that the natural gas is extracted domestically, which was then transported and consumed at the station G. During each process, a large amount of GHGs along with other pollutants are released, which is determined based on energy use at each process of the fuel chain.

The analysis of air emissions at station G is based on actual operating conditions using 100% natural gas for the given periods. The results are analyzed and compared. The characteristics of Unit G for periods 1999-00, 2000-01, 2001-02 are provided in Table 1. As stated earlier, during 2001-02 the Unit G was running on 100% diesel fuel. The chemical compositions of natural gas are given in Table 2, which is based on information obtained from the EM model for Indian natural gas.

Table 1 Characteristics of Unit G (1999-2002)

Unit	1999-00	2000-01	2001-02
Installed capacity (MW)	100	100	100
Installed Generation (GWh)	876	876	876
Plant load factor	68%	61%	36%
Units Generated (GWh)	597.19	536	318.3
Calorific Value			
Natural Gas (KCal/100 cu meter)	9,655	10031	0
HSD/SKO (KCal/KL)	8,348	8,125	9,504
Fuel Consumption			
Natural Gas ('000 cu. meter)	86,297	49,670	0
Diesel (KL)	47,575	81,774	75,664

Source: AEC

Table 2: Chemical Composition Indian Natural Gas .

Composition	Vol %
CH_4	86.78

Composition	Vol %
C_2H_6	7
C_2H_4	0
C_2H_2	0
C_3H_8	3
C_3H_6	0
$C_4H_{10}n$	1.8
$C_4H_{10}i$	0
C_4H_8	0.3
CO	0
CO_2	1
Hydrogen	0
Nitrogen	0.1
H_2S	.0005

Source: Characteristics of Natural Gas from EM Model

To determine the air emissions at the power plant using 100% natural gas, the total consumption diesel was converted to natural gas based on the calorific value provided in the Table1 for each year. The calorific value of natural gas from the year 2000-2001 was substituted for the year 2001-2000 since the Unit G was running on 100% diesel for the given year. The efficiency of the power plant was determined based on this converted value, while keeping the output (generation) constant. The methodology of obtaining efficiency of the power plant and the volume of gas used for each year is provided in Appendix. A.

Results

Annual emission from burning 100% natural gas at Unit G for the given period is presented in Table 3. The results also include air emissions per unit of electricity generation for the given period.

Table 3 Air emissions from Burning 100% Natural Gas at Unit G

Years	Fuel Use (cubic meter of gas)	Efficiency	Output (MWh)	SO_2		NOx		PM		CO		CO2-Equivalent	
				Tons	Kg/MWh	Tons	Kg/MWh	Tons	Kg/MWh	Tons	Kg/MWh	Tons	Kg/MWh
Emissions from Stack													
99-'00	127,431,000	38.84	517,190	27	0.05	1,026	1.80	44	0.08	448	0.79	299,800	526
00-'01	115,906,000	44.25	536,000	25	0.04	933	1.58	40	0.07	409	0.69	272,800	462
01-'02	75,664,000	40.22	318,000	17	0.05	610	1.74	27	0.08	271	0.77	178,400	509
Emissions from all other process (including production and transportation of fuel)													
99-'00				9		111		6		30		22,340	
00-'01				8		101		6		27		20,322	
01-'02				5		66		4		18		13,271	
Total													
99-'00				**36**		**1,137**		**51**		**478**		**322,200**	
00-'01				**33**		**1,034**		**46**		**436**		**293,100**	
01-'02				**22**		**676**		**30**		**289**		**191,600**	

Appendix A

Efficiency of Unit G for the Past Three Years

Year	Input		Output		Efficiency
	1000Cu meter/year	Kcal/year	GWH/yr	Kcal/yr	
99-00					
Natural Gas	86,297,000	7.76673E+11			
Diesel*	41,134,000	3.70206E+11			
Total	127,431,000	1.14688E+12	517.19	4.45427E+11	**38.84**
00-01					
Natural Gas	49,670,000	4.4703E+11			
Diesel*	66,236,000	5.96124E+11			
Total	115,906,000	1.04315E+12	536	4.61627E+11	**44.25**
01-'02					
Natural Gas	0	0			
Diesel*	75,664,000	6.80976E+11			
Total	75,664,000	6.80976E+11	318	2.73876E+11	**40.22**

***These numbers represent the natural gas equivalent to diesel as diesel fuel was converted to natural gas.**

POLICIES and REGULATIONS[1]

Starting in 1992, the Government of India shifted its emphasis from pollution control to pollution prevention. The main initiatives and actions taken are done within the framework of the Air (Prevention & Control of Pollution) Act, 1981. These essentially include:

1. Transport Sector:

Emission control initiatives to cover:

- Phased switchover from leaded to unleaded petrol from1995 in the metro cities to start with.
- Introduction of Vehicular Pollution Checks for all vehicles moving on the roads in the metropolitan cities coupled with a phasing out of the older vehicles and replacement of two-stroke engines.
- Improved engine efficiency coupled with use of catalytic converters in new vehicles. A Supreme Court directive stipulates the adoption of Euro-1 and Euro-II emission norms in a time bound manner.
- Introduction of low-sulfur diesel and low benzene gasoline in a phased manner along with promotion of alternative fuels like Compressed Natural Gas (CNG)
- Revision of emission norms

Two major drawbacks in pollution control and prevention include:

- Unreliability of monitored and also submitted data.
- Inadequacy of competent and trained personnel in the regulatory agencies.

Because of the deteriorating effects on air quality caused by rapid industrialization in India, the Air (Prevention and Control of Pollution) Act covers the prevention, control and abatement of air pollution. The State Pollution Control Boards are also required to grant consent for industrial facilities/units operating in air pollution control areas as declared by the concerned State Governments.

The 1986 Environment Protection Act is an umbrella Act providing for the protection and improvement of the environment and related issues. It specifically provides that:

> "No person carrying on any industry, operation or process, should discharge or emit or permit to be discharged or emitted any environmental pollutant in excess of such standards as may be prescribed".[2]

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[1] Based on materials from: (a) *State of the Environment Report, 1999*; (b) *Ministry of Environment and Forests Notifications1999*; (c) *Air Pollution Control in Various UT(s), Ministry of Environment and Forests Notifications 1987 – 1989*; (d) *Ministry of Environment and Forests, Annual Report 2001 – 2001.*

Under the 1986 Act, guidelines have been formulated for the handling and management of toxic wastes. This Act also formed the basis for developing the Environmental Impact Assessment Notification in 1994 leading to mandatory environmental clearances by the Central and State Governments for various kinds of development activities including those involving 29 types of highly polluting industries.

A process for easier and quicker redress of public grievances, relating to environmental degradation was introduced in 1985 through introduction of the Public Interest Litigation (PIL) mechanism, under which the allegedly aggrieved parties could approach the courts, in public interest, for intervention at no cost.

Since 1985 this mechanism has been used in various cases involving industry / project authorities / State & Central Government.

Fiscal Incentives

Under the Air and Water (Prevention and Control of Pollution) Acts several fiscal incentives have been introduced. Some of the important provisions include the following:

- Income tax exemption;
- Depreciation allowance;
- Investment allowance, and
- Customs duties at reduced rates.

The Ministry of Environment and Forests (MoEF) adopted the Policy Statement for Abatement of pollution in response to the increasingly adverse air, water and noise, etc., pollution in the country and especially in the major urban areas. The policy provides several measures in the form of regulations, legislations, agreements, fiscal incentives and various other preventive strategies for the abatement of pollution. The focus of the various programs and schemes of the Ministry and its associated organizations related to pollution prevention and control is on aspects such as promotion of clean and low-waste technology, re-use or recycling, improvement of water quality, natural resource accounting, institutional and human resource development, control of pollution at source rather than the traditional end of the pipe treatment.

The major benefit of this approach, as perceived by the MoEF is that when waste is reduced and/ or eliminated or solvents are re-extracted and reused; it leads to resource conservation during various industrial processes and minimizes the levels of pollutants in the surrounding environment.

The MoEF deals with prevention and control of pollution by adopting a multi-pronged approach. Emphasis is placed on the development of environmental standards, waste minimization circles, environmental epidemiological studies, preparation of zoning atlas for industrial sites, control of vehicular pollution, promotion of environment education

[2] Legislative Matters, *State of the Environment Report, 1999.*

and awareness, and natural resource protection, etc. Major activities carried out by the MoEF, under several programs include:

1. **The Taj Protection Mission**

Based on Supreme Court directives and rulings, various programs related to the protection of the Taj Mahal on 50:50 cost share basis, between the Central & State governments, were recommended by the Planning Commission.

A Mission Management Board under the Chairmanship of the Chief Secretary of the State of Uttar Pradesh (U.P.) was established to oversee the implementation, monitoring and review of the various proposed programs. Ten projects were submitted relating to uninterrupted power supply, increase in water supply, improvement of drainage and sanitation, city/municipal tree planting schemes in the context of environmental protection of the Taj Mahal.

2. **Environmental Health**

The MoEF also established a Committee on "Environment and Health" to review the status of Environmental Health and to develop appropriate policy, strategy and action plans for environmental health. Within the MoEF an Environmental Health Cell has been created, which is responsible for implementing the recommendations of the Committee. Environmental epidemiological studies have been initiated in 11 areas to assess the health impacts due to the effect of pollution. The MoEF also commissioned the preparation of a National Environmental Health Profile and studies on comparative health risk assessments in eight cities. A project to study benzene exposure and its adverse health effects has also been commissioned.

3. **Environmental Statement (as Part of Environmental Audit)**

The submission of an Environmental Statement, to the concerned Sate Pollution Control Boards, by polluting units seeking consent to proceed with operations, either under the 1974 Water (Prevention and Control of Pollution) Act, or the 1981 Air (Prevention and Control of Pollution) Act, or both as well as for the required authorization under the 1989 Hazardous Wastes (Management and Handling) Rules, has been made mandatory through a Gazette Notification under the Environment (Protection) Act of 1986.

The Environmental Statement enables the units to take a comprehensive look at their industrial operations and facilitates understanding of material flows and focus on areas were waste reduction and consequently savings in input cost is possible.

4. Status of Pollution Control in 17 Categories of identified Highly Polluting Industries

The Central Pollution Control Board (CPCB) has identified 1,551 large and medium industrial units in 17 industrial categories as being highly polluting units and these have been given specific timeframes within which to install the necessary pollution control equipment to comply with the established standards. Progress towards complying within the specified timeframes is monitored, and quarterly reports are prepared by CPCB based on the inputs received from the concerned State Pollution Control Boards (SPCBs).

As of 31 December 2001, out of the identified offending 1,551units, 1,350 have implemented the required pollution control equipment, 177 industries have been closed down and the remaining 24 industries are still in default. Legal action has been taken against these 24 units, under the provisions of the 1986 Environment (Protection) Act.

5. Development of Environmental Standards

The MoEF is responsible for developing and issuing industry specific as well as general effluent and emission standards for different categories of industries under the 1986 Environment Act. So far the Ministry has set up environmental standards for almost all categories of polluting industries. The standards for certain categories are being reviewed. During 2001 two Expert Committee meetings were held to review the standards for soda ash, brick kilns, coke oven plants, and diesel-generator sets.

6. Recognition of Environmental Laboratories under the Environment (Protection) Act, 1986

Under Section 12 and 13 of the 1986 Environment Act, the MoEF provides national recognition for environmental laboratories and the Government Analysts working in the laboratories to carry out the functions entrusted to them under the Act. While powers for approval of environment laboratories of the Government and autonomous organizations have been delegated to the Central Pollution Control Board, the laboratories in the private sector have to be approved by the Ministry.

The Ministry also participates in the joint inspection of environmental laboratories with CPCB, State Pollution Control Board and Pollution Control Committees. All the recognized laboratories have to participate in the annual Analytical Quality Control (AQC) exercise conducted by the CPCB.

7. Industrial Pollution Complaints

During 2001, MoEF received more than 350 complaints from various individuals, organizations, and/or NGOs regarding pollution caused by certain industries. Air pollution complaints were received against cement-making units, thermal power plants and brick kiln units and complaints of water pollution were received against sugar mills, distilleries, tanneries, paper and pulp industries. Based on the reports of the Pollution

Control Boards, the offending units were directed to provide the necessary pollution control measures.

8. Green Belt for Abatement of Pollution and Environmental Improvement in Cities/Town in Tamil Nadu

A "Green Belt for Abatement of Pollution and Environmental Improvement" program has been launched in five cities/towns of Tamil Nadu (Chennai, Salem, Coimbatore, Madurai and Tirunelveli) and in 102 Municipalities. The objectives are to reduce the adverse effects of air, water and noise pollution and to improve the aesthetic beauty of the specific urban and municipal areas. The implementation approach is mainly through awareness building and involvement of people in planting and protecting the trees. The participating agencies include Forest Departments, NGOs, Public Works Departments, Highways Department, Revenue Department, Local Bodies, industrialists and Industry Associations.

9. Urban Environment

The Urban Environment Information System is designed to develop a database for the fast growing urban centers, in coordination with local municipalities. The objective of this program is to:

- Develop awareness among politicians and local administration of the local environmental problems and improvements needed.
- Inform people of the local situation and improvements achieved from year to year.
- Help identify key environmental issues.
- Undertake detailed studies, such as environmental management plans (EMPs) and other environmental assessments, in order to prepare detailed actions plans for implementation of various measures to protect and conserve environment.
- Bring competition among the different wards of the municipalities and among the various cities & towns for improving the environment.

10. Assistance for Abatement of Pollution

Under this scheme, the Central Government is to provide grants-in-aid funding to the State Pollution Control Boards, Environment Departments of State Governments and Pollution Control Committees of Union Territories, with the aim of strengthening their technical capabilities. Assistance is also provided for various environmental pollution control programs and projects.

11. Zoning Atlas

A Zoning Atlas (Spatial Environment Planning) Program was taken up by the Central Pollution Control Board under the Environment Management Capacity Building

Technical Assistance Project of the World Bank. The various activities undertaken during 2001 include the following, among others:

(a) **District-wise Zoning Atlas for citing of industries -** Work has begun in 53 districts covering 16 states including Andhra Pradesh, Assam, Bihar, Gujarat Manipur, Jammu & Kashmir, Tamil Nadu, Uttar Pradesh, Karnataka, Kerala and West Bengal.

(b) **Industrial estate planning studies -** Industrial estate planning studies have been started for 15 sites. A manual has been developed for undertaking similar studies in other parts of the country.

(c) **Mapping of environmentally sensitive zones and industrial sites on a State basis -** Work has been completed for the States of Bihar, Meghalya, Kerala, Goa and Andhra Pradesh, Maharashtra, Karnataka, and Jammu & Kashmir. Work is continuing in the States of Orissa, Gujarat, Tamil Nadu, Manipur, West Bengal, Uttar Pradesh, Punjab, Assam and Rajasthan.

(d) **Environmental management plans (EMPs) for urban areas, mining areas, and other environmentally fragile areas including tourism sites -** Preparation of EMPs for the Taj Trapezium Zone (Uttar Pradesh), the mining areas of Dhanbad (Jharkand), Korba (Madhya Pradesh), the residential township of Vasai Virar of Thane district (Maharashtra), the tourism areas of Bakel Fort (Kerala) and the biosphere reserve of Panchmarhi (Madhya Pradesh) is in progress.

(e) **Environmental Atlas of India –** Joint compilation of various environmental related information, presented in the format of maps and text, by the CPCB and NATMO. The mapping work of the Atlas has been completed.

(f) **Capacity Building in the field of Spatial Environmental Planning -** A national center for Spatial Environmental Planning has been created at CPCB for undertaking various environmental planning and mapping tasks.

(g) **Training -** Overseas training on 'Spatial Environmental Planning' was held for working level officers during the year. In addition, on-the-job training is provided to technical teams from the SPCBs and executing agencies on an ad hoc basis by the CPCB.

(h) **Infrastructure Development -** The operating and technical infrastructure including GIS hardware and software, audio-visual equipment and cartographic equipment have been installed at CPCB for undertaking spatial environmental planning.

Control of Vehicular Pollution

The MoEF plays a coordinating role with the concerned ministries and its associated bodies/organization including the Ministry of Road Transport & Highways, the Ministry of Petroleum and Natural Gas, the Ministry of Heavy Industries and Public Enterprises for improvements in automobile technology, improvement in fuel quality, expansion of urban public transport systems and promotion of integrated traffic management as the vehicular emissions is the major cause for deterioration of urban ambient air quality.

In co-ordination with the MoEF, the Ministry of Road Transport & Highways has issued the following recent notifications:

- GSR 779(E), dated 29 August, 2000 extended the more stringent three emission standards known as Bharat Stage II (which are similar to the Euro-II emission standards) for registration of motor cars and Four-wheeler Passenger Vehicles with Gross Vehicle Weight (GVW) equal to or less than 3500 kilograms in Kolkata and Chennai effective from July 1, 2001. These standards were already in effect within the NCT of Delhi and in Mumbai (including Greater Mumbai) since April 1, 2000 and January1, 2001 respectively.
- GSR 286(E) dated 24 April, 2001, notified *inter-alia* Mass Emission Standards for vehicles with GVW exceeding 3500 kilograms and the same was made effective in the NCT of Delhi six months later, October 24, 2001. Based on S.O. 731(E) dated 31 July 2001, these standards were extended to Mumbai (including Greater Mumbai), Kolkata and Chennai were made effective from October 31, 2001.
- GSR 284 (E) dated 24April, 2001, notified Mass Emission Standards for Liquefied Petroleum Gas (LPG) driven vehicles this was made effective from 24 May 2001.
- GSR 853(E) dated 19 November 2001, notified Mass Emission Standards for Compressed Natural Gas (CNG) driven vehicles to be in effect six months later. This notification also included safety and procedural requirements for approval of CNG and LPG operated vehicles, the role of the test agency, the responsibilities of vehicle/kit manufacture/kit supplier, the responsibility of owners/users and the statutory requirements of registration of vehicles. The notification No. GSR 99(E) dated 9 February 2000 specifying Mass Emission Standards for Compressed Natural Gas (CNG) driven vehicles expires, once the new notification comes into force.

Environment Pollution (Prevention and Control) Authority (EPCA) for the National Capital Region has submitted its XI and XII Progress Reports. These Reports include the steps taken to mitigate and the monitoring of various measures for control of vehicular pollution. The Authority submitted special reports on Clean Fuels and Standards for CNG vehicles and Refilling Stations with specific recommendations as directed by the Supreme Court. As a result of the monitoring by the Authority, gasoline with a maximum of 1% benzene has been made available in the NCR from April 1, 2001 and 87 CNG stations have been commissioned with about 53,302 vehicles including 3,727 buses now operating on CNG in Delhi.

In Mumbai, 24 CNG outlets are in operation with about 26,296 CNG-fueled vehicles.

The MoEF is also working within an Expert Committee established by the Ministry of Petroleum and Natural Gas in September 2001 to prepare an "Auto Fuel Policy" for the entire country, including major cities. The aim is to develop an implementation program, taking into account the vehicular emission standards (as recommended by the Inter-Ministerial Task Force to the Ministry of Petroleum and Natural Gas) and the work on ethanol blending of gasoline and use of bio-fuels in transportation (as done by the group set up by the Ministries of Petroleum and Natural Gas and Non-conventional Energy Sources). This Committee submitted its interim report to the Government in January 2002 and has been accepted.

Central Pollution Control Board

The Central Pollution Control Board (CPCB), an autonomous body of the MoEF which was set up in September 1974, coordinates the activities of the State Pollution Control Boards (SPCBs) and the Pollution Control Committees (PCCs) and advises the Central Government on issues concerning the prevention and control of environmental pollution. CPCB, SPCBs and the PCCs are responsible for implementing legislation relating to prevention and control of pollution. The CPCB also provides technical services to the MoEF for implementing the provisions of the 1986 Environmental Act.

During 2001, the CBCB emphasized a nation-wide pollution prevention plan, particularly with respect to mitigating vehicular pollution, pollution control in 17 highly polluting industries, implementation of action plans for restoration of environmental quality in adversely affected areas, noise pollution control and proper management of solid waste, hazardous waste and bio-medical waste.

Illustrative activities of CPCB during 2001 are given below:

Ambient Air Quality Monitoring

The Central Pollution Control Board (CPCB) in collaboration with the State Pollution Control Boards (SPCBs) established a National Ambient Air Quality Monitoring (NAMP) network, comprising 290 stations in 92 cities/towns to collect, compile and disseminate information on air quality.

The ambient air quality is monitored by the CPCB, SPCBs, and the Pollution Control Committees and by some universities and special institutes. The data generated is transmitted to CPCB for verification, analysis, compilation and publication in a consolidated report.

The air quality of different cities/towns, with respect to three critical pollutants, is compared with the respective National Ambient Air Quality Standards and is then placed into four broad categories based on an Exceedence Factor (EF) as calculated by the following ratio.

$$\textbf{Exceedence Factor (EF)} = \frac{\text{Observed Annual mean concentration of criteria pollutant}}{\text{Annual standard for the respective pollutant and area class}}$$

The four air quality categories are:

- Critical pollution (C): When EF is more than 1.5;
- High pollution (H): When the EF is between 1.0-1.5;
- Moderate pollution (M): with and EF between 0.5-1.0; and
- Low pollution (L): where the EF is less than 0.5

(a) Trace Metal in Ambient Air of Delhi

The monitoring of lead, cadmium and zinc in the ambient air of Delhi has been underway since 1992. In January 2000, four more metals - chromium, copper, zinc and nickel - were added to this list. Iron concentration was found to be high in all types of land use areas. Copper and zinc were also present in significant amount but their levels were 3 and 5 times lower than iron. After the introduction of unleaded gasoline in Delhi, the level of lead has gone down drastically and is well below the national ambient air quality standards. The presence of cadmium, chromium and nickel was low.

(b) Trend Analysis of Air Pollution in Delhi

A decrease in the annual average of SOx was observed in industrial areas of Delhi. The annual mean concentration of SOx did not exceed the National Ambient Air Quality Standards (NAAQS) (annual average) during all the years in which monitoring has taken place. The decreasing trend might be due to the introduction of low-sulfur diesel fuel in Delhi.

A decreasing trend in NOx levels was also observed, which might be due to the prohibition on use of commercial vehicles that are more than 15 years old in the National Capital Region.

High levels of CO were observed in Delhi due to the increase in the number of vehicles, especially passenger cars.

OTHER STEPS TAKEN BY GOVERNMENT TO CONTROL AIR POLLUTION IN DELHI

A. Government of National Capital Region of Delhi

The Supreme Court has issued directives for control of vehicular pollution in Delhi in its orders dated 28-7-98 and 22-9-98 in the Writ Petition (Civil) No. 13029/1985 in the matter of M.C. Mehta vs Union of India and others for General Notice of the public. The measures taken include:

- Restricted use of all Commercial Vehicles including taxis, which are 15 years or older from October 2, 1998.
- Restrictions on use of commercial vehicles during the day, to be strictly enforced from August15, 1998.
- Expansion of older pre-mixed fuel pumps (Petrol and 2T oil) to be stopped from December 31, 1998.

- Ban on the supply of loose 2T oils at petrol stations and service garages to be enforced December 31, 1998.
- The following time plans are to be adhered to in respect of the specific items indicated by all the relevant authorities:

1) Augmentation of public transport (stage carriage) to 10,000 buses.	1.4.2001
2) Elimination of leaded petrol from NCT of Delhi	1.9.1998
3) Supply of only pre-mix petrol in filing stations to two-stroke engine vehicles.	31.12.1998
4) Replacement of all pre-1990 autos and taxis with new vehicles on clean fuels.	31.3.2000
5) Financial incentives for replacement of all post –1990 autos and taxis with new vehicles on clean fuels.	31.3.2001
6) No 8-year old buses to ply except on CNG or other clean fuels.	1.4.2000
7) Entire city bus felt (DTC & Private) to be steadily converted to single fuel mode on CNG.	31.3.2001
8) New ISBTs to be built at entry points in north and Southwest to avoid pollution due to entry of inter-state buses.	31.3.2000
9) GAIL to expedite and expand from 9 to 80 CNG supply outlets.	31.3.2000
10) Two independent fuel-testing labs to be established.	1.6.1999
11) Automated inspection and maintenance facilities to be set up for commercial vehicles in the first phase.	Immediate
12) Compressive I/M program to be started by the Transport Department & private sector.	31.3.2000
13) CPCB/DPCC to set up new stations and strengthen existing air quality monitoring stations for critical pollutants.	1.4.2000

B. Additional steps taken to control pollution in Delhi include the following:

1. The Government has formulated a comprehensive Policy for Abatement of Pollution that lays stress on both the control and preventive aspects of pollution;
2. The ambient air quality of Delhi is monitored regularly through a network of monitoring stations under the National Ambient Air Quality Monitoring Program;
3. Ambient air quality standards and emission standards for industrial units have been notified;
4. Emissions from highly polluting industrial units and thermal power plants are regularly monitored and action is taken against the defaulting units;
5. Unleaded petrol is now available throughout the country. Sulfur content in petrol/diesel also has been reduced.
6. Gross emission standards for on-road vehicles and mass emissions standards for all categories of new vehicles have been notified under the Central Motor Vehicles Rules, 1989. More stringent emissions norms have also been notified.
7. Fiscal incentives are provided for installation of CNG kits.

Source: Rajya Sabha Unstarred Q.No. 663; 28th July, 2000

C. Conceptual framework drawn up by Indian Government to convert some major cities into ECO cities

The Government has drawn up a conceptual framework for Eco-cities. State Government agencies have been asked to draw up Environmental Management Plans for the following cities: Delhi, Mumbai, Calcutta, Chennai, Bangalore, Hyderabad and Ahmedabad.

No foreign collaboration has been envisaged as yet for development of such Eco-cities. The steps taken by Government to check generation of pollution in the cities include:

- (i) Ambient air and water quality standards have been laid down;
- (ii) A network of ambient air quality and water quality monitoring stations have been established;
- (iii) Green belt for abatement of pollution and environmental improvement has been initiated in five cities/towns and 102 municipalities in Tamil Nadu;
- (iv) Preparation of Zoning Atlas for siting of industries based upon environmental considerations in various districts of the country has been taken up;
- (v) Action Plan for ensuring proper management of municipal solid waste in Delhi has been prepared;
- (vi) Action Plans for control of pollution in Delhi and Mumbai are being implemented;
- (vii) 24 critically polluted areas have been identified. Action plans have been drawn for restoration of environmental quality in these areas;
- (viii) Urban environment management plans for Kanpur and Haldia have been prepared;
- (ix) Emission standards for vehicles are being enforced;
- (x) CNG is supplied for automobiles through a number of retail outlets in Delhi and Mumbai to cater to the CNG fitted vehicles;
- *(xi)* Public awareness campaign on the effects of pollution has been launched.

Source: Rajya Sabha Unstarred Q.No. 2201; 11th August, 2000

D. Measures taken by the Government to regulate and control noise

The Government has taken several measures to regulate and control noise pollution, including the following: - (i) Noise pollution is regulated under the Air (Prevention & Control of Pollution) Act and the Environment (Protection Act.
Ambient noise standards have been prescribed under the Environment Protection Act for automobiles, domestic appliances and construction equipment at the manufacturing stage.

Source : Lok Sabha Starred Q.No. 398; 21st August, 2000

E. Taj trapezium zone pollution (prevention & control) authority

MINISTRY OF ENVIRONMENT AND FORESTS ORDER New Delhi, the 13th May, 1998 Order S.O. 350 (E):

In exercise of the powers conferred by sub-sections (1) and (3) of section 3 of the Environment (Protection) Act, 1986(29 of 1986) (hereinafter referred to as the said Act), the Central Government hereby constitutes an authority to be known as the Taj Trapezium Zone Pollution (Prevention and Control) Authority (herein referred to as the Authority) consisting of the following persons for a period of two years with effect from the date of publication of this notification in the Official Gazette, namely :-

(1) Commissioner, Agra Division as Chairman;
(2) Chairman, Utter Pradesh State Pollution Control Board as Member;
(3) Deputy Inspector General of Police, Agra Range as Member;
(4) Member-Secretary, Central Pollution Control Board as Member;
(5) A representative of the Ministry of Petroleum and Natural Gas as Member;
(6) A representative of the Ministry of Environment and Forests as Member;
(7) A representative of the Archaeological Survey of India as Member;
(8) Vice-Chairman, Agra Development Authority as Member-Convener.

The authority shall, within the geographical limits of Agra Division in the Taj Trapezium Zone in the State of Uttar Pradesh, have the power to:

(i) monitor progress of the implementation of various schemes for protection of the Taj Mahal and programs for protection and improvement of the environment in the above said area;
(ii) exercise powers under section 5 of the said act;
(iii) take all necessary steps to ensure Compliance of specified emission-standards by motor vehicles and ensuring compliance of fuel quality standards;
(iv) deal with any environmental issue which may be referred to it by the Central Government or the State Government of Uttar Pradesh relating to the above said area;

The foregoing powers and functions of the Authority shall be subject to the overall supervision and control of the Central Government.

The Authority shall be authorized to exercise the powers under section 19 of the said Act.

The geographical limits of the Taj Trapezium Zone have been defined in the shape of a trapezoid between 26 45 N & 77 15'E to 27 45 N & 77 15 E in the West of the Taj Mahal and in the East of Taj Mahal between 27 00' N & 78 30 E to 27 30' N & 78 30 E.

The Authority may co-opt experts for facilitating the work assigned to it.

The Authority shall furnish a report about its activities at least once in two months to the Central Government in the Ministry of Environment and Forests.

The Authority shall have its headquarters at Agra in the State of Uttar Pradesh.

Source: MINISTRY OF ENVIRONMENT AND FORESTS, Vijai Sharma, Jt. Secy, 1 October, 1999

F. Fuel quality aspects related to auto emissions and challenges ahead

Stricter emission norms being enforced in India with the recent order of Supreme Court will require automobile industry to introduce newer technologies for vehicles.

Since the pollution from automobiles depends upon the engine technology as well as fuel quality, the whole issue has to be addressed through common programs to find cost effective solutions in terms of improved automobile technologies and enhanced fuel properties. There are specific fuel properties that have direct impact on emissions. These have been identified through the US Auto Oil Program as well as European EPEFE (European Programme on Emissions, Fuels and Engine Technologies). Steps being taken to improve the fuel quality in India with specific reference to the parameters given in tables and under Indian situation have been highlighted. The efforts of petroleum industry towards meeting these challenges including cost implications have been discussed below.

The problem of pollution in the Indian cities particularly Delhi has reached an alarming stage. A rapid increase in the vehicle population in Delhi from 0.2 million in 1970 to 3.3 millions in 1997 is a major contributor to the pollution in the city. Poor maintenance practices, use of older vehicles, worsening traffic conditions and fuel adulteration add to this growing pollution.

While US started emission control activities in 1970s, India started such actions only in 1991 when emission standards were made applicable for the automobiles produced in India. Initial emission norms in India have been very mild and stricter norms came into effect only from the year 1996.

But the real stringent emission norms have come about with the recent order of Supreme Court asking for all the non commercial private vehicles to meet the Euro I norms immediately i.e. by June, 1999 and Euro II norms by April, 2000.

These emission norms will bring about new engine technologies in the country. While the automobile manufacturers are actively trying to deal with this situation and are making considerable efforts to meet this challenge, petroleum companies in the country are looking at it as a much bigger challenge ahead. The engine technology and the fuel quality have to improve together and be compatible with each other. At the same time, fuel quality upgrades are being demanded to reduce emissions from the current 'in-use' fleet of vehicles.

1. VEHICLE EMISSION NORMS IN INDIA:

Emission norms effective from 1996 and year 2000 for passenger cars & two/three wheelers are given in Table 1.

The emission norms for diesel vehicles applicable in India for April 2000 have been indicated in Table 2.

In Table 3, the Euro I and Euro II emission norms for passenger cars are indicated. In the same Table, the limiting values for Euro III and Euro IV norms have also been given.

The Supreme Court Order of 14th April, 1999 has superseded the earlier gazette notification for emission norms for the year 2000 for petrol and diesel cars to be registered in the National

Capital Region. However, the emission norms for two and three wheelers would remain the same, which in any case are one of the most stringent in the world.

With respect to fuel quality requirements, it may be noted that the emission testing for compliance of norms is carried out with the reference fuel and the directive pertaining to Euro I or Euro II norms does not make any reference to the quality of commercial fuel. The emission from in-use vehicles running on commercial fuel may therefore be higher than those new vehicles complying with the Euro II & I standards.

This implies that in-spite of having stricter emission standards the ambient air quality will continue to deteriorate unless measures are taken for reducing emissions from "in use" fleet of vehicles. This has led to simultaneous revisions in the fuel quality specifications. While Euro I norms implementation did not warrant any major fuel specification changes, the implementation of Euro II norms were preceded by a Directive 93/12/EEC dated 23rd March, 1993 relating to sulfur content. The sulfur content in diesel was reduced from the level of 2% w/w to 0.05% w/w by October 1996.

2. INDIAN FUEL SPECIFICATIONS AND RECOMMENDATIONS FOR FUTURE:

The Bureau of Indian Standards in May 1999 accepted the earlier target specification for the year 2000 and these are shown Tables 4a & 4b.

However, the Ministry of Surface Transport and the Ministry of Industry have been putting pressure for further fuel quality changes particularly with respect to meeting the Euro II norms. The expected recommendation is with regard to reduction of sulfur to 0.05% in diesel fuel.

In future, the fuel specifications for gasoline as well as diesel will have to be revised and perhaps brought in line with the European specifications. The time lag will also have to be bridged.

The expected likely changes in specifications of gasoline and diesel in India are discussed below:

GASOLINE:

Octane Number
Although, the octane number has no direct correlation with the emission control, the automobile industry has been seeking upward revision in various forums. According to them, this revision is essential to enable them to bring in the latest technology into the country. As this parameter cannot be handled in isolation. The present BIS specification stipulates a 87 octane number which will be revised in the year 2000 when Anti Knock Index (AKI) R+M/2 will be introduced with a limit of 84 which is significantly lower than the European limit of around 90 for the lowest grade which indicates that India may have to revise this specification significantly upward in the year 2005.

Oxygen Content
The international specification puts the oxygen limit at a maximum of 2.7% in the fuel. Although, the European specification does not specify any minimum limit for oxygen in the fuel, the US Clean Air Act of 1990 has specified that oxygenates must be used in the gasoline sold in 41 cities which are under non attainment limits of carbon monoxide. The Ministry of Environment has been deliberating for specifying mandatory use of oxygenates for the gasoline sold in the National Capital Region with a view to control carbon monoxide emissions particularly in winter months.

Benzene
Benzene limit is 5% max but the Ministry of Environment under the Environment Protection Act (EPA) have issued notification for limiting this to 3% in the National Capital Region. There are demands for restricting this to 1% in near future. This limit of 1 % in any case will have to be implemented in future all over the country.

Aromatics & Olefins
Presently, there are no limits for aromatics in the gasoline but in future India may have to limit the aromatics up to a maximum of 35/40%. Similarly, the limits for olefins at around 20/15% may have to be implemented.

Sulfur Content
The sulfur content limit as per BIS specification for the year 2000 will be 0.1 % which may have to be brought down to a level of 0.05% in the next couple of years while limit of 150/50 ppm may have to be implemented by the year 2005. It may be noted that sulfur has a deleterious effect on the efficiency of catalytic converters.

Multifunctional Additive
The use of multifunctional additive is mandatory under US Clean Air Act of 1990. The World Fuel Charter also suggests the use of fuel injector cleanliness/intake valve cleanliness/combustion chamber deposit additives. Since India has already started use of multifunctional additives, this needs to be continued as this helps in control of emissions.

DIESEL FUEL:

Cetane Number
The specification as per BIS for the year 2000 is 48 min. while the European specification would be 51 in 2000 and 53 in 2005. Since most of the diesel engine technology particularly for passenger cars is coming from the European market, the automobile industry is likely to seek harmonization with European specification on this account. Furthermore, the cetane number has significant effect on emissions and the demand of automobile industry is likely to be supported by the Ministry of Environment, the limit may therefore have to be revised upward in the year 2005 to 51/53.

Sulfur Content
The sulfur content in diesel fuel has a direct correlation with the particulate emissions and with the implementation of Euro II norms for non commercial vehicles. The Ministry of Surface Transport and the Ministry of Industry have already sought the reduction of sulfur in diesel to 0.05%. This limit will have to be implemented at least for the cars complying with the Euro II norms from April 2000. The limit may have to be further tightened to 350 ppm and 50 ppm when emission norms corresponding to Euro III and Euro IV are implemented.

The changes expected in Gasoline and Diesel fuel specifications in India by year 2005 are summarized in Tables 5a & 5b.

3. COST IMPLICATIONS FOR FUEL QUALITY CHANGES IN INDIA:

The achievement of fuel quality targets as described above for implementation by the year 2005 would require major investments in Indian refineries during the year 2000-2005.

The refineries will have to do a thorough study of various options available to them for meeting the above specifications and this will be a very challenging task in the years ahead. Whereas new refineries can incorporate technologies for meeting the product quality required for the future, the existing refineries in most cases will have to modify / augment their existing processes by incorporating new technologies for which they will have to create facilities / infrastructure.

The major additional equipment to be installed in Indian refineries to meet the above targets will be diesel hydro-desulfurisation reactors for producing low sulfur diesel; aromatic extraction units; isomerisation units; DHDS revamping at some of the refineries such as those in Mathura and Panipat.

The estimated total investment envisaged by the Centre for High Technology (CHT) for implementing various projects in PSU refineries for upgrading of fuel quality comes to around Rs. 13,500 Crores [US$ 3 Billion]. This has been broken down as Rs. 3500 Crores {approximately US$ 778 million} for gasoline and Rs. 10,000 Crores {approximately US$ 2.220 Billion} for diesel.

This figure may go up substantially if Indian fuel quality has to be brought in line with Euro III and Euro IV.

This will also increase the cost of fuel to be produced and sold in a deregulated scenario. India may have to consider implementing the above plans in a phased manner and market two grades of fuels for different categories of vehicles i.e. complying to less stringent and complying to more stringent norms. The issue however, needs greater examination and the cost benefit analysis needs to be carried out by the automobile industry, oil industry and environmentalists. The idea should be to derive the maximum benefit for the improvement of environment quality if the huge investments are to be made in refineries.

TABLE – 1
EXHAUST EMISSION STANDARDS FOR INDIAN GASOLINE VEHICLES

Category of Vehicles &Exhaust Emissions	Std. Effective April 1991	Std. Effective April, 1996	Std. Effective 1-4-2000
Two Wheelers :			
(a) CO g/km	12-30	4.5	2.0
(b) HC g/km	8-12	-	-
(c) (HC+NOx) g/km	-	3.6	2.0
Three Wheelers			
(a) Co g/km	12-30	6.75	4.0
(b) HC g/km	8-12	-	-
(c) (HC+NOx) g/km	-	5.40	2.0
Passenger Cars			
(a) CO g/km	14.3-27.1	8.68-12.40	2.72
(b) HC g/km	2.0-2.9	-	-
(c) (HC+NOx) g/km	-	3.00-4.36	0.97

TABLE -2
EXHAUST EMISSION STANDARDS FOR INDIAN DIESEL VEHICLES

Category of Vehicles &Exhaust Emissions	Std. Effective April 1991	Std. Effective April, 1996	Std. Effective 1-4-2000
A: Gross Vehicle Weight >3.5 Ton			
(a) CO g/kWh	14.0	11.2	4.5
(b) HC g.kWh	3.5	2.4	1.1
(c) NOx g/kWh	18.0	14.4	8.0
(d) PM g/kWWh	-	-	0.36
B: Gross Vehicle Weight <3.t Ton			
(a) CO g/km	14.3 - 27.1	5.0-9.0	2.72-6.90
(b) JC+NOx g/km**	2.7-6.9	2.0-40	0.97-1.70

* EURO-1 w.e.f 1.6.99 and Euro II w.e.f. 1.4.2000 for private (non-commercial) vehicles in NCR.
** Chassis dynamometer test

TABLE 3
EUROPEAN EMISSION STANDARDS FOR PASSENGER CARS

GASOLINE CARS EMISSION LIMITS

Exhaust emission ingredients	Introduction CVS Procedure from 1982 (g/km)	EU 1 From 1992 (g/km)	EU 2 basis (new test) from 1996 (g/km)	EU 3 From 2000 (g/km)	EU 4 From 2005 (g/km)
CO	20.7	2.72	2.2	2.3	1.0
HC+NOx	5.8	0.97	0.50		
HC				0.20	0.10
NOx				0.15	0.08

DIESEL CARS EMISSION LIMITS

Exhaust emission ingredients	Introduction CVS Procedure From 1982 (g/km)	EU 1 From 1992 (g/km)	EU 2 basis (new test) From 1996 (g/km)	EU 3 From 2000 (g/km)	EU 4 From 2005 (g/km)
CO	20.7	2.72	1.06	0.64	0.50
HC+NOx	5.8	0.97	0.71	0.56	0.30
HC NOx			0.566	0.50	0.25
PM		0.14	0.080	0.05	0.025

TABLE - 4a
REQUIREMENTS FOR MOTOR GASOLINE

Sr. No.	Characteristics	Requirements		
		Leaded Regular	Unleaded Regular	Unleaded Premium
1.	Color visual	Orange	Colorless	Red
2.	Density, 15°C, kg/m3	710-770	710-770	710-770
3.	Distillation:			
	a) Recovery upto 70°C (E70) (%) by volume.	10-45	10-45	10-45
	b) Recovery upto 100°C (El 00), (%) by volume.	40-70	40-70	40-70
	c) Recovery upto 180°C (E 180), (%) by volume, Min.	90	90	90
	d) Final boiling point (FBP), Max.	215°C	215°C	215°C
	e) Residue, percent by volume, Max.	2	2	2
4.	Antiknock index (AKI), min.	84	84	88
5.	Existent gum, g/m3, max.	40	40	40
6.	Potential gum, g/m3, max.	50	50	50
7.	Sulfur, total, percent by mass, max.	0.20	0.10	0.10
8.	Lead content (as Pb), g/l, max.	0.15	0.013	0.013
9.	Reid vapor pressure (RVP), kpa	35-60	35-60	35-60
10.	Vapor lock index (VLI), (VLI=10RVP+7E 70), max.			
	a) Summer	750	750	750
	b) Other months	950	950	950
11.	Benzene content, percent by volume, max.	5.0	5.0	5.0
12.	Copper strip corrosion for 3 h at 50°C	Not more than no 1		

13. Water tolerance of gasoline alcohol blends, temperature for phase separation, °C, max.			
a) Summer	10	10	10
b) Winter	0	0	0

TABLE - 4b
REQUIREMENTS FOR DIESEL FUELS

Sr. No. Characteristics	Requirement HSD	LDO
1. Acidity, inorganic	Nil	Nil
2. Acidity, total, mg of KOH/g, max.	0.20	-
3. Ash, percent by mass, max.	0.01	0.02
4. Carbon residue (ramsbottom) on 10 Percent residue, percent by mass, max.	0.30	1.5
5. Cetane number, min.	48	-
6 Pour point, max.		
Winter	3°C summer	12°C for winter &
Summer	15°C	21 °C for summer
7. Copper strip corrosion for 3h at 100°C	Not worse than no. 1	Not worse than no. 2
8. Distillation:		
85 percent volume recovery at °C, max.	350	
95 percent volume recovery at °C, max.	370	
9. Flash point:		
a) Abel, °c, min.	35	-
b) Pensky, martens, °C. min.	-	66
10. Kinematic viscosity, cst, 40°C	2.0 -5.0	2.5 -15.7
11. Sediment percent by mass max.	0.05	0.10

12. Density at 15°C, kg/m3	820-860	To be reported
13. Total sulfur, percent by mass, max.	0.25	1.8
14. Water content, percent by volume, max.	0.05	0.25
15. Cold filter plugging point (CFPP), max.	6°C for winter & 18°C for summer	
16. Total sediments, mg per 100 ml, max.	1.6	-

TABLE - 5a

CHANGES EXPECTED IN GASOLINE SPECIFICATIONS BY YEAR 2005

PROPERTY	2000 SPEC.	EXPECTED 2005 SPEC.
Octane Number, AKI	84	88
Oxygen Content	Oxygenates Allowed	Oxygenates Mandatory
Benzene, % v/v max	5% (3% in NCR)	1%
Aromatics, % v/v max	No Limit	35/40
Olefins, % v/v max	No limit	20/15
Sulpher, % m/m max	0.1 (may be 0.05 in NCR)	0.015/0.005
Lead Content,gm/ltr	0.013	Not Detectable

TABLE - 5b

CHANGES EXPECTED IN DIESEL SPECIFICATIONS BY YEAR 2005

PROPERTY	2000 SPEC.	EXPECTED 2005 SPEC.
Cetane Number	48	51/53
Sulpher, % m/m max.	0.2 (may be 0.05 in NCR for Euro II cars)	0.035/0.005
T 95, deg C	370	360/350
Polyaromatics, % v/v	No Limit	11 %

SOURCE: INDIAN OIL CORPORATION LTD.; 17TH JULY, 1999

G. Other publicized measures:

a) In Mumbai an exclusion zone within which no conventional autorickshaws can be operated;
b) In New Delhi:
   1. retirement of older vehicles from road usage has been phased in for vehicles older than 30 years, 15 years and 10 years;
   2. all commercial buses, taxis and autorickshaws must be powered by alternative technologies by April 2001;
   3. all 2-wheelers that are 15 years or older must be retired from road use by January 2001;
c) In Mumbai the following article recently appeared in The Times of India:
   "*Mumbai cabs should run on petrol, CNG: High court*"

In a stern measure to curb pollution in the metropolis, the Mumbai High Court has directed the transport commissioner, regional transport authority and the police to ensure that all the 12,000-odd taxis in the city were fitted with petrol engines or run on compressed natural gas (CNG) from November 1.
The order was delivered by Chief Justice B P Singh and Justice S Radhakrishnan who heard a petition filed by smoke affected residents forum. The court directed the authorities on October 20 to forthwith suspend the registration of any such vehicle which run on diesel or fitted with three cylinder engines. Such vehicles would not be entitled to ply unless they switched over to petrol engines or they were run on CNG. The court also ruled that the authorities would impound relevant documents such as RC book and motor vehicle tax book of such vehicles whose registration had been suspended. A sticker would be pasted on the front glass of the vehicle and an entry endorsed to this effect in the RC book. If any taxi owner tampered with the sticker and plied his vehicle, its registration would be cancelled and action taken against him in accordance with law. But if a taxi had converted its engine into a petrol one then its registration would be restored, the judges ordered. Mahanagar taxi union urged that the court order be extended until December 31 but its plea was rejected. The matter is adjourned to November 15.
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