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The prospects—fuel cell motorcycle in Taiwan

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Abstract

The motorcycle industries in Taiwan are facing intensive challenges both from the continuously stringent emission and fuel economy regulation implemented by the government while still having to meet the performance and cost requirements from for the motorist. This paper describes the technology progress of the transition to clean motorcycle propulsion system in Taiwan and also the first zero emission motorcycle pilot commercial programs in the country. From the internal combustion engine to the hybrid system and pure electric power motorcycle, the prospects of fuel cell motorcycle are discussed from the product, the infrastructure and the policy aspects.

Keywords: Motorcycle; Scooter; Internal combustion engine; Hybrid engine; Electric; Fuel cell

1. Introduction

The motorcycles in Taiwan had been the major contributor to the economy growth by providing a very cost-effective transportation services during the early stage when the automotive industry and public transit system are not well-established. Adding the fact that the geological and climatic conditions in Taiwan are also very suitable for the operation of motorcycle in almost all seasons and all areas, the motorcycle industries are flourishing in the last decade. As a result, the annual production reached the peak of 1.5 million in 1995 and became saturated. Currently, there are over 11 million registered motorcycles with the highest motorcycle per capita density (2.1 person per motorcycle) in the world. It is this reason that Taiwan had always become the pioneer in implementing high emission and fuel economy standards. Figs. 1 and 2 show the past, present and the future regulations of emission and fuel economy for the country to move toward a friendlier environment. These strategies include emission durability test, conformance-of-production, on-road inspection and maintenance program for all the motorcycles in-use.

These large amounts of motorcycles totally emit 12% of carbon monoxide and 8% of hydrocarbon of the global emissions in this country. With regard to the CO_2 emission, the motorcycle contributes 6.6% of the transport sector. Particularly in Taipei City, motorcycles contribute 35% of carbon monoxide and 60% hydrocarbon emission. The smoke and noise issues are also part of the accompanying problems.

Many efforts had been taken by the motorcycle industries and government-sponsored organization to research and develop high efficiency internal combustion engines (hereafter called ICE) and the after-treatment systems. The current trend is to abandon the production of two-stroke engines by year 2000 and concentrate on the improvement of the four-stroke engine mainly by introducing electronic control injection system. Another jump-through technology which is attempted to be implemented by the Environmental Protection Administration (EPA) is the pure electric scooter program. Together, all these activities will put Taiwan to be the leader in the realization of a clean motorcycle society.

Very limited effort had been put in the fuel cell research and development for motor vehicles in Taiwan. But it cannot be neglected that the rapid development of fuel cell recently may change the game of ICE for the whole

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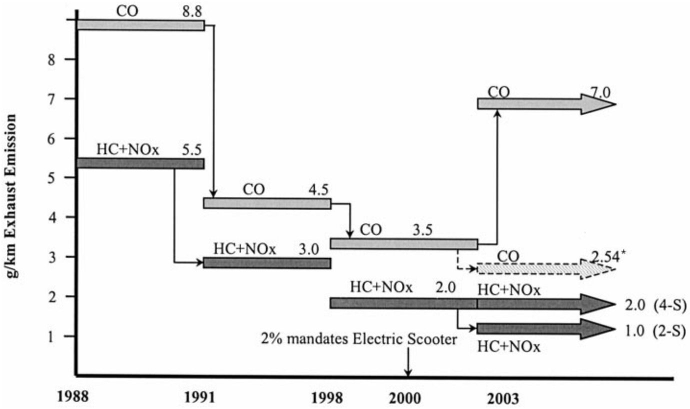

Fig. 1. The CO emission standard is normalized to warm start data for comparison purpose. * Note: Cold start test is introduced in 2003.

motorcycle industries. In this paper, the technical progress of motorcycles in Taiwan moving toward zero emission concepts are reviewed. Finally, the outlook for the fuel cell application is discussed.

2. Driving force for low and zero emission motorcycle

As is the case for automobiles, the most effective driving force to reduce emission and fuel consumption of motorcycles is always from the legislative sector. The emission and fuel economy regulations implemented in Taiwan is clearly seen in Section 1. Summary of the current worldwide emission standards for the motorcycle is shown in Fig. 3. Some important facts need to be noticed. (1) It is quite obvious most regions of the world are in the approach to implement stringent emission standard particularly the country with more motorcycles used. Besides Japan, the Asian countries produce 79% of the total motorcycles in the world. (2) In the near future, the European Union will be the region requiring most stringent emission possibly due to the strong environmental consciousness in these well-developed countries. In the developing countries, the requirement to have the motorcycle to transfer goods and people to keep the economy growth may have to balance the emission of the motorcycle. (3) Still Taiwan is the only country requiring zero emission motorcycle production through legislative approach so far.

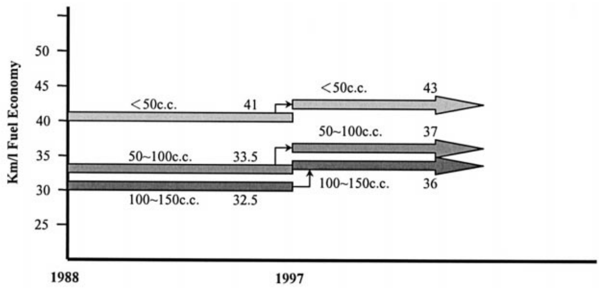

Fig. 2.

Without the critical and most effective driving force of the mandatory zero emission vehicle requirements, even for the EUIII emission standard, it is still possible to apply lean burn ICE-battery hybrid and heated catalytic converter technologies to meet the requirement [1].

The other factor affecting the zero emission motorcycle application is the international agreement to reduce CO_2 for the global warming concern. For the internal combustion engine, since hydrocarbon fuel is used, it is inevitable to have CO_2 emission due to the combustion process of hydrocarbon and air. The amount of CO_2 emission is reflected by the fuel economy. The legislation may play an important role in the implementation of severe fuel economy standard. Taiwan, again, is the only country setting the fuel economy standard for motorcycles in the world. Quite effectively, this is also a good measure of the energy efficiency to the motorcycle makers as shown in Fig. 4a,b,c [2]. It cannot be neglected that this constraint had always kept the engine designer on the right track to keep the engine efficiency high without heavily relying on the after-treatment technology when introducing new engine models. Similarly, noise regulation is also part of the legislative approach and can be taken to measure the environmental effect of the motorcycle.

Although the emission, fuel economy or noise regulation alone will not necessarily create a scenario for the fuel cell technology, together the combined benefit of high energy efficiency, quiet and pollution-free power unit may set a very good position for the fuel cell to come in the future.

A transition between the ICE and the zero emission power unit for motorcycles is necessary because the new technology needs to be developed to commercial level, and

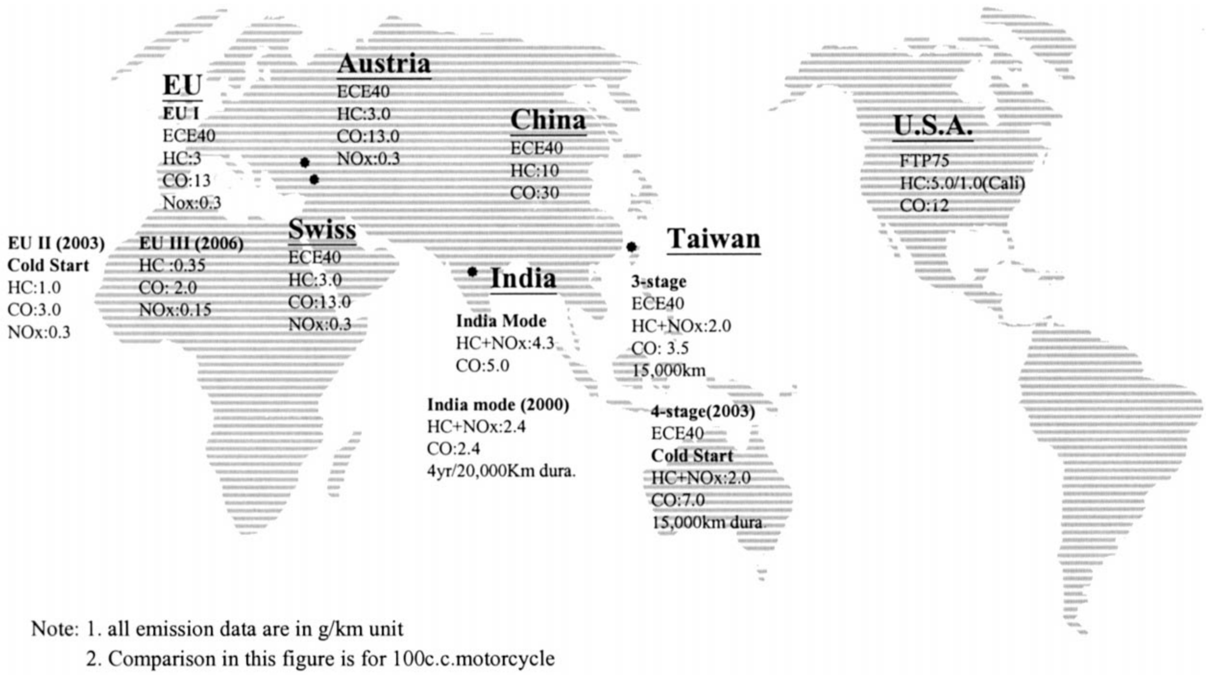

Fig. 3.

more importantly, the infrastructure (if not the same) needs to be well-established which may take a much longer time than the technology itself.

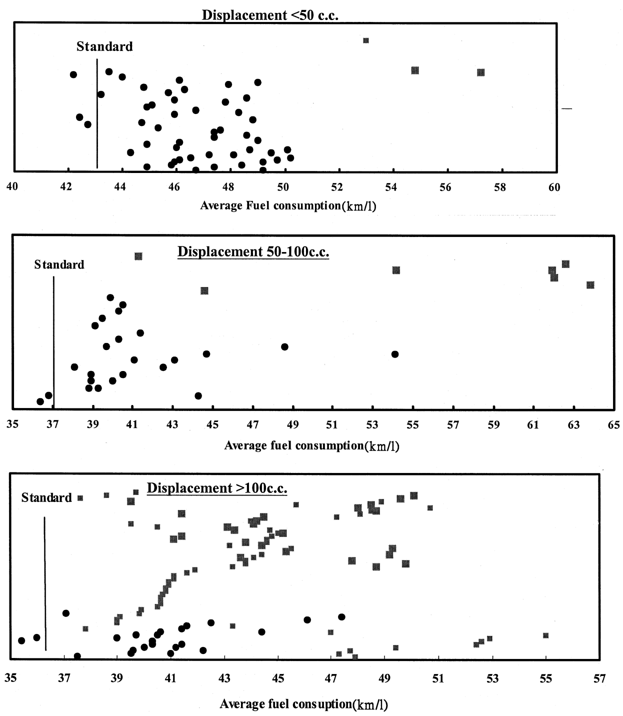

Fig. 4.

3. Commercialisation of zero emission scooter in Taiwan

The first sale of commercial electric motorcycle actually had been started in 1982 even before the implementation of emission regulation. Later, triggered by the worsening urban pollution problem, the concept of introducing large-scale sale of pollution-free scooters began in 1997. A survey conducted by the department of transportation on the current motorcyclist in 1998 also indicated that 38.3% of them express the will to purchase an electric scooter if possible. Thus, followed by the initiation of electric scooter development programs during 1992 to 1998 sponsored by the Energy Committee and EPA, a continuous 42-month's program was started in 1999. The objective is to develop the next generation of electric scooter (EC3) to keep supporting the goal of accumulated sale of 3 million electric scooters by year 2010. The content of the new generation electric scooter will be discussed later.

As the mandatory 2% zero emission scooter will become effective in 2000, five local companies have actively been promoting and marketing the electric motorcycle in Taiwan during 1998–1999. By July 1999, a total of 5000 electric motorcycles had been sold to the general public. Table 1 shows the comparison of the market-available electric motorcycles in various aspects.

A recent survey conducted on these electric motorcycle buyers in April 1999 indicates that the product ranking generally falls in 'Fair'. Not surprisingly, the short cruise range, the heavy weight of the motorcycle and the long

Table 1
Comparison of electric, hybrid and ICE scooters

	Hybrid	EV1	EV2	EV3	EV4	EV5	A125	B50	C50	H50
Configuration	Parallel	Electric	Electric	Electric	Electric	Electric	Gasoline	Gasoline	Gasoline	Hybrid
Motor power (peak)	3.2 kW	3.2 kW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.3 kW
Motor	DC Brushless	DC Brushless	DC Brushless	DC Brushless	DC Brushless	DC Brushless	N/A	N/A	N/A	A.G. Asynchronous
Battery capacity	12 V/ 16 A h*4	48 V/26 A h	48 V/26 A h	48 V/40 A h	48 V/26 A h	24 V/52 A h	N/A	N/A	N/A	36 V/8 A h
Charging time (h)	N/A	8	6	6–8	3–4	8	N/A	N/A	N/A	N/A
Engine displacement	50 c.c.	N/A	N/A	N/A	N/A	N/A	125 c.c.	50 c.c.	50 c.c.	50 c.c.
Engine power	2 kW/ @6000	N/A	N/A	N/A	N/A	N/A	6.6 kW/ @7500	2.3 kW/ @7500	N/A	2.5 kW @6000
Transmission	Gear	Gear	CVT	CVT	CVT	Gear + chain	CVT	CVT	CVT	CVT
Dry weight (kg)	100	119	111	141	115	95	110	83	83	100
Acceleration 0–30 m (s)	4.5	5.1	N/A	4.3	N/A	N/A	4.5	5.8	5.6	N/A
Gradeability (°)	20	12@10 kph	N/A	18@10 kph	8@10 kph	12@10 kph	N/A	N/A	N/A	N/A
Max. speed (kph)	60	51–55	60	60	60	40	78.0	56.0	59.9	49
Fuel consumption ECE40/ECE47*	65 km/l	N/A	N/A	N/A	N/A	N/A	N/A	42.5 km/l	45.4 km/l	40 l/km
Fuel consumption @30 kph	N/A	15.6–18.6 Wh/km	N/A	29 Wh/km	N/A	19.6 Wh/km	54.7 km/l	59.6 km/l	61.3 km/l	N/A
BSFC (g/kW h) min	300	N/A	N/A	N/A	N/A	N/A	300	310	310	330
Cruise range (km) ECE40/ECE47*	> 200	40*	N/A	33	N/A	55.8	234	255	272	N/A
Initial cost (UDS)	*Concept	1984	1969	2062	1969	1094	1740	1203	1187	*Prototype
Sale cost subsidy (USD)		1203	1187	1094	1187	719				N/A

charging time required are the three concerns ranked 'unsatisfactory' and 'extremely unsatisfactory' due to the low energy density lead–acid battery used. However, the 'acceleration' and the 'low noise' are also the two items that users rank 'most satisfactory' for the clean motorcycle. The development of the ZES2000 electric scooter is fully described in EV-15 technical paper [3]. An EC3 scooter development program is currently undergoing testing in Industrial Technology Research Institute to keep develop the next generation electric scooter for better performance and market value. The main technologies to be developed are:

1. Battery: apply high energy density Li–ion battery and intelligent battery energy management system.
2. Integrated energy management: optimization of energy release and charge strategy. Fast charging system development.
3. Power unit: developing high efficiency motor and optimize driver control system.

A brief description of the EC3 engineering vs. the existing ZES2000 is shown in Table 2.

3.1. Hybrid system

Having recognized the disadvantages of the pure electric motorcycle, the emergence of a hybrid concept of IC engine and battery is natural. In 1997, Honda Motors released a hybrid two-wheeler with MHS concept in the 1997 Tokyo motor show. Only the frame and power unit was shown, without much information of the system performance. The frame is aluminum and a water-cooled 49 c.c. engine is packed with a DC brushless motor together driving the rear wheel. The rated power output is 0.6 kW. It claimed to target a 60% drop in CO_2 emission and 2.5 times better fuel efficiency. The gasoline engine delivers power for high-speed performance and for hill climbing while its electric motor engages for low-speed cruising. In August 1999, a more sophisticated hybrid powertrain prototype was released in Japan [4]. The prototype features a '+C engine' which is equipped with an air pump to super-charge the intake air. Lean burn combustion is claimed. The electric motor operates at low speed condition, while the engine engages in high load operation. The engine is based on the 50 c.c. 'super cub' design fitted but with advanced injection system. The engineering specifications are not available.

Table 2
Comparison of ZES200 and EC3

Item		Model	
		ZES2000	EC3
Performance	Max. speed (kph)	50	55
	Acceleration 0–30 m (s)	5	4.8
	Gradeability	10°/20 kph	12°/20 kph
	Cruise Range (°) ECE47	40	60
	Cruise Range (°) 30 kph	60	80
	Weight (kg)	120	< 90
Charging	Normal	8 h for 40 km	8 h for 60 km
	Quick	–	15 min for 30 km
Battery	Life (cycle)	200	600
	Cost (USD/kW h)	300	< 300

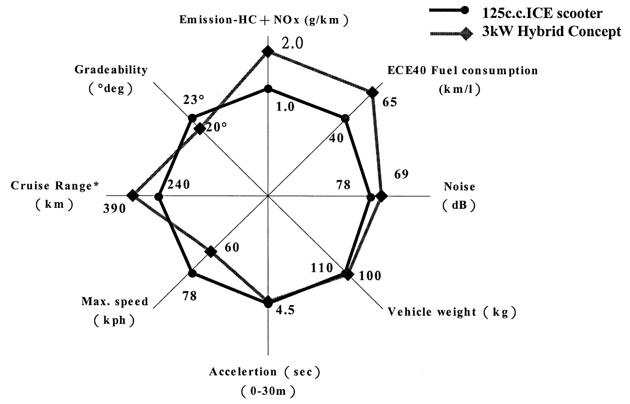

Fig. 5.

AVL also had published a hybrid concept HYC in 1999 [1]. The system uses a water-cooled 50 c.c. two-stroke engine with a relatively small capacity motor (0.75 kW) and battery (36 V/8 A h) mainly for power-assisted use during acceleration. The test data reported good acceleration, very low emission and fuel economy. But when compared with four-stroke engine of the same capacity, the fuel consumption benefit is not so significant.

An ITRI concept of hybrid system particularly for the market in Taiwan is also in the early stage of development. Gasoline will be the only fuel required for the hybrid power unit using the current infrastructure. By optimizing the energy management of the IC engine and battery, a very much improved fuel economy can be achieved and the cruise range would become of no concern. A four-stroke 50 c.c. engine is selected while the total hybrid power is to cope with the performance of a 125 c.c. engine in low to medium speed ranges but with much better economy.

One of the strategies applied in this hybrid system is to run the electric motor only during the low speed condition so that the emission in urban region is limited to minimum. The IC engine will be controlled to operate at the optimal BSFC region where the emissions are also lower. The poor emission and fuel consumption characteristics of ICE in the partial load operation mostly used in urban area thus are avoided. However, the weight of the battery (initially lead acid) is still the major factor. The initially chosen lead acid battery would add the total vehicle weight nearly up to a 125 c.c. motorcycle level. As lightweight frame materials are used and higher energy density batteries become available, it is expected to weigh 100 kg. The initially target performance of this concept compared with a 50 and 125 c.c. ICE is in Fig. 5 and Table 1.

Because energy transfer causes loss, the hybrid concept is still limited by the best energy efficiency of the ICE if the energy comes solely from gasoline. All the emission and fuel economy improvement effects are also limited to the optimal engine characteristics. As a transition before the future fuel supply infrastructure is defined (which may be Hydrogen, Methanol or Electricity), the hybrid concept with the existing hydrocarbon fueling will still be the best concept at this stage.

4. Fuel cell motorcycle

Taiwan will definitely be the first country to realize zero emission electric scooters in the world. The government officials are all confident in implementing this mandatory regulation and the first target of reaching 10,000 electric scooters sale can be met before year 2000. The motorcycle industries are also actively promoting the product. These first buyers, happy to foresee a clean environment to come, are the pioneers of the promising future.

Based on the previous 3 years of marketing electric scooter, the government, the industry and the electric scooter buyer all sufficiently realize the issues of the introduction of alternative fuel vehicle. These issues can be discussed in three aspects.

4.1. The product

It has been demonstrated in automotive applications that fuel cells could significantly reduce emissions almost to zero and achieve double the energy efficiency of the IC engine. But for motorcycle applications, the issues are cost and weight.

4.1.1. Cost

Cost is very sensitive to the motorcycle buyer because the price of a motorcycle not only has to reflect the economic power for the person who makes the purchase decision but also will be justified by the benefit in the way of using it. If not for pleasure or racing, the alternatives of subcompact car or using public transport will greatly affect the intention to purchase a motorcycle. Currently, the electric scooter buyer in Taiwan may receive a maximum of nearly US$1000 from the government depending on the power system of the scooter. The final price the buyer pays is still just close to a two-stroke 50 c.c. ICE scooter. If there is no incentive from the government, a fuel cell, similar to the electric power, although it meets the zero emission vehicle definition will face the same difficulty to gain public acceptance. At present, it is still difficult to compare the fuel cell motorcycle operating cost with the ICE because the definition of fuel for the fuel cell varies. However, the total cost of the initial purchase, operation, maintenance and part replacement must be all considered.

4.1.2. Weight

Weight is another sensitive concerns for the motorcycle. The need to push the motorcycle or sometimes pull a fallen motorcycle upright requires some strength for ordinary people. A typical weight distribution of a 50 c.c. ICE scooter and the ZES2000 electric scooter are compared in Table 3. A fuel cell power unit, if it has to compete with the current ICE scooter, needs to match the weight and space as indicated in the table.

Table 3
Vehicle weight of three motorcycles

Weight	Model		
	ZES 2000	50 c.c. ICE (4-S)	Fuel cell
Fuel tank (with 6 l fuel) (kg)	0	5.9	
Engine + transmission + starter (kg)	0	27.0	
Motor (kg)	0	0	
Motor + transmission (kg)	21.0	0	
Fuel cell stack (kg)	0	0	34.6
Condenser + air pump + others (kg)	0	0	
Reformer (kg)	0	0	
Battery (kg)	39.7	1.7	
Driver + charger (kg)	7.0	0	
Others (body, frame seat, wheels, etc.) (kg)	51.5	48.5	48.5
Total (kg)	119.2	83.1	83.1

4.2. The motorcycle industries

Obviously, the current ICE motorcycle industries will be changed as the power unit now requires totally different components and system concepts. The industries need to establish a new supply chain for the new power unit to assure the success of integrating the whole motorcycle.

4.3. The infrastructure

4.3.1. Fueling

The fuel and the fueling infrastructure issues for the fuel cell power vehicle have been discussed and analyzed quite thoroughly by some studies [5]. If the fuel cell motorcycle requires fuel other than the widely existing petroleum-based fuel such as gasoline and diesel, two experiences of introducing alternative fuel in the motor vehicle in Taiwan can be reminded here.

(1) In early 1989, the EPA started a series of programmes studying LPG application in buses and automotive. The results showed quite impressive improvement in the HC, CO emission as well as the operation cost. An initiative to encourage the taxi to use LPG in major cities was implemented in 1993. EPA subsidised the taxis when buying either the original automotive LPD car or retrofit with LPG kit. It was thought that the LPG vehicle technology is very mature and the successful demonstration in many cities would gradually bring this program to island-wide scale. The following discovery of the difficulties to construct LPG station especially in the city, and the occurrence of several explosion incidents related to LPG leak-

age destroyed the public confidence. It was projected to be a promising program to reduce the urban emission. Now less than 10,000 taxis were sold totally and there are only three LPG fueling stations available in the whole island.

(2) The electric scooter faces the similar difficulty. The motorcyclists are not guaranteed to have the access to an electric power plug for recharging the battery either in the office or at home. Actually, the current buyers of the electric scooter represent the few of the public who have convenient access to power plug. In fact, this is also a demand to the government from all the motorcycle makers in Taiwan before they can justify the full investment. Without the success of charging infrastructure, the motorcycle maker would expect a less promising sale volume than the government had predicted.

As most of the fuel cell researches had clearly indicated, pure hydrogen would achieve the best power efficiency, followed by methanol, nature gas and gasoline. Carrying a reformer in a scooter would not only increase the vehicle weight itself but also imply uncertain danger particular for the exposed motorist. With the situation that neither hydrogen nor methanol-fueling infrastructure is available in Taiwan, the lessons from the LPG and electric vehicles must be remembered. The other side of the infrastructure will be a maintenance issue. All the sales and maintenance shops of fuel cell motorcycles need to be trained as they provide the continuous confidence to the users.

The safety aspect is mainly in the hydrogen supply or storage tank. A completely new set of safety regulations governing the vehicle, the fuel station, parts and the maintenance shop must all be studied to assure the public that the fuel cell would be of no safety concern. As the motorcycles are used ‘dynamically’, these safety issues would take a long time to discover and prevent.

4.3.2. The policy

The government sector must establish its full scope of product standards and incentive policies for this clean vehicle’s future. These include: part specification; test procedures for the parts and systems; test procedure for the emission and energy consumption; safety regulation of the parts and systems; incentive of the clean vehicle to the makers, the buyers and the fueling suppliers; long-term research and development programs to study and evaluate the effect of the fuel cell system to the society and environment.

If the fuel cell technology had demonstrated its full capability, the success of marketing the product will not be difficult in Taiwan based on the preceding efforts. But before the introduction of this clean power technology, it is important to fully address the above issues in order to support the existence of the fuel cell power in the emerging period without sacrificing those environmentally conscious pioneers.

5. Conclusion

(1) Motorcycles are providing the basic and personal transport services in many countries. As the direction to move for a clean, energy efficient power source is clearly recognized, implementing mandatory zero emission motorcycle is the most crucial driving force to foster the launch of fuel cell motorcycle in the short future.

(2) Commercialising electric motorcycles has been realized in Taiwan. The pioneering program also had exposed issues and concerns for public acceptance and fueling infrastructure. The most acceptable features of the zero emission electric motorcycle are the acceleration and the quietness of operation, while the most unsatisfactory features are the long battery charging time, inadequate cruise range and the over-weight vehicle mainly caused by the low energy-density lead–acid battery used. The use of higher energy density battery and lightweight frame materials will improve matters.

(3) Hybrid concept is emerging to fill the gap of zero emission power and the currently well-established ICE technology and fueling infrastructure. Quite significant improvement in the fuel economy is achieved and the difficulty to urgently establish the charging infrastructure is alleviated. However, the best energy efficiency and emission are still limited by the optimal ICE characteristics.

(4) Fuel cell technology has demonstrated its capability to significantly reduce the total emission and enhance the total energy efficiency in the automotive application as the basic energy generation concept differs from the hydrocarbon fuel combustion process of ICE. To implement fuel cell motorcycles successfully in Taiwan, the issues of product, infrastructure and the policy must be thoroughly addressed. Of those, the cost and weight of the product, the fueling infrastructure, the governmental incentive program and establishing related test procedures are most important.

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