CLEAN HYDROGEN TECHNOLOGY FOR 3-WHEEL TRANSPORTATION IN INDIA

Final Report

Project Duration: From February 1, 2004-November 30, 2005

Principal Investigator/Author: Krishna Sapru, Ph.D.

DOE Award No: DE-FC26-04NT42060

Submitted by: Energy Conversion Devices, Inc.
2956 Waterview Drive, Rochester Hills, MI 48309
Phone 248-293-7005
Email: ksapru@ovonic.com

Date: November 15, 2005

ABSTRACT

Hydrogen is a clean burning, non-polluting transportation fuel. It is also a renewable energy carrier that can be produced from non-fossil fuel resources such as solar, wind and biomass. Utilizing hydrogen as an alternative fuel for vehicles will diversify the resources of energy, and reduce dependence on oil in the transportation sector. Additionally, clean burning hydrogen fuel will also alleviate air pollution that is a very severe problem in many parts of world, especially major metropolitan areas in developing countries, such as India and China. In our efforts to foster international collaborations in the research, development, and demonstration of hydrogen technologies, through a USAID/DOE cost-shared project, Energy Conversion Devices, Inc.,(www.ovonic.com) a leading materials and alternative energy company, in collaboration with Bajaj Auto Limited, India's largest three-wheeler taxi manufacturer, has successfully developed and demonstrated prototype hydrogen ICE three-wheelers in the United States and India. ECD's proprietary Ovonic solid-state hydrogen storage technology is utilized on-board to provide a means of compact, low pressure, and safe hydrogen fuel. These prototype hydrogen three-wheelers have demonstrated comparable performance to the original CNG version of the vehicle, achieving a driving range of 130 km. The hydrogen storage system capable of storing 1 kg hydrogen can be refilled to 80% of its capacity in about 15 minutes at a pressure of 300 psi. The prototype vehicles developed under this project have been showcased and made available for test rides to the public at exhibits such as the 16th NHA annual meeting in April 2005, Washington, DC, and the SIAM (Society of Indian Automotive Manufacturers) annual conference in August 2005, New Delhi, India. Passengers have included members of the automotive industry, founders of both ECD and Bajaj, members of the World Bank, the Indian Union Minister for Finance, the President of the Asia Development Bank, members of USAID, USDOE and many other individuals, all of whom have had praise for the vehicle and the technology. The progress made through this phase I work and the importance of hydrogen three-wheelers has also resulted in extensive press coverage by the news media around the world.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The internal combustion engine (ICE) has been used by the automotive industry to provide mobility for more than 100 years to an increasing number of people worldwide, which has greatly improved mankind's productivity and quality of life. The world vehicle population is about 800 million today, and is projected to grow to 1.1 billion by the year 2020 with developing countries, including the most populous China and India, expected to experience the highest vehicle growth rate. Global oil consumption by the vehicle fleet is presently about 80 million barrels per day and is expected to reach more than 100 millions per day by 2020. As the demand overruns supply, oil prices will continue to increase. While high oil price will be a mere inconvenience to wealthy people, it will put the dream of mobility out of reach for the majority of the world's population in developing nations. This will have a very significant negative effect on their economies which are globally connected to the economies of developed nations, including the United States. Out of a dark future for the oil era, hydrogen energy provides great hope. In the long term, hydrogen means energy security, energy diversity, and sustainability for all.

Three-wheeler vehicles are popular means of transportation in most developing countries. They are used as both taxis and for moving cargo, with an overall market presently in the millions of units and growing rapidly. Most of these consumers are many, many years away from being able to afford personal transportation vehicles. Hence, the three-wheeler taxi provides the perfect platform for demonstrating a future of hydrogen for mass transportation. Countries such as India, China, Thailand, Indonesia, Bangladesh, Malaysia and Nepal, are highly dependent on these vehicles and these are also the countries where not only is the air quality extremely poor, but are also highly dependent on oil import. Unlike the western passenger vehicle, the three-wheeled vehicles have much better fuel economy (due to their small size and absence of energy guzzling components). This eases the demand for on-board hydrogen fuel storage, and the overall hydrogen fueling capacity needed. Most importantly, it is believed that hydrogen three-wheeler technologies can be more easily deployed in developing countries because the fuel need for the desired range is a small fraction of that needed for passenger cars in developed nations. This also makes it feasible for three-wheelers to be fueled by renewable hydrogen, leading to a true sustainable transportation!

The objectives of this project, partially funded by USAID/DOE were to: 1) Promote the use of U.S. environmental technologies overseas; 2) Address concerns over urban pollution and greenhouse emissions in developing nations; 3) Gain application knowledge of hydrogen that will be beneficial to its commercialization in the United States. To accomplish these objectives, Energy Conversion Devices Inc. in collaboration with Bajaj Auto, India, as a partner has successfully carried out all major technical tasks, which include CNG engine evaluation; its conversion to hydrogen; hydrogen storage system design and construction; air-liquid heat exchange design, vehicular integration and test; finally demonstration and public education, and outreach. Two working prototype hydrogen three-wheeled auto-rickshaws have been developed and integrated for demonstration, one in the U.S., and a second one in India. These hydrogen three wheelers have the following characteristics: 1) cold starting in frigid weather; 2) top speed at 48 km/h; 3) driving range of 130 km; 4) fuel economy 7 grams/km; 5) reversible hydrogen storage capacity 1 kg; 6) 85% refilling in 15 minutes. The technical details of converting a gasoline or CNG three-wheeler to run on hydrogen, including fuel delivery system, compression modification, spark timing control, thermal management, proprietary Ovonic™ solid state hydrogen storage system, and component integration are provided in this report.

The prototype vehicles developed under this project have been showcased and made available for test rides to the public at exhibits such as the 16th NHA annual meeting in April 2005, Washington, DC, and the SIAM (Society of Indian Automotive Manufacturers) annual conference in August 2005, New Delhi, India, and most recently at the SAE meeting in Chennai, India. The vehicle will be displayed at, and made available for rides at the ECD annual shareholders meeting on November 15, 2005. Passengers riding the vehicle to date have included members of the automotive industry, founders of both ECD and Bajaj, members of the World Bank, the Indian Union Minister for Finance, the President of the Asia Development Bank, members of USAID, USDOE and many other individuals, all of whom have had praise for the vehicle and the technology. The progress made through the phase I of this project and the importance of hydrogen three-wheelers has also resulted in extensive press coverage by the news media around the world.

ECD has not only fulfilled the tasks and milestones undertaken during Phase I of this project but has also significantly advanced the field of hydrogen technology for small vehicle transportation. In addition, through this work we have created awareness of the potential commercial application of US hydrogen technology for the huge developing country market. Technical improvement is needed in terms of longer driving range, higher fuel economy, and better performance. It is hoped that USAID/DOE will render further support to the phase II of this on-going project.

INTRODUCTION

Concerns about energy security, air quality and the need for sustainable economic growth are making it imperative that all nations, especially developing countries, begin making an accelerated transition from fossil fuels to clean alternatives. There are many options for alternative energy. These include natural gas, bio-diesel, ethanol, methanol, propane, electric "fuel", solar "fuel", and hydrogen. Whichever "fuel" we may wish to consider, in each case we need to ask questions such as: how is the fuel made? What is the present market? What would be the benefits of using this fuel? What is the potential for its long-term availability? What is the status of the end-use technology? Are there any safety codes and standards for its transport and use? Is it affordable? And above all, is it **sustainable**? Extensive information is available in literature on the benefits and difficulties associated with each of these fuels. It is not the intention here to discuss all these potential fuels but to focus on ***hydrogen***, the ultimate fuel. All the major automotive and energy companies are accelerating their existing plans to develop hydrogen vehicles and the hydrogen- fueling infrastructure. Benefits include the following:

- Hydrogen is a Universal Fuel
- It is available in unlimited quantities
- It can be produced from unlimited, clean, sources like sunlight, wind and biomass
- Hydrogen is clean, non-toxic, non-poisonous
- At the point of use hydrogen produces zero emissions, no particulate pollution, resulting in better air quality
- Reduces global warming
- Will provide Energy Security to all Nations
- Will contribute to Sustainable Economic Growth
- Can be used to replace fossil fuels in all applications, i.e. Transportation, Power generation, Cooking.

While rapid progress continues to be made in overcoming the technical and economic barriers in all areas of hydrogen energy technology including hydrogen production, storage and conversion devices such as fuel cells and hydrogen combustion engines, these technologies are far from meeting the commercial needs of consumers in the developed countries. However, this may not be the case for markets in the developing countries, due to major differences in energy use patterns including low per capita consumption and the nature of the vehicles predominantly used, such as two and three-wheelers instead of personal automobiles.

Hydrogen for Transportation

Motorized vehicles are responsible for a significant percentage of air pollution worldwide. Whereas the industrialized world primarily uses automobiles for personal transportation, the developing world uses two- and three-wheelers powered by two- and four-stroke internal combustion engines. For example, the global motorized 2-wheeler fleet currently exceeds 200 million units and is projected to grow to >500M units by 2010. Most of these vehicles are in India and China. Additionally, there are about 2.4 million three-wheeler taxis on the roads of India and large numbers in other countries such as Bangladesh, Thailand and the Philippines. This market cannot be ignored and can be a critical pathway to the start the move towards a "Hydrogen Economy". In an effort to reduce pollution caused by the use of diesel and gasoline, India has already done a remarkable job of converting a large number of three-wheelers and buses to compressed natural gas (CNG), and there is an on-going effort to extend this transition to hydrogen, through the formation of the National Hydrogen Energy Task Force. India and China are both members of the International Partnership for a Hydrogen Economy (IPHE), formed in November 2003, and led by the United States. In India, while the relatively wealthy segment of the population (a middle class the size of the US population) uses most of the energy and creates most of the pollution, the poor people especially the very young and the elderly, who breathe the same air, suffer the most in health consequences.

Because two and three wheelers are a major mode of transportation, this can be an advantage in the transition to hydrogen as transportation fuel. For example, the average daily driving distance in India is about 20-50 km. While the US hydrogen fueled passenger vehicle will require 4-6 kg of hydrogen on board to deliver the desired range of 480 km before refueling, the Indian scooter or three-wheeler will need about 300 grams to 1 kg of hydrogen for a range of 50-150 km. These lower per-vehicle fuel requirements can allow the country to leapfrog, by implementing hydrogen technologies in a time frame of 3-5 years, if the political will exists. But the developing countries will not be able to do this alone. Successful implementation will require appropriate international collaborations and the necessary resources. Early use of clean hydrogen combustion technologies for transportation, will also position developing countries for a smooth transition to fuel cells, which are expected to be more energy efficient in the long run, but which are probably at least 15-20 years away from widespread commercialization. Additionally, utilization of the existing Internal Combustion Engine (ICE) manufacturing and maintenance infrastructure does not involve the need for large capital investment.

Transitioning to a hydrogen energy economy requires widespread availability of cost effective hydrogen fuel. For India, we have identified three options to get started: These are, use of low cost electricity from the bagasse co-generation in sugar mills to produce hydrogen via electrolysis of water; hydrogen by-product from the chlorine-caustic industry; and direct gasification of biomass to hydrogen. India is one of the world's largest producers of sugar from sugar cane. These sugar mills have the potential to generate power significantly in excess of their captive needs. It is estimated that just 1MW power can result in the production of about 162,000 kg (162 tons) of hydrogen per year. This is sufficient for 32.4 million kilometers of driving with a scooter or about 16 million kilometers for a three-wheeler. Thus, even if a small fraction of the total power from bagasse cogeneration is used to produce hydrogen fuel for transportation and distributed power generation, it can have a very positive impact on air quality and reduction of imported fossil fuels, while significantly helping towards sustainable economic growth.

EXPERIMENTS, RESULTS AND DISCUSSIONS

1. Description of Bajaj Auto Ltd. Three-Wheeler Taxi

Bajaj Auto Limited found in 1913, is headquartered in Akurdi, Pune, India. Bajaj Auto Ltd. is a world class manufacturer, equipped with modern machinery, employing over 11,000 employees, building scooters, motorcycles and 3 wheeled utility vehicles totaling more than 1.3 million units per year. While the motorcycle was the major vehicle segment (74.4%) in all two-wheeler market (5.05 millions in sales in 2002-2003) in India, Bajaj Auto was the second largest two motorcycle manufacturer in India during 2002 -2003, with a market share of 23.1%. The Indian three-wheeler sales is 283,000 in 2002-2003, Bajaj Auto is the predominant player in this vehicle section with a market share of 68.5%. The three-wheeler market is made of two broad segments: three and six passenger vehicles, and goods carriers. Bajaj Auto is a market leader in three seat passenger vehicle segments producing a complete range of auto-rickshaws powered by gasoline, diesel, CNG and LPG engines. Bajaj Auto has been a clear leader in producing and marketing environmental friendly CNG and LPG three-wheeler vehicles.

Three-wheelers have a long history in Europe and Asia as extremely durable and reliable passenger and delivery vehicles. With new high torque, clean burning, 4 stroke engines, these machines have the low operating costs of a scooter with the toughness of a truck. With a top speed of 40 MPH, they are obviously not intended for freeway use, but are ideally suited to local and inner-city transportation and delivery. Bajaj three-wheeler passenger rickshaw, pickup truck, and delivery van are also marketed in the United States through authorized dealers. According to Bajaj USA, a few improvements have been made for the U.S. market, some of the more notable are: a full, laminated glass wrap-around windshield, dual headlights, a fully hydraulic braking system and an anti-dive front end. The major use of these three-wheelers in US is to haul farm produces such as hay and fruits etc., or warehouse goods transport if it is converted to hydrogen and emission free.

The three-wheeler selected for this project is an auto-rickshaw, which is a popular passenger vehicle for middle-income families and city low fare taxi. In large metropolitan area, like New Delhi, where strict emission rules are enforced, the three-wheeler rickshaw is fueled by CNG. It is made a duel-fuel vehicle, with petrol or gasoline being an emergency fuel after CNG is run out. The technical specification of the three-wheeler rickshaw is summarized in the following table

Engine	
Type	4 Stroke
Cooling Type	Forced Air Cooled
Displacement	173.5 cc
Max Power	6.5 bhp(4.78 kW) @ 5000 rpm
Max Torque	9.3 Nm @ 2500 rpm
Ignition Type	DC Ignitor
Transmission Type	4 forward and one reverse
Clutch Type	Wet, multidisc type
Electrical System	
System	12V DC
Head Light	35/35W
Horn	12 V DC
Chassis	
Chassis Type	Monocoque
Maximum Payload	322 kg
Suspension	
Front Suspension	Oscillating hub supported by coaxial spring & hydraulic shock absorber with antidive link
Rear Suspension	Independently sprung wheels by trailing arm with helical spring and Hydraulic shock absorber
Tyres	
Front Tyre Size	4.00-8, 4 PR
Rear Tyre Size	4.00-8, 4 PR
Brakes	
Front Brakes	Hydraulic expanding shoe type
Rear Brakes	Hydraulic expanding shoe type
Fuel Tank	
Fuel Tank Capacity	CNG - 29 litres Water equivalent, Petrol- 3 litres
Dimensions	
Overall length	2625 mm
Overall width	1300 mm
Overall height	1710 mm
Wheel Base	2000 mm
Ground Clearance	200 mm
Minimum Turning Radius	2.88 m
GVW	358 kg

2. ECD Technology for Engine Conversion to Run on Hydrogen Fuel

Three major modifications have been made for hydrogen conversion of a Bajaj CNG three-wheeler engine, which includes changes to fuel delivery system, spark timing control, and engine compression ratio. The original engine features a carburetor for gasoline in its fuel delivery system. Both carburetor and the fixture for CNG gaseous fuel delivery were retained to keep the cost of conversion low. To find the right spark timing for the hydrogen engine, the original Bajaj capacitance discharge ignition has been removed and replaced by a digital programmable control system. Since hydrogen has much lower density than that of gasoline or CNG, the power output of the converted engine is reduced. With an increase of compression ratio, much of the fuel economy and power rate of the hydrogen engine are regained. The details of these major changes for the conversion to hydrogen engine are described in the following sections.

Hydrogen three-wheeler consists of three major components: hydrogen ICE engine, ovonic on-board solid state hydrogen storage system, and heat management system. The details of vehicle integration are also described in this report.

Hydrogen Fuel Delivery System

The hydrogen fuel delivery into the engine intake port is realized with air aspiration by a Venturi featured in a carburetor, as illustrated in Figure 1. The hydrogen gas in the tank at a pressure of 300 psig passes through three stages of pressure reductions, and reaches to the circular Venturi at a very low pressure (0.34 inch water) above the atmosphere. As the throttle after the Venturi is wide open, air rushes into the engine cylinder during the intake stroke. When the air passes the Venturi, a negative pressure is created. The vacuum effect draws hydrogen out from the regulator. The air/fuel mixture flows past the throttle into the cylinder. The wider the throttle opens, the more hydrogen fuel is fed to the combustion chamber, more power output the engine generates. To optimize the engine performance such as horsepower, torque and fuel economy, air/fuel ratio and spark timing are needed to be adjusted. For the adjustment of air/fuel ratio, a restrictor is featured on the two-stage regulator. This restrictor controls the flow factor of the hydrogen out from the regulator. Less restriction gives rise to a rich air/fuel mixture, and vise verse for a lean mixture. For the Bajaj three-wheeler engine, the effective air fuel ratio, Lambda is 2 at idling and 1.2 at wide opened throttle.

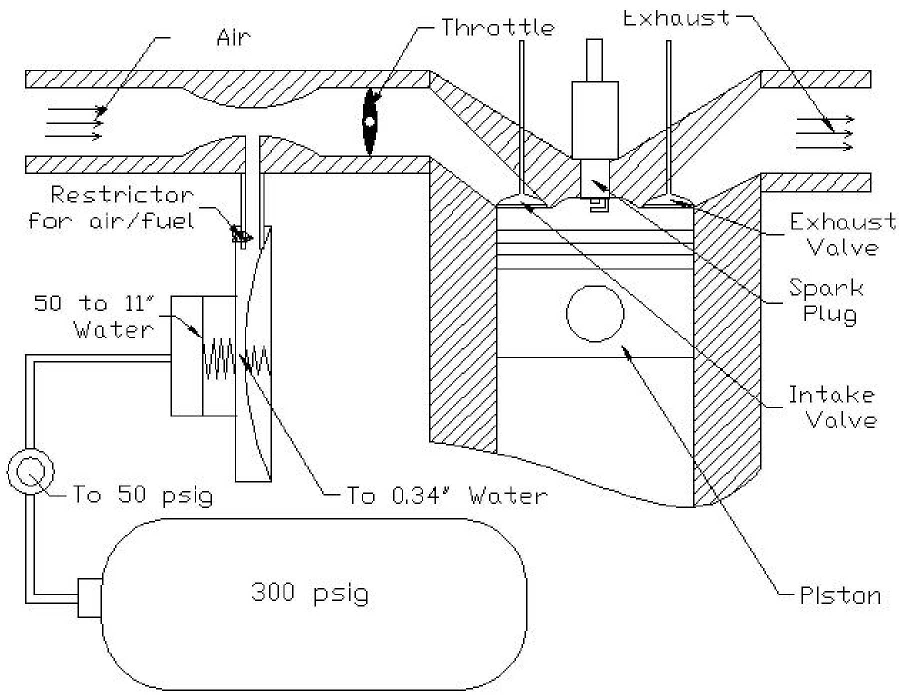


Figure 1. Hydrogen fuel delivery and fuel/air ration adjustment

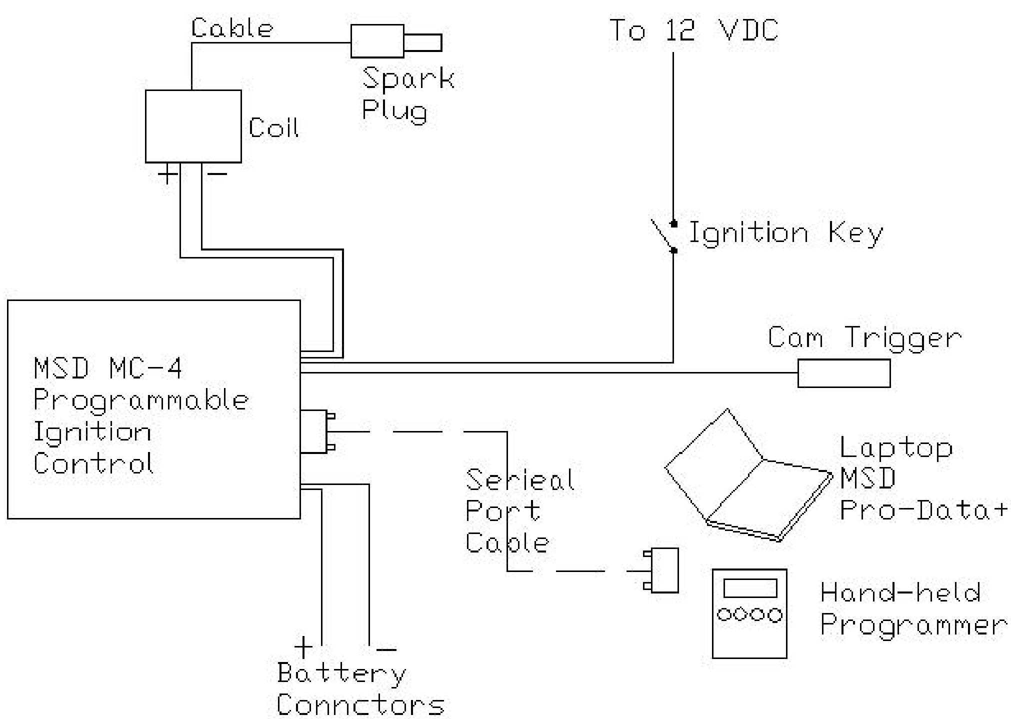


Figure 2. Wiring diagram of MSD MC-4 programmable digital ignition timing module

Spark Timing Control System

Since hydrogen burns much faster than other types of fuels, such as gasoline and natural gas, the spark timing for hydrogen ICE has to be retarded. More importantly, eliminating the waste spark during the exhaust stroke is essential to avoid back-firing. We removed the ignition trigger in the crankshaft flywheel, and placed it to the camshaft wheel, which renders only one firing every other cycle. The sparking retard is implemented by using a programmable ignition digital control module MSD MC-4. The wiring and configuration of the ignition control module is shown in the figure 2.

The Programmable MC-4 uses a high speed RISC microcontroller to control the ignition's output while constantly analyzing the various inputs such as supply voltage, trigger signals and rpm. The high speed controller can make extremely quick compensations to the timing and rpm limits while maintaining accurate timing signals to within +/- 0.1° and +/- 10 rpm. The circuits and controller of the MC-4 have been thoroughly de-bounced and suppressed to create protection against Electro Magnetic Interference

The MC-4 features a capacitive discharge ignition design. The majority of stock and aftermarket ignition systems are inductive ignitions. In an inductive ignition, the coil must store energy and step up the supplied voltage to maximum strength between each firing. At higher rpm, since there is less time to charge the coil to full capacity, the secondary voltage falls short of reaching its maximum energy level which results in a loss of power or a top end miss. The MC-4 Ignition features a capacitor which is quickly charged to 490 - 505 volts and stores this energy until the ignition is triggered. With the CD design, the voltage sent to the coil is always at maximum power even at high rpm.

The MC-4 produces full power multiple sparks for each firing of a plug. The number of multiple sparks that occur decreases as rpm increases, however the spark series always lasts for 20° of crankshaft rotation. Above 3,300 rpm there is simply not enough time to fire the spark plug more than once, so there is only one full power spark.

Spark Timing for the converted hydrogen engine is determined by two parameters: one is camshaft trigger position; another is retarding setting by the MSD MC-4 programmable digital ignition control system. The camshaft trigger position is set at 22 degree BTDC. The MSD MC-4 ignition timing module retards the sparking by 14 degree. Therefore, the actual spark timing is 8 degree BTDC.

Hydrogen ICE Compression Ratio Increase

We removed the standard piston (9:1) and replaced it with a custom made piston of 16:1 compression ratio, to increase the thermal efficiency and more power and torque by approximately 11%. The theoretical horsepower increase of the engine is about 15% as the compression ratio increases to 16:1 from 9:1.

Procedures for Hydrogen Engine Test

- Powered up computer and connected all sensors to verify that everything is in working condition.
- Load Cell was wired for optimizer and during calibration it was determined that the cell was bad. A new load cell was ordered, installed and calibrated.
- Thermocouples were wired to DAQ hardware.
- A hygrometer was set up for the optimizer. The hygrometer consists of a pressure transducer for atmospheric pressure, a dry bulb temperature and a wet bulb temperature. These values are then fed into an equation which calculates relative humidity.
- A gear reduction box was fabricated to change the transmission output shaft speed to match the engine crankshaft speed.
- The cylinder head, intake manifold, and exhaust manifold have been drilled and tapped for Optrand optical pressure transducers. These sensors work with the Optimizer system to perform real-time combustion analysis.
- The starter motor has been wired. A key switch in tandem with a push button operates the starter (Figure 3).
- A 12VDC battery was purchased and connected to engine. Engine cranks over and oil pressure was achieved
- A magnetic pickup sensor was placed on the cam shaft sprocket cover (Figure 4).
- A window was placed in the flywheel cover so that timing can be verified (Fig 5).
- Tried starting three-wheeler engine but spark was firing 25° advanced from TDC. This caused the flywheel key to shear.
- Replaced flywheel key.
- Moved cam pickup magnet 15° retarded from TDC.
- Tried starting engine once again and flywheel key sheared again. Retarded cam magnet pickup another 15°.
- Aligned encoder to TDC on engine

- Dyno was removed from rollers.
- Upon mounting the dyno to the gearbox it was discovered that an adapter was needed.
- Adapter was ordered and received, and dyno was successfully installed.
- Load cell was installed (Figure 6).
- Calibrated load cell while mounted to dyno. Had to remove rubber bushing and counter-weights to make a linear calibration.
- Battery and ignition were relocated to bottom of cart (Figure 7).
- A solenoid valve has also been wired to the key switch. If the key switch is in the off position the valve will be closed.
- An oil pressure gauge was installed.
- The MSD Ignition unit has been installed (Figure 8). The timing is set as follows:

RPM:	Advance:
0-800	5°
2500-8000	12°-4°
8000+	4°

- A pressure transducer was placed in the exhaust manifold.
- An O_2 sensor was placed in the exhaust manifold.
- Thermocouples have been placed in both the intake and exhaust manifolds
- A pressure transducer has been placed within the intake manifold.

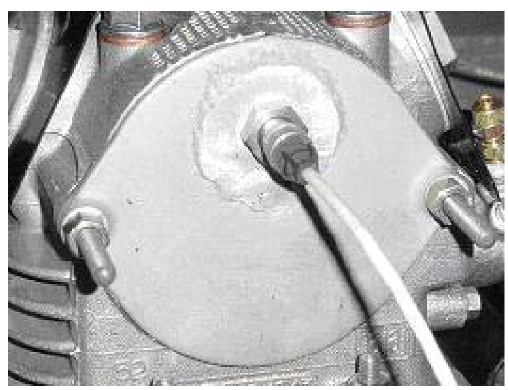


Figure 3. Engine dashboard which houses ignition switch, starter button And oil pressure gauge

Figure 4. Magnetic pickup sensor placed on camshaft sprocket cover

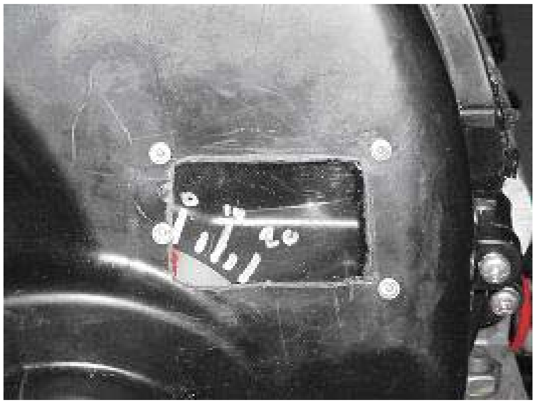


Figure 5. Timing window placed on flywheel cover
Figure 6. Dyno and Load Cell mounted to gear box

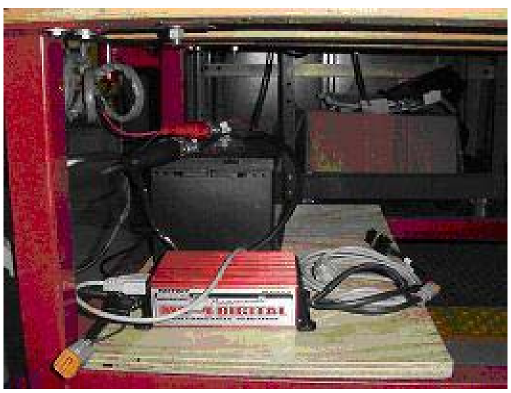


Figure 7. Battery and ignition relocated underneath the cart
Figure 8. MDS ignition unit

Performance of the Hydrogen Engine

A 173 cc Bajaj (BAL) CNG three-wheeler engine was converted to run on hydrogen. The engine initially delivers 94% of the pre-conversion power, but during the second vehicle conversion at the BAL facilities in India, we were able to achieve with hydrogen, 100% of the CNG power. We have obtained engine data manually, without the use of the Optimzer. Figure 9 shows a typical spark curve for smooth running without backfiring.

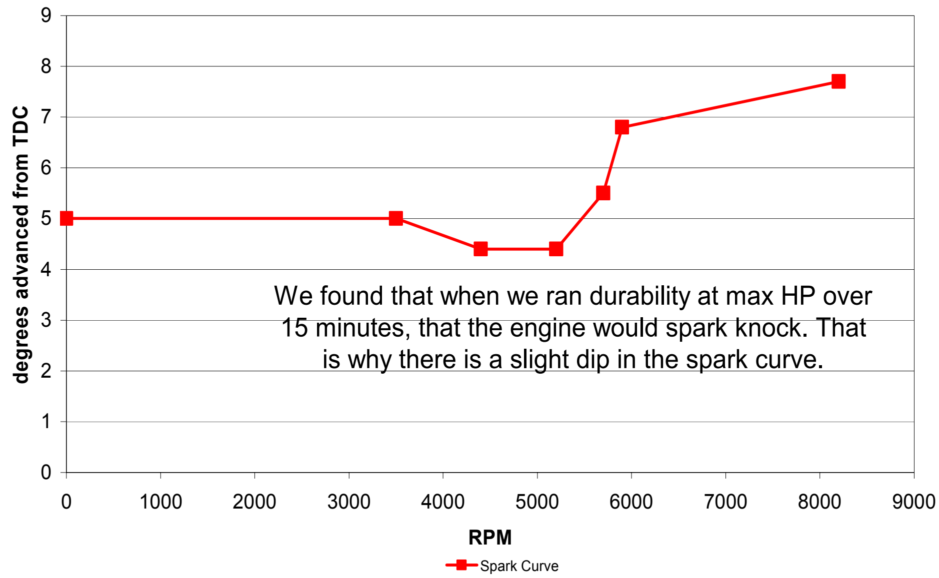


Figure 9. Spark timing used to eliminate knocking

We found that when running the engine at maximum HP for over 15 minutes, the engine would spark knock. The spark curve in Figure 9 was then adjusted to compensate for this. Hence the observed a dip in the spark curve. The air/fuel ratio was adjusted to maximize power. Torque and power curves were generated and are shown in Figure 10.

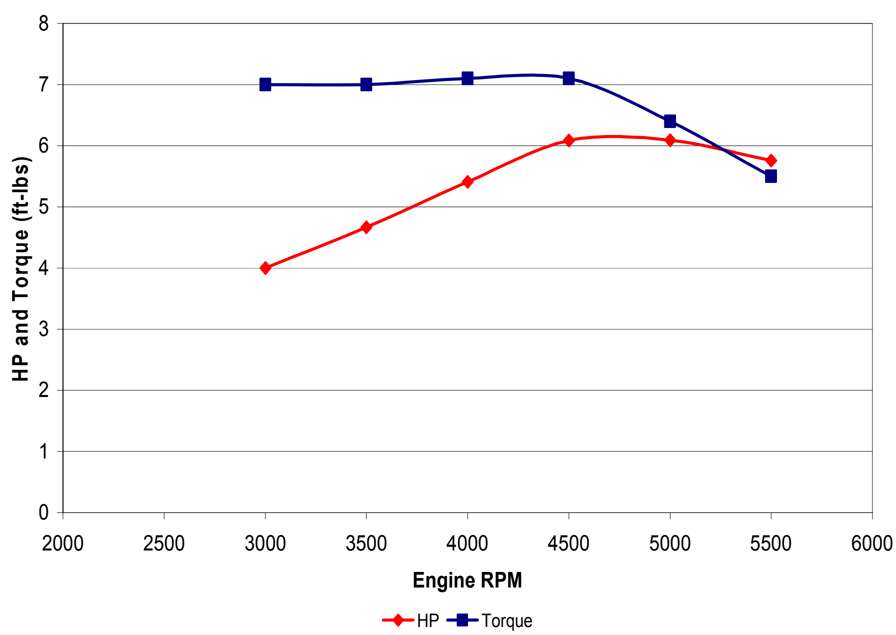


Figure 10. A plot of horse power and torque versus engine RPM

Figure 10 shows that a maximum HP of 6.1 is obtained at 4700 RPM. Before conversion to hydrogen the maximum advertised HP reported for this engine is 6.5. Thus, it is very encouraging to see that with this first un-optimized 3 W engine conversion to hydrogen, we retain almost 94% of the power.

3. Ovonic Solid State Hydrogen Storage System

Several hydrogen storage technologies are available, including high- pressure gaseous storage, cryogenics storage of liquid hydrogen, and storage as a solid in metal hydrides. Each storage technology has its advantages and drawbacks, depending on the application. For large-scale consumer applications proposed here, namely small vehicles and small power generators, safety being a top-most priority makes metal hydride storage a clear choice, especially for transportation. Metal hydrides that reversibly store hydrogen at low temperatures and pressures offer a compact and safe method to store hydrogen fuel on-board. Enough hydrogen can be stored on-board to have an acceptable driving range between refueling. ECD, the world leader in metal hydride technology has developed a strong patent portfolio in this area. ECD's storage alloys are mass-produced and packaged in specially engineered containers to provide maximum volumetric and gravimetric energy densities, while simultaneously optimizing heat transfer properties.

Thermodynamic Property of Metal Hydride

The metal hydride alloy selected for on-board hydrogen storage is OV 693. Large batch of material, usually in a quantity of 400 to 700 pounds are prepared by induction melting. Comprehensive experimental study has been conducted for this alloy. The measurements include PCT at various temperatures for both absorption and desorption; cycle test. The experimental results of metal hydride storage alloy OV 693 are presented in Figure 11 to Figure 14.

Ovonic Hydrogen Storage System Structure and Test

The Ovonic solid state hydrogen storage system consists of a MH containment tank (Figures 15, and 16) with integral heat exchanger, and reversible metal hydride hydrogen storage material. The tank is bolted into the vehicle chassis via a cradle mount and two tank retention straps. In order to reduce the weight of the vessel, ECD has developed a proprietary technology to combine a lightweight fiber wrapped pressure vessel with our heat exchanger and liquid manifold. The fiber wrapped vessel was provided by Dynetek.

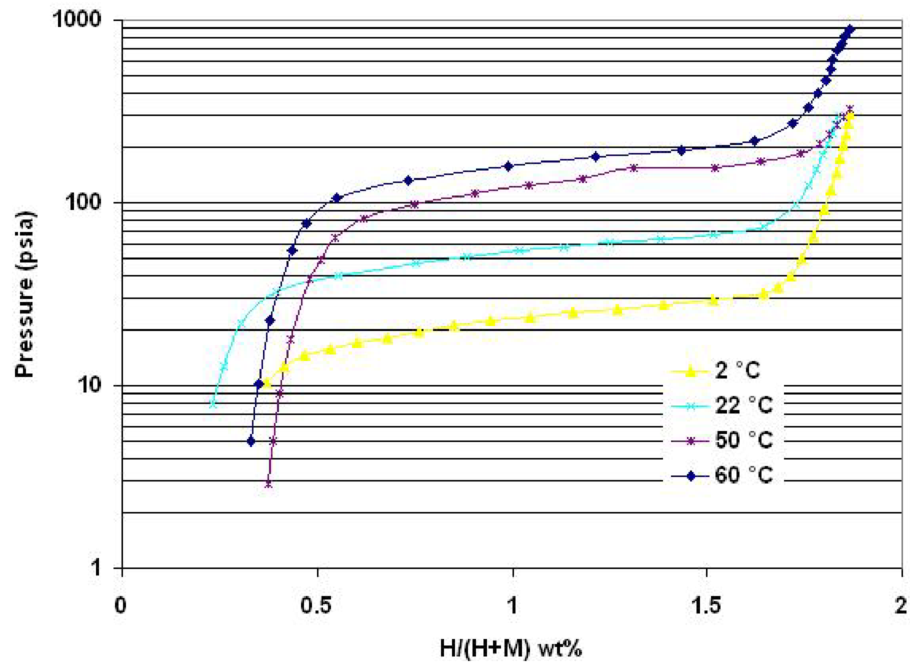


Figure 11. De-sorption pressure composition isotherm of OV693 alloy

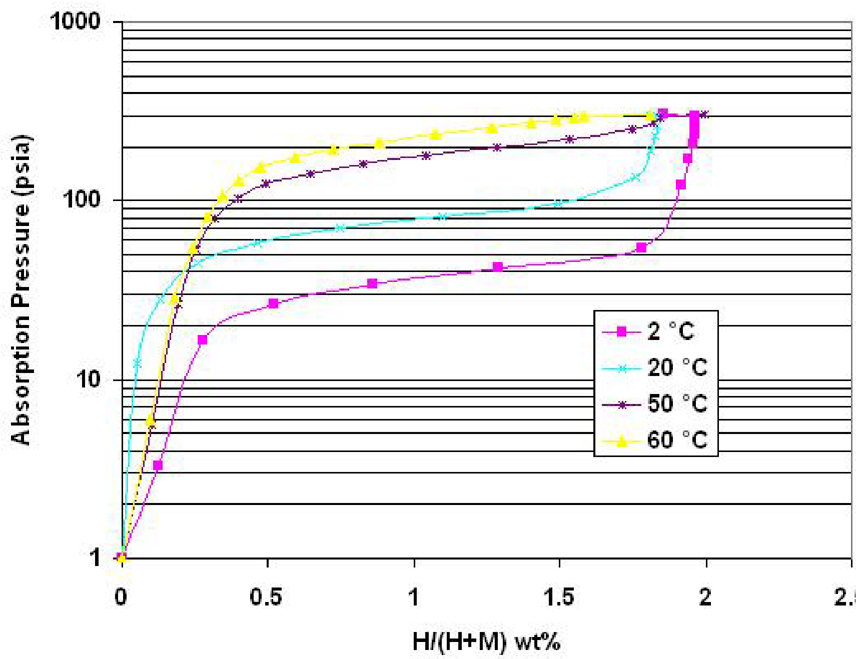


Figure 12. Absorption pressure composition isotherm of OV693 alloy

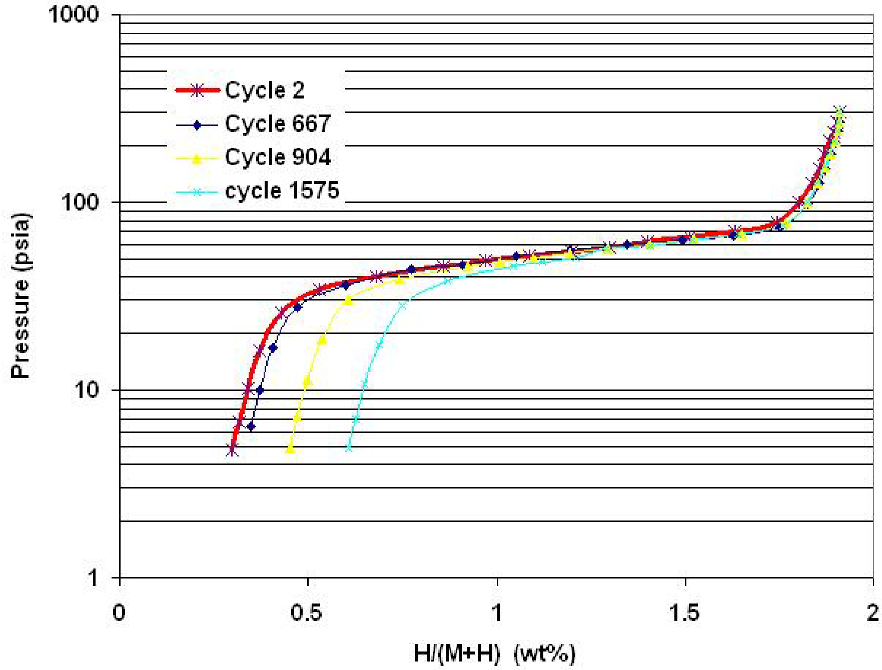


Figure 13. Cycle test results of OV693 at ambient temperature

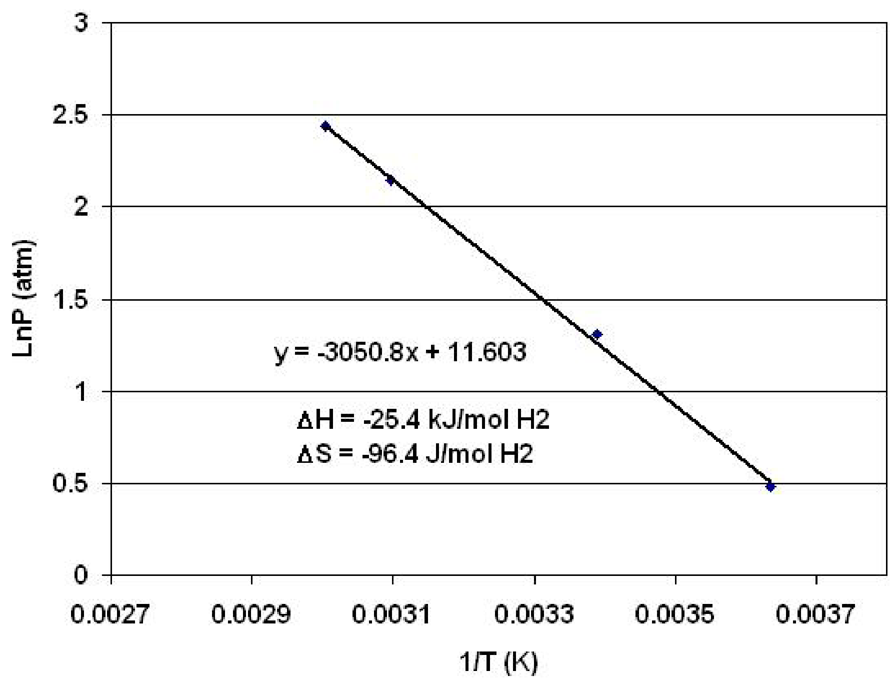


Figure 14. van't Hoff plot of OV693 alloy's hydrogen desorption

Figure 15. Prototype Ovonic solid state hydrogen storage system

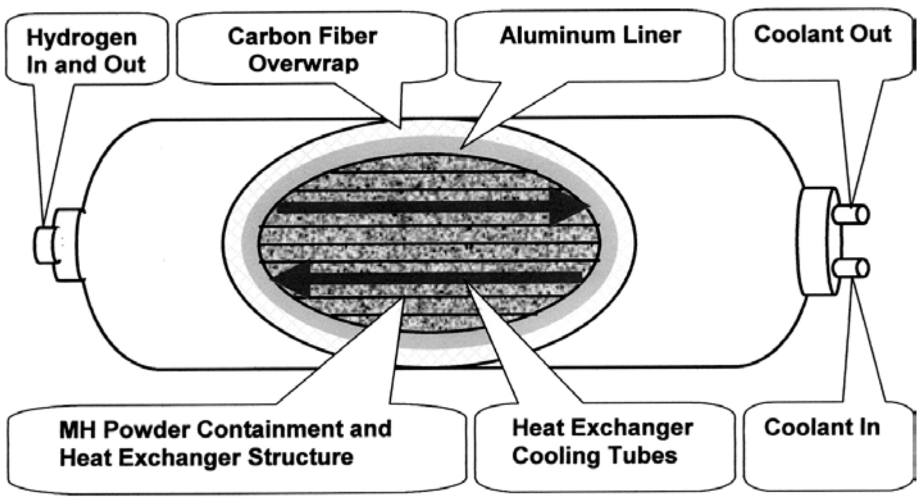


Figure 16. Schematic of Ovonic solid state hydrogen storage system

The vessel with the heat exchanger and liquid manifold was hydrostatically pressure cycled between 290 psi and 4500 psi for 15,000 cycles without leakage. It was then hydrostatically burst. The burst pressure was 13,801 psi, which is above the minimum required burst pressure of 10,800 or 3 times the 3600 psi service pressure.

4. Hydrogen Three-Wheeler Vehicle Integration

The hydrogen storage system and hydrogen engine are integrated, and mounted on the chassis of three-wheeler. The schematic showing the hydrogen fuel delivery and heat management is shown in Figure 17. The integrated fuel/engine system consists of four major subsystems:

1. Ovonic composite metal hydride hydrogen storage system
2. Hydrogen gas regulation and metering system
3. Engine and exhaust system
4. Heat management system

As shown in Figure 17, four thermocouples are also used for the monitoring of tank temperatures, with three of them sandwiched between the aluminum liner and the out-layer of woven carbon fiber bonded with epoxy, and the fourth one channeling into the tank center position. The mounting of composite tank to a vehicle must insert rubber band between a clamp and tank, and use spring cushioned fasteners, to accommodate the expansion of the tank (up to 1 cm circumference increase).

The hydrogen storage tank can be refilled through a Swagelok quick connector (7). The isolation shut-off valve (9) must be turned off during refilling to prevent low rate hydrogen leakage from the two-stage regulator (11). The pressure gauge (6) mounted on the front dashboard reads the tank pressure once the vehicle ignition switch turns on. A pressure regulator (8) reduces the tank pressure to about 50 psig. Right after the regulator, a thermal mass gas flow meter (9) is inserted for monitoring the fuel consumption. The flow meter is rated to 200 SLPM. The fuel used in unit of liter is displayed by a totalizer that is mounted on the front dashboard. The two-stage regulator (11) reduces the hydrogen pressure from 50 to 11" water at its first stage, followed by a reduction of the pressure from 11" water to 0.34" water, which is barely above the atmospheric pressure.

Since heat is needed to release hydrogen stored in the tank, and engine is air cooled, exhaust heat must be taped to heat the metal hydride inside the composite tank. An Alfa-Laval heat exchanger (designated as 14, 19) is used to convert the exhaust heat from the engine to coolant heat. The heat exchanger is made of stainless steel and its staggered plates are fusion welded according to the manufacturer. After the exhaust passes the heat exchanger, the temperature of the engine exhaust is nearly assume the temperature of the coolant, which is a indication of excellent performance of the heat exchanger. The muffler (15) is retained to reduce the engine noise.

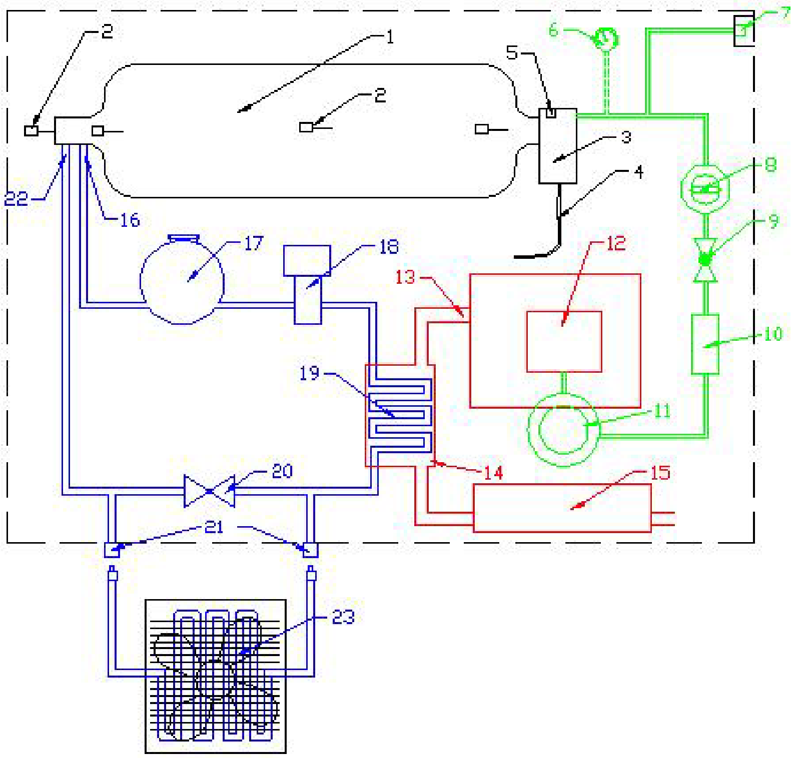


Figure 17. Schematic of integrated hydrogen three-wheeler

The coolant heat transfer loop consists of coolant expansion tank (17), fluid pump (18), Alfa-Laval heat exchanger (19), diversion valve (20), and a portable radiator for heat dissipation. For refilling, the diversion valve is closed so that the coolant flows through the portable radiator, where the hydrogen absorption heat is dissipated. Depending on the size and cooling capacity, the time for a 90% refilling the on-board storage system ranges from 0.5 to 4 hours. Once the refilling is completed, the portable radiator can be removed from the coolant loop by plugging out the quick connectors (21). At the same time, the diversion valve (19) should be opened allowing the coolant to circulate. When the vehicle starts, the hydrogen stored in the tank fuels the ICE engine. The exhaust heat released by the running engine increases the temperature of the coolant. With the heated coolant circulate through the internal heat exchange tubes inside the storage tank; the energy is conducted to the metal hydride storage medium. The temperatures at four locations by thermocouple sensors (2) recorded a continuous increase as the engine runs. Which indicates that the thermal energy transferred from the exhaust heat to the tank is more than the energy needed to release the hydrogen stored in the tank.

5. Hydrogen Three-wheeler Road Test

The prototype hydrogen three-wheeler was road-tested on February 2, 2005. The average driving speed was 25.9 km/hour. The maximum speed was 50 km/hour. The driving range read from odometer was 130.6 km or 82 miles. The starting pressure of the hydrogen tank is 225 psig at 19.3 degree C. The ending pressure of the hydrogen tank is 30 psig, with the center temperature at 49 degree C and 40 degree C at surface. The vehicle's hydrogen fuel economy is calculated to be 7.2 g/km or 11.5 g/mile. The Figure 18 shows the temperature responses of the hydrogen storage tank to the road operation in the first three hours.

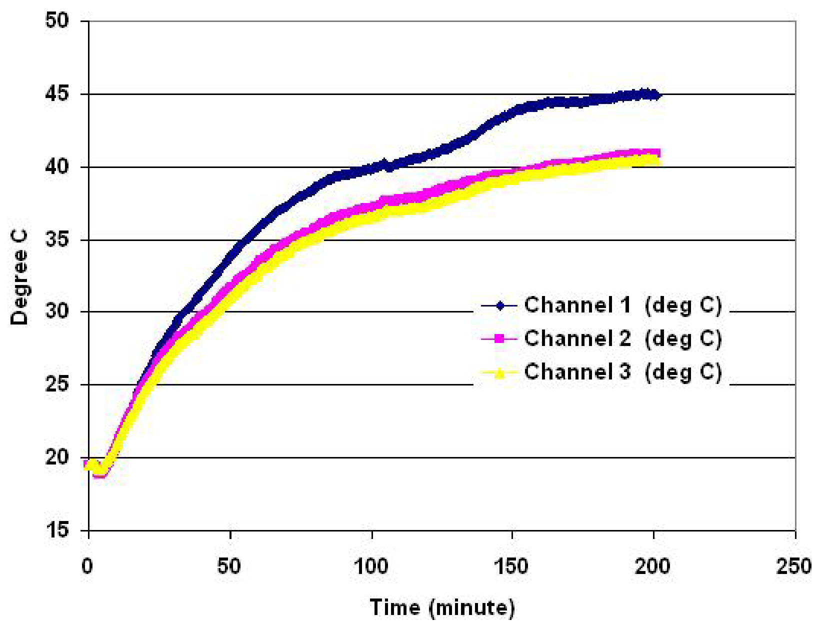


Figure 18. Temperature responses of hydrogen storage tank To the first three hour road test

Figure 19 shows the first prototype hydrogen three-wheeler and its first passengers, ECD founders Mr. Stan Ovshinsky and Dr. Iris Ovshinsky, and project manager Dr. Krishna Sapru.

Figure 19. First prototype hydrogen three-wheeler and its first passengers
From left to right: Dr. Sapru, Mr. Stan Ovshinsky, and Dr. Iris Ovshinsky

6. Technical Training of Bajaj Auto Engineers in ECD

Indian three-wheeler manufacturer was informed with the progress and an engineer from Bajaj was invited to visit ECD and to be trained. On March 13, Mr. Joshi from Bajaj arrived at ECD for one week technical training to help with the transfer of technology. During his stay, he drove the hydrogen three-wheeler around the ECD corporate head quarters. After that, the three-wheeler was disassembled to show him the details of conversion configuration and structure (see **Figure 20**). The following training and documents were provided:

Training:

1 Engine conversion procedure, including details on hydrogen delivery, ignition timing control, and cam ignition trigger modification

2 Basic knowledge about ovonic metal hydride and PCT, and engineering design of Ovonic hydrogen storage system

3 Exhaust heat management combining engine exhaust and hydrogen storage system heat exchanger

4 Hydrogen gas loop configuration and its safety fixture

5 Road driving test

6 Touring ECD's other technologies, such as Ovonic nickel metal hydride battery and fuel cells

Documents provided

1. Schematic of hydrogen vehicle conversion and component integration

2. Ovonic solid state hydrogen storage system activation and refueling procedure and safety precaution
3. Hydrogen fuel metering methods
4. Engine ignition control unit (MSD MC-4) computer software
5. Inventory of all needed components to be shipped to Bajaj for a conversion.

Figure 20. Mr. Joshi (left standing) from Bajaj, India in ECD for training

7. Prototype Hydrogen Three-Wheeler in India

After the technical training of Bajaj Auto engineer, ECD shipped by air a complete conversion kit to Bajaj Auto Ltd. in Pune, India. The conversion kit included all components outlined in the section of hydrogen three-wheeler integration, from solid state hydrogen storage system, fittings, valve and gauges for hydrogen fuel delivery, and parts for water loop and heat exchanger. In the summer of 2005, ECD kept communication with and encouraged Bajaj Auto to initiate the assembly of a second prototype hydrogen three-wheeler in its Pune manufacturing facility for demonstration in India. In August, 2005, BAL requested ECD to help with the conversion of the second vehicle in India. ECD project manager and one engineer traveled to Pune, and worked with a team of Bajaj Automotive engineers. Using ECD's conversion kit, the second hydrogen prototype three-wheeler was converted to hydrogen, assembled and various components integrated. ECD personnel also trained BAL personnel in the procedure for the activation of the on-board hydrogen storage system. With hydrogen filled up in the storage system, the hydrogen three-wheeler was up and running. Figure 21 shows the second prototype hydrogen three-wheeler and its first passengers, Mr. Bajaj, the CEO of Bajaj Auto Ltd and project manager Dr. Krishna Sapru of ECD.

Figure 21. Hydrogen three-wheeler in India and its first passengers Mr. Bajaj and Dr. Sapru

PUBLIC EDUCATION ON HYDROGEN ENERGY AND OUTREACH

Demonstration of Hydrogen Three-Wheeler in the United States

In today's fossil fuel based economy, hydrogen is an intermediate product used mainly in petrol-chemical and fertilizer industries. It is not yet perceived by general public to be feasible for future transportation fuel. There is still doubt about the safety of hydrogen. To promote public awareness on the feasibility of hydrogen transportation, ECD exhibited the hydrogen three-wheeler in Washington, DC during the annual conference of National Hydrogen Association, from March 30 to April 1. Rides were offered to a number of by standers on street, conference attendees. Among those who rode the hydrogen three-wheeler include USAID program manager Dr. Cindy Lowry and Michael Miller of DOE/IPHE (see Figure 22 and Figure 23).

In the summer of 2005, hydrogen three-wheeler was also demonstrated to and test-driven by the delegates of the Society of Indian Automotive Manufactures, and Dr. Chidambaram, the chief scientific adviser to the Indian prime minister (see Figure 24 and Figure 25). In September 2005, Mr. A. Wilde and Mr. P. Osborne from the World Bank ASTAE program visited and rode the hydrogen auto-rickshaw in ECD's facility in Rochester Hills, Michigan (see Figure 26).

Figure 22. Dr. Cindy Lowry of USAID & Friend at NHA Conference Washington DC, March, 2005

Figure 23. Michael Mills of DOE/IPHE at NHA Conference Washington DC, March, 2005

Figure 24. Some members of the Indian Auto Delegation representing TVS, Cummins, Ashok Leyland

Figure 25. Dr. Chidambaram (middle), science adviser to the Indian prime minister

Figure 26. Mr. A. Wilde and P. Osborne from the World Bank, ASTAE.

Demonstration of Hydrogen Three-Wheeler in India

In the early September, Bajaj Auto Ltd. exhibited the white hydrogen three-wheeler in the annual convention of the Society of Indian Automotive Manufacturers (see Figure 27).

Figure 26. ECO DRIVE: The President of Asian Development Bank, Mr. Haruhiko Kuroda, the Bajaj Auto CMD, Mr. Rahul Bajaj, And the CII President, Mr. Y.C. Deveshwar

Media Coverage of the Hydrogen Three-Wheeler

The prototype hydrogen three-wheeler and its demonstration have drawn tremendous attention around the world. Some of the media reported about the hydrogen three-wheelers are:

1. Fuel Cell Canada
2. Fuel Cell Works
3. Green Car Congress
4. H2 CarBiz
5. Hindu Business Line
6. Hydrogen and Fuel Cell Letter
7. Hydrogen Now
8. Hydrogen Power News
9. Hydrogen Use
10. Indian Express
11. Indolink-NRI News

12. New Delhi US Embassy News
13. News Target
14. USAEP
15. USAID

Copies of the detailed coverage are attached to this report as an Appendix A.

CONCLUSION

Two drivable prototype hydrogen three-wheeled auto-rickshaws have been successfully developed and demonstrated to hydrogen and automotive community in the United States and India. The vehicle performance was found to be comparable to that of the counterpart CNG version. The experimental results also indicate that the proprietary ovonic solid state hydrogen storage system can meet fuel requirement to provide a medium driving range of 130 km. The demonstrations of hydrogen three-wheelers in U.S. and India have produced remarkable public interest on hydrogen and its application in transportation. More than 15 media organizations from news papers to online newsletters have reported the progress made by this project. In order to put hydrogen three-wheelers on streets in developing countries, further public awareness on the feasibility and safety of using hydrogen as a transportation fuel, and further technical improvement in terms of longer driving range, higher fuel efficiency, and better performance is need. A Phase II proposal has been submitted to address these and other challenges such as developing a commercialization plan and enhancing the partnership to include companies such as the Indian Oil Corporation to install the hydrogen fueling infrastructure in India. Phase II work will take the project to the pre-commercialization stage, subsequent to which ECD will seek commercialization avenues.

ACKNOWLEDGEMENT

ECD would like to thank our Indian partners for this Phase I project Bajaj Auto Ltd. for providing two CNG three-wheeled auto-rickshaws for the conversion to run on hydrogen and the assistance from the its engineering team for the assembly and test of the second hydrogen vehicle in India. Special thanks go from the PI and her team to Mr. Stanford Ovshinsky, ECD founder for his vision and for encouraging and promoting this work, and to Mr. Rahul Bajaj, the CEO of Bajaj Auto for his interest in clean transportation; Mr. Basu for coordinating the tasks performed by the Bajaj team. We wish to acknowledge the USAID, for partial financial support, especially the USAID Delhi team consisting of Mr. John Smith-Sreen, Ms. Kristen Easter and Mr. K. Balakrishnan, and to the USDOE/NETL office, especially Dr. James Eckmann for being the NETL project manager and visiting ECD to monitor progress. Our thanks to the Society of Indian Automotive Manufacturers (SIAM), for hosting several meetings of the current and potential future partners, at their offices in Delhi, and, for including the hydrogen three-wheeler demonstration in their most recent 2005 annual conference.

REFERENCES

1. K. Sapru, S. Ramachandran, Z. Tan, 12th Annual US National Hydrogen Association March 6-8, 2001 meeting in Washington, DC.
2. K. Sapru, S. Ramachandran, Z. Tan "Hydrogen- The New Oil- for Sustainable Transportation & Distributed Power Generation", invited talk at "International Symposium & Exposition on Alternative Energy Vehicles", Indian Institute of Technology, November 23-25, 2001, Kanpur, India.
3. K. Sapru, "*Hydrogen –The New Oil*. Near Term Business Opportunities for Hydrogen in Developing Countries", The 2002 Hydrogen Investment Forum. April 3-4, 2002, Washington, DC
4. K. Sapru, Hydrogen – "The New Oil", Hydrogen for Transportation and Distributed Power for India, invited talk presented at the Science & Technology India Conference, 10-12 April 2002, New Delhi, India.
5. USDOE, 2002 Annual Progress Report.
6. K. Sapru; Ovonic™ Metal Hydrides for Hydrogen Powered Transportation and Distributed Power Generation, Seventh SAEST Conference, Chennai, India, November 2002.
7. K. Sapru, Z. Tan, P. Sievers, C. Cunnington, M. Bazzi and A. Griffith: Hydrogen-ICE Two- and Three-Wheeled Vehicles & Distributed Power Generation for Developing Countries, 15th Annual U.S. Hydrogen Conference, April 26-30, 2004,Los Angeles, CA
8. K. Sapru, P. Sievers, Z. Tan, and M. Bazzi, 16th Annual Conference of US National Hydrogen Association March 31-April 2, 2005, Washington, DC.

APPENDIX A

A PARTIAL COLLECTION OF MEDIA COVERAGE OF THE HYDROGEN THREE WHEELERS

BY

NEWSPAPERS AND NEWSLETTERS AROUND THE WORLD

(From Page 34 to 56)

The Sunday EXPRESS

Sunday, July 17, 2005

PRINT THIS STORY

Close this window

Front Page

Move over CNG, a hydrogen auto?

US company develops hydrogen-fuel-run three-wheelers, trial runs successful

LALIT K JHA

MINNEAPOLIS, JULY 16 The great Indian autorickshaw may have just shifted to the eco-friendly CNG but it's ready for the generation-next fuel.

Krishna Sapru with Stan Ovshinsky, ECD founder, and Iris Ovshinsky, co-founder and a senior vice-president of the ECD

Taking a major leap towards Indo-US co-operation in the energy sector, the United States Department of Energy (DOE) and US Agency for International Development (USAID) have helped develop a hydrogen-run three-wheeler for Indian roads.

The Rochester Hills (Michigan)-based Energy Conversion Devices (ECD) has successfully converted and developed a CNG-run three-wheeler of Bajaj Automobiles into one run on hydrogen fuel.

With trial runs earlier this year, in extreme cold climatic conditions, giving a mileage of 130 km per 900 gm of hydrogen (equivalent to four litres of petrol), scientists believe the end product could yield much more.

After the first vehicle conversion at ECD, a Bajaj automotive engineer was trained in the conversion process. Another CNG auto is being converted at the Bajaj headquarters using the conversion kit provided by ECD.

"Now it is awaiting trial runs, before commercial launch," Stan Ovshinsky, ECD founder, told *The Sunday Express*.

The vehicle has already created ripples in the Indian auto industry and government circles. A high-level Indian delegation visited ECD in April, which included members from Tata Motors, Ashok Leyland, TVS, Mahindra and Mahindra, Maruti, Eicher, Cummins India, Society of Indian Automotives Manufacturers and the Automotive Research Association of India.

A month later, Principal Scientific Advisor R. Chidambaram dropped in to have a look. He also had a ride on the hydrogen-run three-wheeler on May 19.

The hydrogen-fuel autorickshaw project has been led by Krishna Sapru, an Indian American scientist. Having spent over 30 years in developing alternative fuel technologies, she has as many as 30 patents to her credit.

"Use of hydrogen as an alternative clean fuel can help reduce our dependence on foreign oil and thus make significant contributions to energy security, and clean air,'' Sapru said.

Sapru said work on the project started soon after a contract was signed with USAID and DOE in February 2004. A CNG-engine was imported from Bajaj in a few weeks and the autorickshaws arrived in November.

''By this time 96-98 per cent of the conversion process was over and we fitted the (hydrogen) engine in the vehicle. For the next few months, it went for rigorous tests which included starting and running under temperatures below freezing level,'' she said.

One attractive factor is the amount of fuel which needs to be stored on an average Indian three-wheeler is a fraction of what is needed for automobiles favoured by US consumers. ''The smaller storage capacity significantly reduces technological challenges in introducing the vehicles into the Indian market. For this we use ECD's safe, solid-state hydrogen storage technology which fits in the same space of the existing fuel tank,'' she said.

There are about 24 lakh three-wheelers in India, according to official estimates—most of them run on petrol except for about 70,000 in Delhi that run on CNG.

But hydrogen fuel still faces a huge hurdle: the cost. Scientists are at work to make the fuel economic to conquer the next frontier in energy.

URL: http://www.indianexpress.com/full_story.php?content_id=74601

The potential of metal hydrides

“Whether you like it or not, metal hydrides are the only storage technology to show practical applications.” That was the statem Rosa Young, vice president of technology at Texaco Ovonic Hydrogen Systems (TOHS), opened her presentation. “Onboard h the number one challenge for FCVs. None of the current technologies meet all the requirements.” Young believes metal hydride safest H2 storage option through natural chemical bonding of the H2 to the hydride itself. Further advantages include compactr low-pressure operation, cold-temperature start-up, and use of onboard waste heat for releasing hydrogen. Packaging of metal h and a storage system using this option will be tested onboard a 2004 Toyota Prius. Young also discussed use of metal hydrides portable fuel cell applications. Benefits offered in stationary applications include a small unit footprint and direct refill from an ele processor, and for portable applications, compactness and low-pressure operation.

Krishna Sapru, Energy Conversion Devices Inc.’s (ECD’s) director of thermal hydride products, highlighted a huge volume mark stored in metal hydrides: in two- and three-wheeled vehicles in countries like India, with 70,000-plus CNG vehicles in Delhi alon comparable market, and major cities in both countries are suffering from severe pollution. Systems for these vehicles will need compact. ECD has participated in a demonstration of a 250-cc, hydrogen-fueled, ICE-powered scooter with onboard metal hydr close in size to India’s three-wheelers. The company has also developed a 10-kg stand-alone metal hydride fueling station that to 30 scooters. This genset could also be configured for stationary or distributed power generation.

Such products, said Sapru, “would allow developing countries to leapfrog to H2.” India in particular has domestic renewable res H2 could be derived: “bagasse,” or sugar mill waste, that could be electrolyzed; other biomass that could be directly gasified; H the chlor-alkali industry; and methane that could be steam reformed.

Energy Conversion Devices (ECD) converts and develops a Bajaj Automobiles CNG-run three-wheeler to run on hy fuel

Publication Date:18-July-2005
08:46 AM US Eastern Timezone
Source:India Express

Krishna Sapru with Stan Ovshinsky, ECD founder, and Iris Ovshinsky, co-founder and a senior vice-president of the ECD

The great Indian autorickshaw may have just shifted to the eco-frier CNG but it's ready for the generation-next fuel.

Taking a major leap towards Indo-US co-operation in the energy sec the United States Department of Energy (DOE) and US Agency for International Development (USAID) have helped develop a hydroge run three-wheeler for Indian roads.

The Rochester Hills (Michigan)-based Energy Conversion Devices (E has successfully converted and developed a CNG-run three-wheeler Bajaj Automobiles into one run on hydrogen fuel.

With trial runs earlier this year, in extreme cold climatic conditions, giving a mileage of 130 km per 900 gm of hydrogen (equivalent to four litres of petrol), scientists believe the end product could yield much more.

After the first vehicle conversion at ECD, a Bajaj automotive engineer was trained in the conversio process. Another CNG auto is being converted at the Bajaj headquarters using the conversion kit provided by ECD.

''Now it is awaiting trial runs, before commercial launch,'' Stan Ovshinsky, ECD founder, told The Sunday Express.

The vehicle has already created ripples in the Indian auto industry and government circles. A high level Indian delegation visited ECD in April, which included members from Tata Motors, Ashok Leyl TVS, Mahindra and Mahindra, Maruti, Eicher, Cummins India, Society of Indian Automotives Manufacturers and the Automotive Research Association of India.

A month later, Principal Scientific Advisor R. Chidambaram dropped in to have a look. He also had ride on the hydrogen-run three-wheeler on May 19.

The hydrogen-fuel autorickshaw project has been led by Krishna Sapru, an Indian American scient Having spent over 30 years in developing alternative fuel technologies, she has as many as 30 pat to her credit.

''Use of hydrogen as an alternative clean fuel can help reduce our dependence on foreign oil and tl make significant contributions to energy security, and clean air,'' Sapru said.

Sapru said work on the project started soon after a contract was signed with USAID and DOE in February 2004. A CNG-engine was imported from Bajaj in a few weeks and the autorickshaws arri in November.

''By this time 96-98 per cent of the conversion process was over and we fitted the (hydrogen) eng in the vehicle. For the next few months, it went for rigorous tests which included starting and runr under temperatures below freezing level,'' she said.

One attractive factor is the amount of fuel which needs to be stored on an average Indian three-wheeler is a fraction of what is needed for automobiles favoured by US consumers. ''The smaller storage capacity significantly reduces technological challenges in introducing the vehicles into the Indian market. For this we use ECD's safe, solid-state hydrogen storage technology which fits in tl same space of the existing fuel tank,'' she said.

There are about 24 lakh three-wheelers in India, according to official estimates—most of them run petrol except for about 70,000 in Delhi that run on CNG.

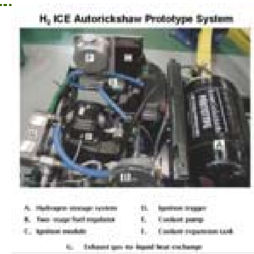
But hydrogen fuel still faces a huge hurdle: the cost. Scientists are at work to make the fuel econc to conquer the next frontier in energy.

~

HOME

Ovonics, Bajaj Hydrogen ICE Three-Wheeler on Display in India

SEPTEMBER 01, 2005



The H2 ICE system for the threewheeler. Click to enlarge.

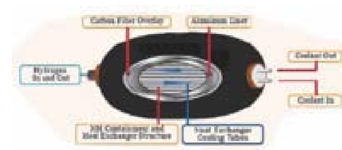
A prototype three-wheeler (autorickshaw) developed by ECD Ovonics and Bajaj Auto (BAL) and powered by a hydrogen-burning internal combustion engine (H_2ICE) is on display for the first time at the annual convention of the Society of Indian Automobile Manufacturers.

For Bajaj, the hydrogen ICE concept three-wheeler is a step along the way to more advanced hybrids and potentially fuel cell vehicles.

> *A change in the energy scenario for the transportation sector is inevitable—the industry would be prudent to prepare for it.*
>
> *There are synergies in the pursuit of AFV [Alternative Fuel Vehicle] technologies. This requires a consolidated, multi-technology approach.*
>
> *BAL would like to be a front runner in the adaptation of these technologies, and is making a long-term commitment to pursue alternate fuel technologies with specific five-year goals.*
>
> —Shubhangi Chiplonkar, Bajaj Auto

Bajaj earlier had developed an all-electric three-wheeler, the ECOrick.

There are two hydrogen ICE autorickshaw prototypes, one in the US at Ovonics, the other at Bajaj. Both are based on Bajaj's 173.5-cc CNG-fueled three-wheelers. Bajaj is the largest manufacturer of three-wheeler taxis in India, while ECD Ovonics contributed its expertise in solid-state hydrogen storage and engine conversions.



Ovonics prototype metal hydride storage for the autorickshaw.

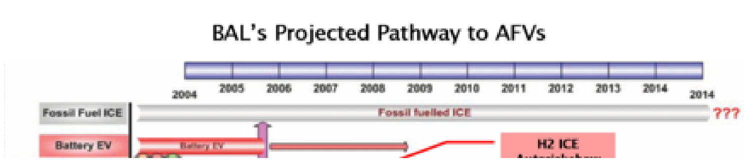
Ovonics, in essence, designed a metal hydride storage system that would fit in the place of the existing three-wheeler fueling tank in addition to converting the engine.

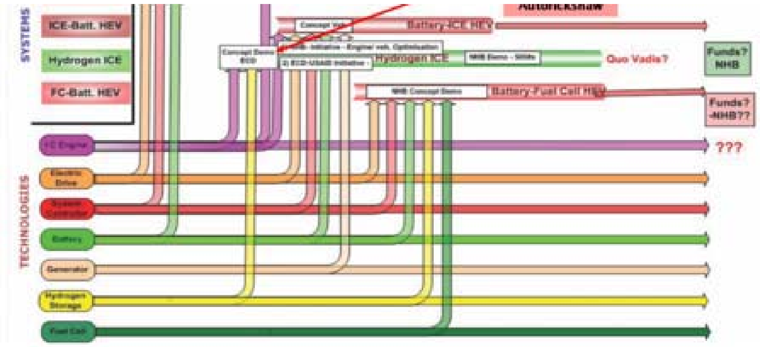
Trial runs earlier this year, in the cold climatic conditions of Michigan, yielded a range of 130 km (81 miles) per 900 gm of hydrogen (equivalent to about 3.4 liters of gasoline, or 0.9 gallon of gasoline). That works out to about 2.6 liters equivalent/100km, or 90.5 mpgge (gallon gasoline equivalent) US. The developers think they can do better.

The US version of the prototype has performed at 94% of the level of conventional Compressed Natural Gas (CNG) three-wheelers. The Indian prototype on display at SIAM will now go into further testing.

Next steps for the hydrogen transportation initiative include exploring fuel availability, fueling infrastructure, and safety codes and standards.

Three-wheeler taxis form the biggest chunk of public transport vehicles in India. A move toward a cleaner alternative fuel would mitigate air pollution and negative effects of climate change.





Bajaj Auto's projected technology development pathways. Click to enlarge.

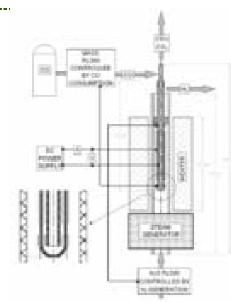
Resources:

- Electric Vehicles at Bajaj Auto
- Metal Hydride Background

in Engines, H_2, India | Permalink | Comments (1) | TrackBack

DOE Funds SRI International to Develop Steam Electrolysis System

AUGUST 31, 2005



SRI's Experimental Steam Electrolysis System

The DOE has awarded SRI International, an independent nonprofit research and development organization, a four-year, $2.2 million contract to develop a prototype of a low-cost steam-electrolysis system for the generation of hydrogen.

The project goal is to generate ultra-pure hydrogen at a cost of $2 to $3 per gallon gasoline equivalent (gge) delivered. The current cost of hydrogen by electrolysis is some $4.75 to $5.15 per gge (delivered) on average, according to the DOE.

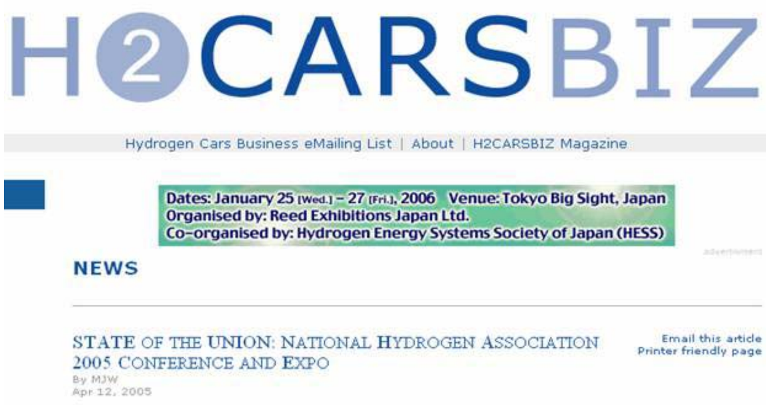
Conventional electrolysis uses electrical current to split water into hydrogen at the cathode (+) and oxygen at the anode (-). Steam electrolysis uses heat to provide some of the energy needed to split water.

The basic approach of the proposed system is as follows:

- Decompose water electrochemically into H_2 and O_2 on the cathode side of a high-temperature electrolyzer.
- Oxygen ions will migrate through an oxygen-ion-conductive solid oxide electrolyte.
- Gas mixtures on the cathode side (H_2+ H_2O) and on the anode side (CO + CO_2) will be reliably separated by the solid electrolyte.
- Depolarization of the anodic process will decrease the electrolysis voltage 5-10 times, and thus the electricity required for H_2 generation and the cost of produced H_2.

The SRI team expects energy efficiencies of 60%–70% with respect to primary energy consumption and 75%–90% with respect to total energy into the electrolyzer. Total expected energy consumption for the high-temperature steam electrolyzer is around 6–8 kWh/kg H_2.

SRI's modular system design will allow scaling up and customization to meet a



The most modest of these was an Indian 3 wheel taxi with a single piston ICE converted from CNG to metal hydride by ECD Ovonics. This is to be shipped back to India to be the production prototype, and so it will almost certainly become the first commercial production hydrogen vehicle in the world,

Bajaj-US agency combine develops hydrogen-run auto

Our Bureau

ECO DRIVE: The President of Asian Development Bank, Mr Haruhiko Kuroda, the Bajaj Auto CMD, Mr Rahul Bajaj, and the CII President, Mr Y.C. Deveshwar, on the hydrogen fuel-run auto, jointly developed by Bajaj Auto and The Energy Conversion Devices of the US, in the Capital on Thursday. - Kamal Narang

New Delhi , Sept. 1

AN Indo-American business alliance forged under the United States-Asia Environmental Partnership (US-AEP) has developed a three-wheeler powered by hydrogen fuel. The vehicle, being exhibited at the annual convention of the Society of Indian Automobile Manufacturers (SIAM), is one of the two such demonstration models in the world.

The development of the vehicle is a step in international efforts to mitigate climate change through a future hydrogen economy, a US Embassy release said here today. The Energy Conversion Devices of Troy, Michigan, and the Pune-based Bajaj Auto Ltd (BAL) have worked together to make the prototypes a reality, the release said. The vehicles perform at levels equal to those of conventional Compressed Natural Gas (CNG) three-wheelers, the release said.

The next step for the hydrogen transportation initiative includes exploring fuel availability, fuelling infrastructure, and safety codes and standards that would raise performance to the level of a gasoline-fuelled vehicle. The other existing demonstration vehicle is now on the streets of Troy, Michigan, near its American developer.

The Indian model is housed at the Bajaj headquarters in Pune. Another key partner in the effort is the US Department of Energy, the release said, adding that the United States Agency for International Development (USAID) also provided funding of $500,000.

The Hydrogen & Fuel Cell Letter

Alternative Energy News Since 1986 April 2005 Vol. XX No. 4 ISSN 1080-8019

April 2005

The Indian Bajaj three-wheeler single-cylinder i.c. engine taxi converted by Energy Conversion Devices from

The four-day event was noteworthy for what seemed like an unprecedented number of hydrogen-fueled vehicles both inside the 15,000 sq. ft. exhibition hall but also outside in the traditional "Ride & Drive" event. Some 20 vehicles were on hand, ranging from a tiny 1-cylinder Indian cargo Bajaj three-wheeler adapted by Energy Conversion Devices to hydrogen that took participants for rides around the parking lot of the Marriott Wardman Park Hotel to a sleek, long 12-cylinder BMW record-breaking race car (*H&FCL Nov. 04*) on display in the exhibition area.

The Indian Bajaj three-wheeler single-cylinder I.C. engine taxi converted by Energy Conversion Devices from compressed natural gas fuel to hydrogen under a partnership program between the U.S. government (USAID) and industry.

Hot!! Indian Americans Develop Hydrogen Fueled Autorickshaw --- Sapru’s current emphasis is on development, testing and commercialization of Hydrogen-ICE (Internal Combustion Engine) two and three wheeled vehicles for transportation, & Hydrogen-ICE generators for distributed power generation. She is pursuing alliances to create an infrastructure as well as to facilitate commercialization of hydrogen technologies in India. Which is why she is evaluating the availability and potential cost of hydrogen in developing countries. --- INDOlink --- Jul 20, 2005

September 2, 2005

Energy Conversion Devices co-develops hydrogen 3 wheeler

Energy Conversion Devices of Troy, Michigan along with Bajaj Auto Ltd created a hydrogen powered 3 wheeler that was on display at the annual convention of the Society of Indian Automobile Manufacturers.

> The vehicles perform at levels equal to those of conventional Compressed Natural Gas (CNG) three-wheelers …
>
> The next step for the hydrogen transportation initiative includes exploring fuel availability, fuelling infrastructure, and safety codes and standards that would raise performance to the level of a gasoline-fuelled vehicle.

Cat:

- Hydrogen vehicles
- Hydrogen car

| Time: 8:44 am

Collaboration brings hydrogen three-wheelers to India

The Indian transportation sector has been growing leaps and bounds with the sales of cars, motorcycles and scooters growing at red hot levels. But for Indians, the three-wheeler or autorickshaw has for decades been the ubiquitous means of transportation. There have been recent efforts to convert these vehicles to compressed natural gas (CNG) but the majoritity of 2.5 million vehilces still run on gasoline or diesel. A public-private partership has now successful trialed a three wheeler that ran on hydrogen.

The United States Department of Energy (DOE) and US Agency for International Development (USAID) have been working with Michigan based Energy Conversion Devices to develop a hydrogen-run three-wheeler for Indian roads. They used a local Bajaj Automobiles three wheeler for the trial, running the machine through varying temperatures and road conditions. Tests showed a yield of 130km for the equivalent of 4 litres of gasoline in compressed hydrogen.

The hydrogen-fuel autorickshaw project has been led by Krishna Sapru, an Indian American scientist who has spent over 30 years in developing alternative fuel technologies. "Use of hydrogen as an alternative clean fuel can help reduce our dependence on foreign oil and thus make significant contributions to energy security, and clean air," commented Sapru.

Mon, 2005-07-18 16:27

add new comment

Indian Americans Develop Hydrogen Fueled Autorickshaw

By Francis C. Assisi

Email this page Keep this page Print this page

20 July 2005 -- Working with the Michigan based Energy Conversion Devices (ECD), and supported by the U.S. DOE (Hydrogen Program), two Indian American scientists -- Krishna Sapru and Subramanian Ramachandran – have achieved a significant breakthrough by developing a hydrogen-run three-wheeler for Indian roads.

The latest trial runs, conducted this year, resulted in the successful conversion of a CNG-run Bajaj three-wheeler (autorickshaw) into one run on hydrogen fuel. With the trial run conducted in extreme cold climatic conditions, the test is reported to have given a mileage of 130 km per 900 gm of hydrogen (equivalent to four liters of petrol).

In their report the authors state: ‘The overall goal of this project is to demonstrate the potential for commercialization of a small, hydrogen fueled vehicle using ECD’s proprietary metal hydride storage system as a fuel tank. Two of the major components of the project have been (a) the conversion of a gasoline-powered scooter to run on hydrogen and (b) integration of the metal hydride hydrogen storage system into the hydrogen-ICE scooter. Both these tasks have been successfully accomplished. The eventual goal is to fuel the vehicle with domestically produced renewable hydrogen…Our study has also shown that electrolytic hydrogen is viable for recharging the metal hydride tanks and the availability of cost-effective hydrogen in India (which we chose as a test case) is not a barrier.’

Meanwhile, the vehicle has already created ripples in the Indian auto industry and government circles. A high-level Indian delegation visited ECD in April, which included members from Tata Motors, Ashok Leyland, TVS, Mahindra and Mahindra, Maruti, Eicher, Cummins India, Society of Indian Automotives Manufacturers and the Automotive Research Association of India.

According to Fuel Cell Today, the achievement is one more step towards a global hydrogen economy, where India and China are expected to play key roles. Says Sapru: "We have to push this. This is the solution to all our problems relating to environmental and energy security."

The process has been patented by the inventors on July 19, 2005, and assigned to the Troy (Michigan)-based ECD where Dr. Sapru is Director of Thermal Hydride Products and has focused her attention on Hydrogen. Her key inventions include: Development of high efficiency, non-precious metal electro-catalysts for water electrolysis and alkaline fuel cells; Metal Hydrides leading to the development of the nickel/metal hydride battery technology and hydrogen storage alloys systems; Design and construction of machines for novel alloy production.

ECD previously converted a Honda scooter with a small internal combustion engine to burn hydrogen, with the fuel stored in a metal hydride tank tucked neatly underneath the seat. The project group's leader, Sapru, believes that similar simple, low-cost scooter conversions could be big business in India, where scooters and small three-wheelers, typically of the highly polluting two-stroke engine type, constitute a main mode of personal transportation.

‘‘Use of hydrogen as an alternative clean fuel can help reduce our dependence on foreign oil and thus make significant contributions to energy security, and clean air,’’ says Sapru, who spent over 30 years in developing alternative fuel technologies and has as many as 30 patents to her credit.

Sapru’s current emphasis is on development, testing and commercialization of Hydrogen-ICE (Internal Combustion Engine) two and three wheeled vehicles for transportation, & Hydrogen-ICE generators for distributed power generation. She is pursuing alliances to create an infrastructure as well as to facilitate commercialization of hydrogen technologies in India. Which is why she is evaluating the availability and potential cost of hydrogen in developing countries.

THE TECHNOLOGY

Fuel cells combine oxygen and hydrogen through a process that uses a catalyst (usually platinum) to separate electrons from the hydrogen molecule (H2 2 electrons + 2 protons). The "magic" of the fuel cell is that it sends the electrons out from one terminal through an external circuit as usable electricity while the protons simply travel a short distance through the cell. Then, at the second terminal, the protons combine with incoming electrons and oxygen to form water. The chemical equation is simple: $2H_2 + O_2 = 2H_2O$. The fuel cell produces a steady current of the borrowed electrons as long as hydrogen fuel and oxygen are provided.

According to the patent, the system essentially consists of a hydrogen powered ICE, a fuel induction system for controlling the amount of hydrogen supplied to the ICE, an ignition system for combusting the hydrogen, an on-board hydrogen storage unit, an on-board hydrogen fuel gauge for measuring and displaying the amount of hydrogen stored, an on-board micro-controller, a visual indicator showing the amount of hydrogen present, and a hydrogen gas flow metering system for tracking the amount of hydrogen input into the hydrogen storage unit.

Sapru said work on the project started soon after a contract was signed with USAID and DOE in February 2004. A CNG-engine was imported from Bajaj in a few weeks and the autorickshaws arrived in November. ‘‘By this time 96-98 per cent of the conversion process was over and we fitted the (hydrogen) engine in the vehicle. For the next few months, it went for rigorous tests which included starting and running under temperatures below freezing level,’’ she said.

One attractive feature is that the amount of fuel, which needs to be stored on an average Indian three-wheeler, is a fraction of what is needed for automobiles favored by US consumers. ‘‘The smaller storage capacity significantly reduces technological challenges in introducing the vehicles into the Indian market. For this we use ECD’s safe, solid-state hydrogen storage technology which fits in the same space of the existing fuel tank,’’ Sapru said.

After the first vehicle conversion at ECD, a Bajaj automotive engineer was trained in the conversion process. Another CNG auto is being converted at the Bajaj headquarters in India using the conversion kit provided by ECD.

HYDROGEN BASED ENERGY

The notion of a hydrogen-based energy system has attracted visionary thinkers, scientists, engineers, clean-energy advocates, and environmentalists for more than a century. Jules Verne predicted hydrogen as fuel in The Mysterious Island (1874): "Yes, my friends, I believe that water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable."

The comparison of hydrogen and oxygen as fuels with coal suggests that Verne was imagining the burning of hydrogen, but not its alternative use--powering a fuel cell producing electricity, heat, and water. In 1897, Wilhelm Ostwald, a distinguished German physical chemist who won the Nobel Prize in Chemistry 12 years later, noted, "fuel cell research is to be strongly recommended as a route to protecting the earth's resources."

But, as of now, the big obstacle is manufacturing cost. A conventional internal combustion engine costs $30--45 per kilowatt (1 kw = about 1.35 HP) to manufacture, while fuel cell systems for mobile applications are believed to cost $2,000--4,000 per kilowatt, with some systems costing as much as $20,000 per kilowatt. When mass produced, those figures are expected to drop steeply and become more affordable in the developing world.

Contrary to earlier, more optimistic projections, today's conventional wisdom is that tens of thousands of fuel cell cars, at best a few hundred thousand, will be on the world's roads by 2012—2015.

Meanwhile in her paper titled ‘Hydrogen the new oil’ presented at the Symposium on Alternate Energy at IIT Kanpur, Dr. Sapru argued for the swift introduction of such a hydrogen-based economy in India. She pointed out that India was unique in having all the necessary resources to implement a hydrogen-based infrastructure at a competitive cost. Though it may seem a long shot, the paper showed how the excess power made from the raw materials of the sugar industry could be used to produce cost-effective hydrogen.

The vision of an economy in which hydrogen is the primary energy currency resonates with environmental, security, and power reliability concerns, especially among the younger generation. After years of promising development, the technology is advancing into the commercial arena. Enterprises across a broad sweep of the economy, including automobile manufacturers, electric utility companies, municipal sewage systems, manufacturers of power-generation equipment, high-tech start-ups, and national governments, are all exploring options for making the hydrogen economy work.

It may be too early to say for sure, but signs are strong that hydrogen will occupy center stage of the Indian economy in coming decades.

It is noteworthy that at the first Indo-US Fuel Cell Workshop, held under the auspices of the Indo-U.S. Science and Technology Forum in Washington, DC, Dr. Sapru focused on near term business opportunities that will benefit both the US and India.

She pointed out that while the hydrogen infrastructure and hydrogen storage are two major critical barriers to fuel cell and hydrogen commercialization in the west, this issue can be easily overcome in India, allowing the country to easily "leap frog" to clean technologies.

francisassisi@hotmail.com

PRESS RELEASES 2005

U.S.-India Partnership Powers a Hydrogen-Fueled Three-wheeler in India

1 September 2005

New Delhi - For the first time on public display in India, a three-wheeler vehicle powered by hydrogen fuel will be exhibited today at the annual convention of the Society of Indian Automobile Manufacturers.

The vehicle is one of two such demonstration models in the world. Its conventional combustion engine was converted to use hydrogen fuel through an American-Indian business alliance forged by the United States-Asia Environmental Partnership (US-AEP), a program of the United States Agency for International Development (USAID). The result is a milestone in U.S.-India energy cooperation, and international efforts to mitigate climate change through a future hydrogen economy.

Energy Conversion Devices of Troy, Michigan, and Bajaj Auto Limited of Pune, India, worked together to make the prototypes a reality. The U.S. company is a world leader in renewable technologies and Bajaj is the largest manufacturer of three-wheeler taxis in India.

Three-wheeler taxis form the biggest chunk of public transport vehicles in India. A move toward a cleaner alternative fuel would mitigate air pollution and negative effects of climate change.

The vehicles perform at levels equal to those of conventional Compressed Natural Gas (CNG) three-wheelers. Next steps for the hydrogen transportation initiative include exploring fuel availability, fueling infrastructure, and safety codes and standards that would raise performance to the level of a gasoline-fueled vehicle.

The other existing demonstration vehicle is now on the streets of Troy, Michigan, near its American developer. The Indian model is housed at the Bajaj headquarters in Pune, Maharashtra.

Another key partner in the effort is the U.S. Department of Energy. USAID provided funding of $500,000 to support the alliance.

Posted Jul 29, 2005 PT

Scientists achieve hydrogen-powered vehicle

Two Indian American scientists have successfully developed a three-wheeler for the road that runs on hydrogen power. If you enjoy this article, you may also be interested in an article entitled 'The Top Ten Technologies: #2 Hydrogen Economy Enablers.'

See more articles like this one at www.HydrogenHeadlines.com

Original news summary: (http://www.indolink.com/displayArticleS.php?id=072005113739)

- Working with the Michigan based Energy Conversion Devices (ECD), and supported by the U.S. DOE (Hydrogen Program), two Indian American scientists -- Krishna Sapru and Subramanian Ramachandran -- have achieved a significant breakthrough by developing a hydrogen-run three-wheeler for Indian roads.
- The latest trial runs, conducted this year, resulted in the successful conversion of a CNG-run Bajaj three-wheeler (autorickshaw) into one run on hydrogen fuel.
- In their report the authors state: 'The overall goal of this project is to demonstrate the potential for commercialization of a small, hydrogen fueled vehicle using ECD's proprietary metal hydride storage system as a fuel tank.
- Two of the major components of the project have been (a) the conversion of a gasoline-powered scooter to run on hydrogen and (b) integration of the metal hydride hydrogen storage system into the hydrogen-ICE scooter.
- The eventual goal is to fuel the vehicle with domestically produced renewable hydrogen...Our study has also shown that electrolytic hydrogen is viable for recharging the metal hydride tanks and the availability of cost-effective hydrogen in India (which we chose as a test case) is not a barrier.'
- According to Fuel Cell Today, the achievement is one more step towards a global hydrogen economy, where India and China are expected to play key roles.
- Her key inventions include: Development of high efficiency, non-precious metal electro-catalysts for water electrolysis and alkaline fuel cells; Metal Hydrides leading to the development of the nickel/metal hydride battery technology and hydrogen storage alloys systems; Design and construction of machines for novel alloy production.
- Fuel cells combine oxygen and hydrogen through a process that uses a catalyst (usually platinum) to separate electrons from the hydrogen molecule (H2 2 electrons + 2 protons).

Resources

Reports

Archived Reports

Resources for Media

Hydrogen Three Wheeler To Be Tested in India

August 11, 2005 – INDIA -- Under the clean fuels promotion project, supported by US-AEP and USAID's Greenhouse Gas Pollution Prevention Project, a second Bajaj Auto three-wheeler is being converted at Bajaj facilities in Pune to run on Hydrogen (using metal hydride storage technology). The first three-wheeler was converted in March 2005 in Michigan and has since been running successfully since then.

feedback about policies and initiatives. About 60 representatives from Chiangmai, Khon Kaen, Nonthaburi, Pakkred, Rangsit and Udonthani attended this workshop, which was hosted by the City of Chiangmai. King Prachadhipok's Institute (KPI) and the Kenan Institute Asia were the main facilitators of this workshop, supported by US-AEP.

[Back to Top]

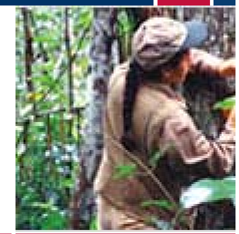
Water Quality Monitoring Training Held in Thailand

August 2–3, 2005 – THAILAND - The Water Quality Monitoring Program

ABOUT USAID | OUR WORK | LOCATIONS | POLICY | PRESS | BUSINESS | CAREERS

USAID FROM THE AMERICAN PEOPLE

ENVIRONMENT



You are here » Home » Our Work » Environment » Climate Change » Policies and Programs

SECTORS
IN THE SPOTLIGHT
RELATED USAID PROGRAMS
SEARCH
CONTACT

Clean Energy Technology

M. Bazzi/ECD

Cindy Lowry (USAID) admiring the Bajaj auto rickshaw, converted to run on 100% hydrogen, displayed at the 16th Annual US Hydrogen Conference, "Partnering for the Global Hydrogen Future."

Overview

Today, approximately 2 billion people in the developing world do not have access to electricity. As they gain access, they will increase the developing world's demand for energy, which is already expected to more than double in the next 25 years (with the transportation sector accounting for the fastest-growing share of total energy use). The production and use of energy have implications for human populations and the environment at the local, regional, and global levels. The combustion of fossil fuels produces carbon dioxide (CO2), the leading greenhouse gas (GHG). Other GHGs include nitrous oxide and methane, a by-product of agricultural production and decomposing solid waste. Rising concentrations of GHGs are believed by many scientists to increase the average global temperature and lead to changes in the earth's climate and weather patterns, a phenomenon known as global climate change.

The challenge, therefore, is to promote economic growth in developing countries while simultaneously reducing GHG emissions that lead to global climate change. This challenge can be met through the expanded use of clean, cost-effective technologies and practices that provide essential services and also have a reduced impact on the environment. Specifically, technologies are currently available to improve efficiency in the industrial, power, transportation, and building sectors. In addition, technologies that utilize renewable resources such as wind, solar energy, biomass, and hydropower have numerous large- and small-scale applications around the world and can be particularly cost-effective in rural areas where access to electricity is limited. Use of renewable sources and energy efficiency measures can decrease consumption of fossil fuels with high GHG emissions, such as coal. In cities, where nearly half the world's population lives, improved public transportation systems and urban planning can reduce energy consumption and GHG emissions from vehicles, landfills, and buildings. By encouraging policies and practices that support the widespread use of energy efficiency and renewable energy technologies at the national and local levels, the dual objectives of providing access to services while helping to mitigate global climate change can be accomplished.

USAID's Approach

In February 2002, President Bush announced that under the new U.S. policy on climate change, USAID would serve as "a primary vehicle for transferring American energy and sequestration technologies to developing countries to promote sustainable development and minimize their greenhouse gas emissions growth." In response to this announcement and in pursuit of the objectives of the United Nations Framework Convention on Climate Change, to which the United States is a party, USAID promotes the diffusion of climate- friendly technologies in developing and transition countries. The Agency encourages the adoption of technologies that meet development goals and reduce GHG emissions by removing barriers to their deployment.

USAID undertakes activities in the urban, industrial, and transport areas of the energy sector with the goal of promoting sustainable development and building technical expertise in the application of climate-friendly technologies. USAID seeks to build capacity to support technical improvements in energy and industrial efficiency, renewable energy, methane capture, and clean technologies while facilitating private sector investment, access to technologies, and policy reform. Through these activities, USAID has helped avoid the equivalent of over 15 million metric tons of CO_2 emissions over the past five years.

USAID has an extensive portfolio of climate change mitigation activities in India, currently the sixth highest generator of GHGs and the second fastest-growing emitter after China. This is due in large part to India's inefficient energy sector, which is responsible for approximately half of the country's total carbon emissions. With USAID support, the Center for Power Efficiency and Environment Protection (CenPEEP) was created to improve the operating efficiency of coal-fired power plants. CenPEEP implements efficiency measures that increase the generation capacity of power plants while reducing the amount of fuel consumed per unit of output. Efficiency improvements allow Indian power plants to increase the supply of much-needed electricity while reducing negative impacts on the environment. CenPEEP's work, coupled with USAID's contributions in demand-side management and renewable energy use, has helped avoid over 7.4 million tons of carbon dioxide equivalents cumulatively since 1997 and has resulted in substantial fuel savings that have reduced the price of electricity for end users. A cleaner, more reliable electricity supply is one way in which USAID is promoting economic development in India while improving environmental quality.

Growth in motor vehicle use, and therefore transportation-related GHG emissions, is taking place at a more rapid pace in developing countries than in the rest of the world. While petroleum consumption in industrialized countries is growing at 1% per year, it is growing by 6% in Africa, Asia, and Latin America. A by-product of fossil fuel combustion is local air pollution, which leads to as many as 4 million premature deaths each year in developing countries.[(1)] According to the International Energy Agency, a bus replaces anywhere from 10 to 40 other motorized vehicles, regardless of whether it is "clean" or "dirty." Encouraging governments to invest in public transportation and convincing riders to use buses and other forms of mass transit are some of the best strategies for providing efficient, sustainable transportation and reducing CO_2 emissions from vehicles.

USAID's activities to limit the growth of transportation-related GHG emissions have resulted in the implementation of a number of sustainable transportation systems. Jakarta, Indonesia, for example, established the first bus rapid transit (BRT) system in Asia, while India has implemented non-motorized transport through the modernization of rickshaws and has secured government approval to develop a BRT in New Delhi. In Senegal, USAID supported the development of an integrated BRT and bikeways plan for Dakar. Such sustainable urban transportation systems not only alleviate traffic congestion, they lead to reductions in emissions of air pollutants that cause respiratory and other health problems as well as global climate change.

Recognizing that energy is one of the major expenditures for poor families living in urban townships, USAID promotes the use of low-cost solar water heating units in South Africa. Solar water heaters significantly reduce household energy consumption and costs while providing hot water to households that could not otherwise afford it. The goal of this program is to promote the installation of solar water heater systems by public housing authorities, thus reducing the cost of housing, power, and other municipal services while reducing health risks and improving the quality of life in South African townships. When aggregated across a township, the energy savings of solar water heaters also result in significant reductions in indoor air pollution and GHG emissions. National interest in solar water heating for low-income households has surged, and as a result, plans are underway to encourage replication of this work by more housing authorities across South Africa.

Conclusion

Because economic and social development are high priorities for developing countries, the activities that USAID supports are part of an integrated strategy that encourages development while addressing the causes and effects of climate change. USAID supports multiple-benefit efforts by providing tools, information, and technical assistance to stakeholders in partner countries throughout the world. The complexity of the problem requires an approach that addresses numerous sectors at varying scales, from industry to the individual. The application of new technologies and practices offers the prospect for continued economic growth with reduced GHG emissions. Recognizing that leaner productivity and greater efficiency are critical for economic success, USAID will continue supporting the commercialization, dissemination, and adoption of environmentally sound technologies. Moving forward, the goal will be to attract more private investment in technologies that meet development needs and reduce GHG emissions.

Footnote

[(1)] *Fuel for Thought: An Environmental Strategy for the Energy Sector*. World Bank.

Back to Top ^

FOIA Requests : Privacy Policy : Email This Page | Plug-ins : FAQs : Help Desk : Contact Us : Site Ma

Last Updated on: May 16, 2005