Case Study: Taiwan Hydrogen Fuel Cell Scooter Fleet Demonstration

In densely populated urban areas around much of the world, many citizens rely on two-wheeled vehicles such as scooters and mopeds as their main form of transportation. These vehicles, despite their small size, are notoriously inefficient; the worst emit 30 times the pollution of a moderately controlled passenger car. Major Asian cities, such as Shanghai, are moving to ban the license of new gas mopeds and bicycles, with the intent to replace 80 percent of existing gas-powered ones with electric versions.

Electric scooters are becoming more and more popular. They help reduce noise and air pollution and have a "green" image. The largest concentration of scooters is in Asia, and sales of electric drive versions are increasing dramatically.

According to "Research and Forecast of China Electric Scooter Industry, 2014-2018" from Huidian Research, the demand for electric scooters in China reached 1.05 million units in 2013, an increase of 31.25% from 2012. Navigant Research (formerly Pike Research) estimates annual sales of electric two-wheel vehicles will reach 60 million units in China by 2018.

Overall, sales in the region are expected to increase 10-fold between 2012 and 2018[i], resulting in a cumulative sales total of almost 382 million in the period.

The two main technologies used to power these electric vehicles are lead-acid and lithium ion (Li-ion) batteries, but the island of Taiwan, where more than 7 million people rely on scooters for their daily commute, has been a leader in pushing for cleaner forms of two-wheeled transport, particularly fuel cell and hydrogen technologies to power scooters and mopeds.

Why Taiwan?

Taiwan has a small but robust fuel cell industry that includes fuel cell manufacturers, hydrogen generation companies, component suppliers, and integrators. The scooter industry is also well-established; Taiwan is home to three of the top scooter manufacturers, collectively holding a major percentage of the two-wheeled vehicle market. There is also a complete supply chain to support this market, including parts providers, dealers, and maintenance facilities.

To help boost the number of electric two-wheeled vehicles, Taiwan's Ministry of Economic Affairs established a support program, the Taiwan E-scooter Standard (TES), to help offset the cost of purchasing nationally-certified electric scooters. Depending on the scooter type, buyers could receive either NT$7,200 (US$240) or NT$10,000 (US$335); more than 10,000 scooter owners have applied for support (NT$80 million) since it was launched in 2009.

Why Fuel Cells?

A fuel cell is an electrochemical device that combines hydrogen and oxygen to produce electricity. Because they generate much lower, and often times zero, emissions and offer the potential of many

other environmental and economic benefits, fuel cells are currently being deployed around the world for a wide variety of stationary, portable and transportation applications. Many demonstrations are also under way, to test feasibility in certain markets, including two-wheeled vehicles. Like electric two-wheelers, fuel cells are quiet and greatly reduce pollution, but compared to the batteries currently used to power electric scooters, fuel cells offer a longer cruising range and a much shorter refueling time, plus they eliminate the burden of battery recycling or disposal.

In 2010, The Taiwan Institute of Economic Research (TIER) conducted a road test of 30 fuel cell scooters in northern Taiwan, accumulating 120,000 kilometers (74,500 miles) riding through various cities and terrain, including mountains and near the sea. The scooters were from Taiwan-based fuel cell manufacturer Asia Pacific Fuel Cell Technologies (APFCT) and their partners. APFCT has focused on developing proton exchange membrane (PEM) fuel cells for the two-wheeled scooter market since the company was launched in 2000. Since then, APFCT has released several generations of its zero-emission scooter (ZES) and has partnered with several vehicle and fueling companies on projects and trial demonstrations around the world. The scooters used in the 2010 trial accumulated a total of 122,769 kilometers (76285 miles), reached a top speed of 70 kilometers (km) per hour (44 miles per hour) and could travel up to 50 km (31 miles) with 90 grams of hydrogen, more than 300 miles per gasoline gallon equivalent.

Project Details and Data

The second phase of the demonstration was launched in 2012 – a one-year verification project funded by the Bureau of Energy, Ministry of Economic Affairs, supported by the Pingtung County government in southern Taiwan. In this trial, 80 APFCT fuel cell scooters were offered free to the public to ride around a 70 km loop in the beach resort area of Kenting. The scooters were equipped with two easily accessible metal hydride canister under the seat to provide the hydrogen, giving the vehicles a range of around 80 km (50 miles).

Fifty-five scooters were placed at 10 hostels along the route with 25 placed at local police stations, health centers and elementary schools. Three hundred and sixty hydrogen canisters were evenly distributed to seven exchange stations, including gas stations, 7-11 convenience stores, and police stations.

Fuel Cell Specs:

- Type - Proton Exchange Membrane (PEM)
- 1.5 kW, max. power 2.5 kW
- 24 V
- Water-cooled
- Operating temperature 5-40° C

The hydrogen was supplied by San Fu Gas Company based in Kaohsiung. The main maintenance and refill station was located at the “Bao Dao Yao” hostel in Henchuen Township, which also was the location for parts replacement and maintenance. Roadside assistance was also available.

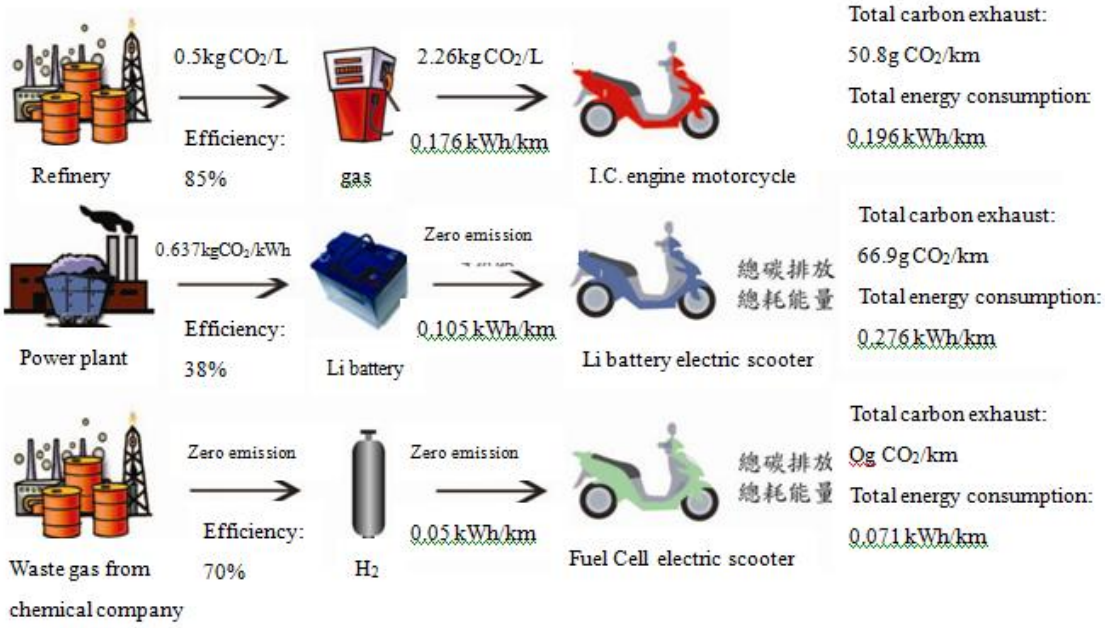
Hydrogen Storage Tank Specs:

- Aluminum alloy
- Diameter - 76 millimeter (mm)
- Length - 365 mm
- Weight – 45 grams
- Hydrogen purity - >99.99%
- Pressure - 10 kg/cm2 (150 psi)

For safety, the hydrogen station was built with metal net floor for ventilation with a hydrogen leak sensor and alarm on the ceiling.

Each scooter was fitted with a GPS system provided by Chunghua Telecom. Researchers monitored the scooters via the GPS system and analyzed a variety of data throughout the year, including driving time, location, direction, altitude, cruising distance, voltage, current and fuel cell stack temperature.

The fuel cell system was analyzed for efficiency and compared to internal combustion engines to determine economic and well-to-wheels efficiency and emission advantages. When the hydrogen is generated from by-product waste gas, a fuel cell-powered scooter is much more efficient and virtually emission-free.



Energy conservation and carbon reduction analysis of various scooters

Source: National University of Tainan (Well-to-Wheels Emission/ Efficiency)

For every 1000 km a scooter accumulated, researchers would measure fuel cell performance; when the unit's performance declined more than 10%, the fuel cell stack was replaced.

On the fueling side, data was collected on hydrogen production and consumption, cost, the refill rate, and the average time for scheduled and unscheduled maintenance. There was also a life cycle evaluation of hydrogen canisters and their connectors.

Other parameters studied included individual vehicle mileage, accumulated mileage, the relationship between the number of scooters and the running hours and days, the relationship between the number of scooters and the cruising distance and the daily running hours.

The scooters were refueled by swapping an empty fuel canister for a full one, a process taking less than one minute. Once new canisters were installed, the rider was able to drive away immediately. The empty canisters were taken to one of three stations capable of refilling 30 canisters simultaneously in 20-30 minutes.

For the trial, employees at the exchange stations performed the canister switch but switching is a simple process that can easily be done by the driver.

Reporting Results

Over the course of the year, the 80 scooters were ridden more than 10,900 times, or about 135 days per scooter. The vehicles accumulated more than 245,000 kilometers (152,000 miles), with an average of 3,068 km (1,900 miles) per scooter.

A total of 453 kilograms of hydrogen was consumed during the project, an exceptional 335 miles per kilogram, which is three times that of a modern gasoline powered scooter (a kilogram of hydrogen contains roughly the same energy as a U.S. gallon of gasoline).

No safety incidents with the scooter or hydrogen fueling were reported during the trial. Five hydrogen canisters were found to have leaked, caused by the deformation of the hydrogen needle valve when the canister was plugged into position. This prompted rigorous testing (10,000 times plugging and unplugging) and the canisters were deemed reliable, durable and safe.

The data collected showed that each scooter experienced some form of abnormal operation five to 10 times during the trial. This included 372 cases involving the fuel cell system, which includes the lithium battery used for standby power, the balance of plant components and hydrogen storage system; 120 involving the mechanical structure of the actual scooter – the frame, braking, lights, tires, etc.; and 17 for motor problems. Of the cases involving the fuel cell system, the main problems reported were the hydrogen recycling and fuel gauge, each garnering 23.7% or 88 instances.

Riders React

In addition to the technical data gathered from the GPS and other testing equipment, riders were encouraged to complete a questionnaire that asked about performance, ease of use, safety, riding experience and expectations. A total of 104 users responded to the 15-question survey.

Most riders (61%) found out about the free scooter demonstration from the hostel where they were staying. A majority had more than 10 years experience riding motorcycles, mostly for general commuting or commuting to work and more than half had heard of fuel cell-powered scooters prior to their riding experience. Most of the riders were satisfied with the scooter's speed, range and handling, as well as the hydrogen canister exchange system. More than 70% said they might purchase a fuel cell-powered scooter in the future (32% said definitely, 40% said maybe). A majority (62%) preferred a price below NT40000 (US$1325) for the scooter and NT30 (US$1) to pay for a hydrogen canister swap.

The project was also an educational opportunity – each hostel and canister exchange posted a bulletin board with route information as well as information on the benefits of hydrogen and fuel cell technology.

APFCT is using the data from these field trials to design a commercial-ready scooter. Focus will be placed on reducing the cost of fuel cell stacks and hydrogen canisters while increasing the size of the vehicle. The data collected by this project will also be used to help establish product technology standards and safety regulations through the International Standards Organization.

Beyond Taiwan's Borders

Many universities, and other companies besides APFCT, have been working on two- wheeled fuel cell vehicles for many years, with several small scale trials conducted in Europe, Japan and the U.S. Suzuki entered into a joint venture with UK fuel cell manufacturer Intelligent Energy - called Smile FC - to commercialize a fuel cell version of Suzuki's Bergman scooter. Initial target markets include Taiwan, India, Indonesia and China.

APFCT's next generation fuel cell scooter

In order to be competitive with battery and gas-powered scooters, manufacturers are continuing to improve acceleration, climbing capability, range and speed, as well as reducing the size and weight of fuel cells to fit comfortably into the limited space available on scooters. A competitive price is expected to be reached once production numbers increase.

[i] http://www.navigantresearch.com/newsroom/nearly-382-million-electric-two-wheel-vehicles-will-be-sold-in-asia-pacific-through-2018

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