Potential for the Commercialization of Fuel Cells in Taiwan

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CONTENTS

INTRODUCTION

An evaluation of the current status of fuel cell technology and potential for commercialization in Taiwan is timely. Taiwan is already ahead of many countries in establishing public-private partnerships for fuel cell research and commercialization. For such partnerships to become successful, governments must take the lead and create the infrastructure (e.g., establish safety codes, share risk of initial investment, and provide market entry support) to make future commercialization possible. Despite years of government and industry collaboration on fuel cell technology development, Taiwan is somewhat behind other countries in coordinating strategic planning for fuel cell infrastructure and commercialization. This paper is meant to spark new discussion on how the government and industry sectors in Taiwan—as well as potential overseas partners and investors—could come together to stimulate the development of markets in Taiwan for fuel cell technology.

Global dependence on fossil fuels has produced increasingly alarming energy and pollution trends worldwide—grim forecasts of diminishing fossil fuel reserves and growing global air pollution problems due in great part to the combustion of fossil fuels. The need to speed up development of new technologies to make renewable and clean energy feasible alternatives is apparent and urgent in every nation.

Fuel cells, with high energy efficiency and clean emissions, represent a promising type of clean energy, particularly in countries—such as Taiwan—that possess insufficient coal or oil reserves. Taiwan—a country with over 23 million people squeezed in about 10,000 square kilometers of inhabitable land—imports all of its energy and is therefore particularly vulnerable in any future energy crisis. In addition, Taiwan faces the challenge of meeting CO_2 emission reduction targets. CO_2 emissions in Taiwan increased approximately 6 percent annually between 1993 and 2003. In 2003 Taiwan's annual CO_2 emissions exceeded 10 tons/person. In light of these energy and pollution challenges, over the past ten years the Taiwanese government has increased its effort to promote fuel cell R&D, which has led to the emergence of some promising private companies.

Although Taiwan is a small country, government and private sector investment into fuel cell research has produced some new, potentially marketable technologies, such as electric bicycles and scooters. Evidence of this progress in technology development was apparent at the "2004 Fuel Cell Seminar" held in San Antonio, Texas where most of the 160 exhibitors were from North America. The Asian presence at the conference included only Japan and Taiwan—the latter having two booths. Thus, Taiwan is—and will continue to be—an important regional player in this field possessing the potential to tap markets in mainland China. This paper presents a review of fuel cell development and opportunities for its commercialization in Taiwan, as well as a brief examination of opportunities for creating niche markets in China. This analysis is meant to highlight the potential of new policies in Taiwan and international collaboration on fuel cell commercialization.

DEVELOPMENT OF ENERGY SAVING AND CLEAN ENERGY TECHNOLOGY IN TAIWAN

Pressing energy needs and growing pollution problems prompted the Taiwanese government to develop a broad range of clean energy policies and support various clean energy technologies, particularly renewable energy. Before embarking on a description of Taiwan's policies and research for clean energy and energy efficiency, wepresent an overview of energy challenges in Taiwan. This brief summary of overall energy consumption, related organization and technology development in Taiwan serves as useful background information for understanding the policy and research groundwork that supports fuel cell development.

Taiwan's Energy Mix

As of 2003, there were approximately six million automobiles and ten million motorcycles in Taiwan. The annual electricity consumption on this island nation is about 160,000 GWh—with approximately 4% from hydropower, 75% from thermal, and 21% from nuclear. Although there are few wind-power electric generators, cogeneration is on the rise. Despite the diversity in energy types, the bulk of Taiwan's energy is still from fossil fuel, with petroleum consumption over the past twenty years increasing about 4.4% annually. (See Table 1 for petroleum consumption trends).

Table 1. Petroleum Consumption Trends in Taiwan (Million liter of crude oil equivalent—MLOE)

Item	1983		1993		2003		1983-2003
	MLOE	%	MLOE	%	MLOE	%	Growth Rate %
Total Consumption	18,909	100	32,036	100	45,085	100	4.4
Industrial	7,752	41	10,375	32	18,983	42	4.6
Transportation	4,036	21	10,764	34	14,981	33	6.8
Power Generation	3,748	20	6,394	20	4,791	11	1.2
Residential	936	5	1,357	4	1,428	3	2.1
Agricultural	875	5	952	3	1,051	2	0.9
Commercial	76	1	150	1	490	1	9.38
Others	1,034	5	790	2	1,590	4	2.2
Non-energy Uses	452	2	1,254	4	1,771	4	7.1

Source: Bureau of Energy, Ministry of Economic Affairs (MOEA)

The petroleum consumption trends in Table 1 highlight that industrial and transportation uses constitute about 75% of the total consumption in Taiwan. The rapid increase of total consumption with a yearly average growth rate at 4.4% has sparked the government to take various measures to promote energy conservation and the development of renewable energy.

A brief examination of renewable energy is highly relevant to a discussion of fuel cell technology potential in Taiwan, for hydrogen is a promising storage option for renewable energy. Policies encouraging energy conservation measures and renewable energy technologies are not only critical to reducing Taiwan's petroleum use, but also have implications for establishing a fuel cell industry.

Successful Energy Conservation Initiatives and Policies

In the area of energy conservation, some major policy achievements in Taiwan (as reported by the Bureau of Energy) include:

- Implementation of an energy auditing system, resulting in savings of 660 GWh of electricity, 61,000 kiloliters of oil, and 161,000 tons of coal in 2003.
- Execution of energy-consumption management standards for electrical appliances in 2003, resulting in an average annual peak load power saving of 130 MW.
- Implementation of fuel economy standards for new vehicles and fishing boat engines in 2003, resulting in an annual fuel oil saving of 130,000 kiloliters.
- Promotion of energy conservation technical services, leading to an annual saving of 130 GWh of electricity and 9,000 kiloliters of fuel oil, and average peak load power saving of 27 GWh in 2003.
- Promotion of measures to shift on-peak energy usage to off-peak hours; by end of 2003 these measures had clipped 4,422 MW off peak load.
- Promotion of a cogeneration system, which by the end of 2003 had an installed capacity of 6,480 MW.
- Implementation of energy conservation in the government sector, which led to an average annual growth rate of electricity usage for the government of 2.8% from 2001 to 2003; this was lower than the 4.4% growth of overall national electricity usage.

The Taiwanese government's Statute for Upgrading Industries provides corporations with incentives to procure energy-conservation equipment in the form of a two-year accelerated-depreciation plan, 13% tax credits, and low-interest loans. The following results were achieved:

- Implementation of accelerated depreciation from 1991 to 2004 amounted to NT$12.1 billion of approved depreciation to corporations for investing in energy-conservation equipment.
- Issuance of low-interest loans from 1994 to 2004, amounting to NT$11.2 billion, accelerated corporate investment in energy-conservation equipment.
- Creation of tax credits from 1995 to 2004, amounting to NT$1,950 million enabled corporations to invest in energy-conservation equipment.

Successful Renewable Energy Initiatives and Policies

In order to integrate and coordinate the tasks of promoting renewable energy, Taiwan's executive branch—the Executive Yuan—adopted the "Renewable Energy Development Plan" on 17 January 2002. The Council for Economic Planning and Development is in charge of coordinating the efforts of related government sectors in promoting renewable energy. Furthermore, a "Renewable Energy Development Bill" will be discussed by the Executive Yuan to establish a legal environment for renewable energy and to facilitate the sustainable utilization of renewable energy. In the area of renewable energy, the government's policies and subsidies led to the following major results:

- For solar water heaters, the installed area of heat collectors in Taiwan has reached 1.23 million cubic meters (m^3). The accumulated area reached approximately 1.27 million m^3 by the end of 2004.
- For photovoltaic demonstration systems, the total capacity that has been approved for subsidization is now 870 kW. The target was to install demonstration systems with a total capacity of 1 MW by the end of 2004.
- For wind-power systems, the total capacity the government approved for specific equipment and electricity rate subsidies is 30.64 MW, and the capacity for approved wind-power projects by the end of 2004 was about 76 MW.
- For geothermal energy, the Energy Bureau is working with local governments to construct demonstration generation systems with multi-purpose utilization. The target is to assist in promoting at least 5 MW of geothermal power generation in five years.
- For small hydropower, the accumulated capacity is now around 166 MW. Estimates are that another 200 MW will be economically feasible in the near future.
- For biogas power generation, the accumulated capacity is now around 20 MW. Estimates are that another 30 MW would be economically feasible in the future.

Over the past two years, the United States has been promoting worldwide activities to develop a hydrogen economy through the International Partnership for the Hydrogen Economy. Hydrogen energy has thus begun to attract many countries as a future energy source. Taiwan, while not a member, has begun to pursue research in renewable energy technologies encouraged by the IPHE. For example, Da-Yeh University in Taiwan has built up a demonstration system using wind energy to produce hydrogen. Moreover, the Taiwan Power Company is now constructing another system to demonstrate an integrated photovoltaic and wind-power system to electrolyze water for hydrogen.

The preceding discussion highlights how the Taiwanese government has been successful in promoting clean energy and conservation, which form part of the foundation necessary for fuel cell development. The rest of this paper first traces the success in the development of electric vehicles—a potential application for fuel cells—and then examines the current status of the electrochemical energy industry in Taiwan, which like renewable energy is a foundational sector needed to develop fuel cell technology. Next follows a presentation of policies and government-supported fuel cell research initiatives, as well as research conducted by universities and private sector companies in Taiwan. In order to place Taiwan in the context of international fuel cell development, the paper then presents a short overview of international fuel cell developments, with a separate section on mainland China. The paper concludes with some recommendations on how the Taiwanese government and research sectors—both independently and with international partners—could push forward fuel cell commercialization in

Taiwan.

PROGRESS IN DEVELOPING ELECTRIC VEHICLES IN TAIWAN

Since one of the potential major applications for fuel cells is in the transportation sector—mainly as substitute for conventional internal combustion vehicles (ICVs) and scooters—it is worth mentioning the current status of electric vehicles (EVs) in Taiwan. If fuel cell vehicles (FCVs) should become a commercial reality in the future, most likely they would still be in a hybrid form coupled with battery or super-capacitor to provide specific performance needs. These hybrid vehicles all use electric propulsion to replace combustion energy and share many common motor, control and body technologies.

When the energy crisis hit Taiwan in the early 1970s, Taiwan launched its first EV program with National Tsing-Hua University collaborating with Yuasa Battery Company of Taiwan and Tanyon Iron works, aiming to develop a lead-acid battery based EV, mainly for use in the postal service. Approximately 200 vehicles were produced and the program continued for about 10 years until the energy crisis subsided.

The second phase for development of these cleaner energy vehicles started about ten years ago in response to a renewed interest worldwide in EV development, motivated mainly by air pollution concerns instead of oil substitution. Since Taiwan is a scooter kingdom and very likely has the highest density of scooter distribution in the world, the central government felt it would be more realistic if the country's research institutions focused on electric scooters in light of the Taiwan's robust scooter industry. In response to the central government's new priorities for promoting EV, in 1997 the Taiwanese Environmental Protection Agency (EPA) announced a subsidy program to encourage the purchase of electric scooters. This subsidy program led to more than five new start-up EV scooter companies, and sparked several existing scooter factories to start developing various EV models. Unfortunately, inconsistent quality and inadequate maintenance of these EV scooters began to dampen the enthusiasm of many customers.

The annual domestic purchase of EV scooters reached a peak over 10,000 in 2000 and quickly dropped to less than 3,000 in 2002 (see Table 2). The EPA canceled the subsidy program in 2003 claiming the number of electric scooters could not reduce air pollution in any significant way, although the EPA has maintained a subsidy program for electric bicycles at NT$3000/unit sold. However the local EV scooter industry manifested its resilience by changing into an export market for scooters and other related electric vehicles. In fact, Taiwan has become the world's leading producer of electric assisted vehicles for the handicapped as shown in Table 3, with Taiwan producing more than 50% of the electric wheelchairs in the world.

Table 2. Number of Electric Bike and Scooter Production in Taiwan

Year	e-bike export	e-scooter export	e-bike domestic	e-scooter domestic	Total production
1998	6,209	214	300	1,508	8,231
1999	18,110	1,038	300	5,132	24,580
2000	37,018	8,407	500	13,257	59,182
2001	19,462	43,359	4,733	3,806	71,360
2002*	42,819	6,762	4,373	2,266	56,220
2003	11,811	86,514	3,173	0	101,498

* The fluctuating figures of e-bike and e-scooter exports are due producers using these two terms interchangeably when reporting their products for export. This chart illustrates, however that the total exports of these two products are steadily increasing.

Source: Industrial Technology Research Institute

Improved lead-acid batteries power all of these electric vehicles. However, lithium batteries, nickel metal hydride batteries, and fuel cells are all being tested for future models. Electric bikes (pedelec) are another increasingly marketable item, for their popularity is growing in mainland China and the market has increased by around 1 million units annually for the past two years. Since Taiwan has a few world famous bicycle producers, such as Giant Company, it is natural for them to go into this market and develop their own brands of pedelec products. All these achievements in the bicycle sector highlight that Taiwan has a solid foundation to develop light-duty electric vehicles (LEVs) based on either battery or fuel cell.

Table 3. Taiwan Exports of Electric Wheelchairs

Year	x1000 NT Dollars	Quantity
1998	846,931	26,622
1999	1,221,948	52,184
2000	2,073,666	78,666
2001	3,512,895	132,541
2002	4,925,423	199,758
2003	7,259,274	302,274

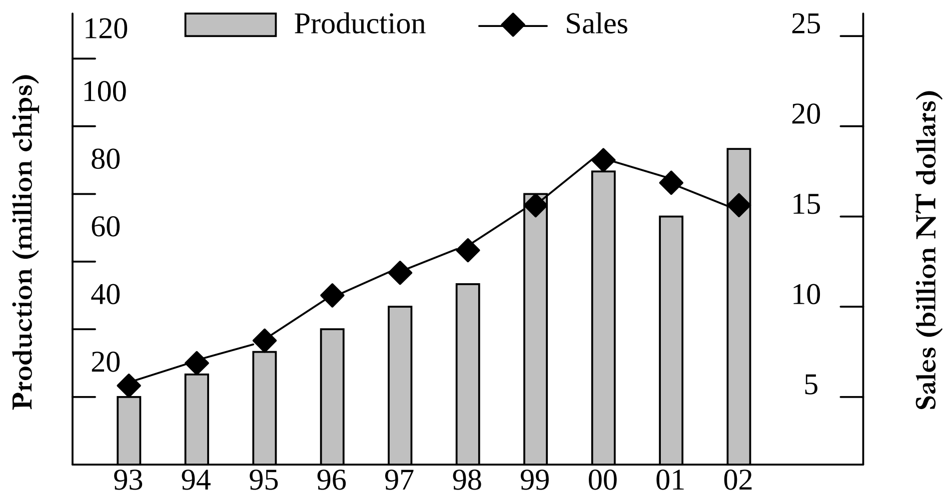
Note: 1 US dollar is equal to NT$32.5 *Source: Industrial Technology Research Institute*

CURRENT STATUS OF ELECTROCHEMICAL ENERGY INDUSTRY IN TAIWAN

Fuel cells are in principle an instrument for transforming chemical energy into electric energy, so their development is heavily dependent on the capacity of a country's electrochemical energy industry, which produces primary cells, rechargeable batteries, and super-capacitors. The strength of Taiwan's existing electrochemical energy industry is a useful measure of the potential for it to develop a fuel cell industry in the future.

Taiwan has moved its primary cell production to mainland China, and the only traditional battery industry remaining is the lead-acid battery. A few of these lead-acid battery firms have partial Japanese ownership or are in technical cooperation with Japanese firms, such as Taiwan Yuasa Company, but most of them are independent local manufacturers. These battery manufacturers supply local needs for automobiles, scooters and other industrial applications, with total annual sales in recent years amounting to almost 20 billion NT dollars, as shown in Figure 1.

Figure 1. Production Quantity and Sales Volume of Taiwan Lead Acid Batteries



Source: Bureau of Energy, Ministry of Economic Affairs

Over the past ten years, Taiwanese research institutes and industries have become quite interested in developing and producing more advanced batteries such as nickel metal hydride (Ni-MH) and lithium (Li) ion batteries. While Taiwan's original Ni-MH producers like NINEX and Delta Green Energy have moved almost all of their production facilities to China, lithium ion battery production—including lithium polymer batteries—is still quite active in Taiwan, with approximately ten active producers and other newcomers in the planning stage. The most established lithium ion battery producers include E-One Moil Energy and Synergy, which have enjoyed full capacity production since 2003, although they struggled before 2002. Their increased business is part of a global trend in that the world production of lithium-type batteries including lithium ion and lithium polymer has increased from 0.86 billion chips in 2002 to 1.25 billion in 2003. Since Taiwan manufacturers produce more than 60% of laptop computers in the world, the local demand for lithium batteries is naturally huge and reached 0.27 billion pieces in 2003.

Since most of the Li-ion batteries are for electronic devices including cell phones and notebook computers their capacities are in the watt-hour range—not large enough for application in the transportation sector. However, a couple of Taiwanese producers like Ultra Life and Pacific-Energytech have started working on larger batteries for transportation application. They have gradually acquired experience in designing KWh-range power sources.

Rechargeable batteries are also useful for practical operation of fuel cells. Fuel cell systems equipped with reformers need seconds or minutes to reach full power. Fuel cell systems designed for applications that require fast start-up—such as back up or emergency power—contain rechargeable batteries. This is usually also true for fuel cells applied to transportation, even without reformers. Batteries or super-capacitors are commonly installed in the system to mitigate the insufficient power density problem encountered by the existing fuel cells.

Cost is the primary hurdle for fuel cells commercialization. The U.S. Department of Energy and other energy agencies around the world are pursuing new technologies that can lower the cost of fuel cell products. Although Taiwan is a small country, since it has a long history and solid foundation for manufacturing batteries, auxiliary control components, and light-duty electric vehicles. This combination of manufacturing skills makes Taiwan an ideal place for producing fuel cell components and products at a relatively low cost.

FUEL CELL DEVELOPMENT AND POTENTIAL APPLICATIONS IN TAIWAN

Major Policymaking Landmarks and Early Development

In Taiwan's Sixth National Science and Technology Conference in 2000, a recommendation was made to urge the government to set up guidelines and a roadmap for fuel cell development in Taiwan. The major goal was to promote effective cooperation among local industries to develop practical systems and peripheral components so Taiwan could acquire a competitive and suitable position in the worldwide fuel cell industry.

In 2001, at the conclusion of the annual meeting of Science and Technology Advisory Group (STAG) of the Executive Yuan, the group made the following recommendations:

(1) A fuel cell promotion group should be established within STAG to promote R&D related to command, control, and communications (3C) products, electric scooters, and distributive power generators. The EPA should encourage fuel cell partnership alliances in the private sector.

(2) In its research funding the National Science Council (NSC) should emphasize innovative research on related devices and material preparation for fuel cells, as well as manpower training; the Ministry of Economic Affairs (MOEA) should be responsible for technology and industry development and establishing codes and standards for fuel cells; and the EPA should be

responsible for fuel cell demonstration projects and promotion.

(3) All agencies should allocate sufficient funding for fuel cell development.

This recent government roadmap for fuel cells actually builds on the fuel cell development that started in Taiwan in the mid-1980 with major funding from MOEA and Taiwan Power Company, which is a national company supplying most of the electricity in Taiwan. Despite this early start, in 2000, the only institute that had been continuously working on fuel cells was the Energy and Resources Laboratories (ERL) of the Industrial Technology Research Institute (ITRI), which is the largest research institute for applied research in Taiwan and is chiefly supported by MOEA. ERL has conducted research on phosphoric-acid-type fuel cells (PAFC) and established a demonstration station in Taipei County. Besides ERL, since the 1980s there has been some scattered academic research carried out in the universities. The government's renewed interest in supporting fuel cell research has led to increased government and private sector attention to fuel cell development over the past three years.

Government Agencies Engaged in Research and Support for Fuel Cells

The Executive Yuan in Taiwan supervises more than 20 ministerial level departments—five of which are active in fuel cell development (see Table 4 for a summary of the governmental funding for fuel cell research in 2003):

(1) *Environment Protection Agency* (EPA) sets up emission limits for manufacturing industries and automobiles, as well as promotes low-emission vehicles by partially subsidizing the purchase of electric vehicles.

(2) *Ministry of Economic Affairs* (MOEA), within which is the Bureau of Energy (BE) that is chiefly responsible for promoting clean energy R&D and applications. Another related branch of MOEA is the Industrial Development Bureau (IDB) that overseas industrial development in all fields. IDB also recently increased its effort to help nurture local fuel cell industries. Still another branch of MOEA is the Department of Industrial Technology (DIT), which helps private industries as well as national laboratories engage in long-term R&D. At this stage, it funds research on proton exchange membrane fuel cell (PEMFC) and direct methanol fuel cell (DMFC).

(3) On the long-term research side, there is the *National Science Council* (NSC) that sponsors research and in 2003 established a special program for fuel cell research. As of 2004 this program had sparked more than 60 fuel cell projects within Taiwanese universities. The funding for fuel cell research increased from NT$11 million in 2000 to over 62 million in 2003. NCS's research support is gradually building up a sizable technical workforce in this field.

(4) Another agency that has recently entered this field is the *Atomic Energy Council* (AEC), which has always been responsible for supervising the operation of Taiwan's three existing nuclear power plants and another one under construction. Since the current central government advocates

gradual phase-out of the nuclear power plants, AEC has shifted its attention to developing renewable energy technologies, mainly fuel cells. They currently focus on solid-oxide fuel cell (SOFC) and DMFC.

(5) The Chung-Shan Research Institute that belongs to the *Ministry of Defense* (MOD) has recently started its fuel cell program with a yearly budget around NT15 million dollars with a main focus on reformer technology.

Table 4. Governmental Funding for Fuel Cell Research in 2003

Departments	Funding in NT dollars (in millions)
National Science Council	30
Environmental Protection Agency	1
Bureau of Energy	105
Industrial Development Bureau	10
Department of Industry Technology	74
Atomic Energy Council	30
Ministry of Defense	15

Source: Taiwan Fuel Cell Partnership

The total annual government research funding for fuel cells in Taiwan is around NT$ 250 million, with PEMFC research constituting about 62% of the budget and DMFC coming next at around 27%. This total figure for fuel cell funding roughly constitutes 10% of the total budget for energy research in Taiwan, which highlights how the central government has regarded fuel cells as one of the most important clean energy technologies for the country. Nevertheless, much more effort by the government is needed if any significant result can be realized.

Fuel Cell Activities in Academic and Research Institutes

Beginning in the 1990s, basic fuel cell research has been conducted in Taiwanese universities covering PEMFC, SOFC and DMFC. Moreover, a few institutes have chosen fuel cell research as their major research theme. For example, Yuan-Tze University has organized a university-wide research team working on both PEMFC and DMFC. Under the sponsorship of MOEA and NSC the university researchers have developed a composite proton exchange membrane and reported encouraging results.[1] Another institute, Min-Dau University also has focused on fuel cells and intends to transform the campus into a fuel-cell demonstration park.

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[1] This composite proton exchange membrane is capable of reaching 0.42 W/cm² at 0.6v under H2/O2, 75C, l atm conditions.

Other universities such as National Taiwan University, National Tsing-Hua University, and Chung Gung University have all received funding from the NSC to undertake fuel cell research. Across these universities the major research topics have included: simulation of fluid channel design, new catalyst formulation, and characterization.

R&D on a more systematic basis is mainly carried out by Taiwan's national laboratories, which have long-term full-time personnel and the larger funding necessary for development-type work. Three important national laboratory examples are highlighted below to illustrate the technology level of fuel cell R&D in Taiwan.

Materials Research Laboratories of ITRI

The Materials Research Lab (MRL) of the Industrial Technological Research Institute (ITRI) is one of the most eminent research centers for the development of portable energy devices in Taiwan. In the area of fuel cells, ITRI researchers chose the direct methanol fuel cell (DMFC) system, since it is considered to have the potential of becoming the next generation of portable power. There are about 70 technical researchers in the electrochemical power lab with more than 20 working on DMFC.

There are three major DMFC research subjects at MRL: (1) low methanol crossover membrane, (2) high performance membrane-electrode assembly (MEA), and (3) more effective DMFC system design. In terms of the first subject area, it is well known among fuel cell specialists that the methanol crossover leads to potential drop at cathode resulting in poor performance of the fuel cell. So MRL has developed a PVDF-based polymer, called MRL-436, in which the methanol permeability is almost one-fifth lower than the benchmark Nafion 117 membrane and the conductivity still remains the same.

In the second areas of research—MEA study—the main areas of research at MRL/ITRI are dispersion of catalyst ink, more effective structure design, and mass-production methods. Due to the sluggish reactions at both anode and cathode, the amount of catalyst loading in conventional electrodes is forced to reach a high level ranging from 4 mg/cm^2 to 8 mg/cm^2. This means the dispersion of catalyst ink is critical. MRL recently had a breakthrough that greatly enhanced the utilization of catalysts. The peak power output of the MEA the lab developed reaches more than 50 mW/cm^2 at 40º C when applying a methanol solution of 10 percent methanol by volume as fuel, and the catalyst utilization in the MEA reaches over 55%. In addition, methods for mass production have also been developed.

In the third key area of research, MRL/ITRI targets portable DMFC designed as the power source for laptop computers. This lab developed a hybrid DMFC and Li-ion battery system. Since increasing packing density is also important, a plane-style MEA stack design has also been developed at MRL/ITRL.

Energy and Resources Laboratories of ITRI

The major research and development of fuel cells in ITRI began in 1987 with the initiation of a feasibility study for establishing fuel cell power plants in Taiwan sponsored by the Taiwan Power Company. The study chose phosphoric acid fuel cells due to the degree of development of the technology, although the study also called for examination of other types of fuel cells. Consequently starting in 1988, the then Energy Commission (now the Bureau of Energy) of the Ministry of Economic Affairs granted a major fuel cell project to the Energy and Resources Laboratories (ERL) of ITRI aimed at developing both components and systems of fuel cells, as well as demonstrating fuel cell technology to the general public. The project was concluded with the operation of an on-site fuel cell power plant in collaboration with the Power Research Institute of the Taiwan Power Company. This plant has generated more than 1 million kWh of electricity with 16,333 hours of accumulated time of operation in three years.[2]

In 1997, ERL started to work on developing Proton Exchange Membrane (PEM) fuel cell systems of 3 to 5 kW capacity that cogenerate both electricity and heat for private homes. Natural gas was chosen as the fuel because of its popularity in residential areas of Taiwan. Hence, the system includes a natural gas reformer, a fuel cell stack, a DC/AC inverter, and a control subsystem. Together with a battery—as well as a hydrogen storage subsystem using metal hydride as the storing medium—the fuel cell system can be used as an uninterruptible power system. The project represents a collaboration between sister institutes in ITRI: (1) the reformers were developed in the Union Chemical Laboratories, (2) metal hydrides as hydrogen storage materials were developed in the Material Research Laboratories, and (3) the system integration was the responsibility of the Energy and Resources Laboratories. In conjunction with the development of fuel cells in ITRI, a test center was built in 2001 to test both fuel cell products developed from the project and those from other developers—including domestic and foreign vendors. At present, seven fuel cell test stations ranging in capacity from 300 watts to 12 kW are installed in the center. Standard operation procedures for each test station were established so that the performance of fuel cell products could be tested in compliance with international standards. Codes and standards governing the use of hydrogen and fuel cells can also be studied with the aids of the testing equipment in the center.

Institute of Nuclear Energy Research

First established in 1968, the Institute of Nuclear Energy Research (INER) is the sole R & D organization on atomic energy science and technologies in Taiwan. Beginning in 2002, INER has directed a portion of its resources towards new energy research. This research agenda is not only to comply with the energy diversification goal of the nation, but also to add new directions for the institute.

INER adopted a five-year program (2003-2007) that called for a speedy development into hydrogen-related technologies and solar cell applications based on compounds of Group III-V elements. A subsequent modified five-year program (2004-2008) emphasized specific areas for future research and

[2] This plant has now ceased operation since its technology became fairly standard without any new R & D value.

development.

In hydrogen production, INER has investigated several types of plasma reformers. Reformers with natural gas transformation rate up to 93% and CO content lower than 100ppm have been demonstrated in the INER laboratory. The process route from bio-fiber through ethanol to hydrogen production is under investigation. In hydrogen storage, multi-walled carbon nanotubes were synthesized by catalytic thermal decomposition of natural gas. Hydrogen storage capacity of 3.3wt% was obtained upon purification and activation of samples, a result with excellent promise.

In fuel cell research, INER is exploring two types of fuel cell systems. For the direct methanol fuel cell (DMFC) system, an air-breathing (passive) design has been assembled that can afford 75 minutes of "talk time" with 1.5 milliliters of methanol. Current goal aims as an alternative approach to assemble a 10-cell stack with 17 W output for command, control, and communications (3C) applications.

In solid oxide fuel cell (SOFC) research, INER covers a broad range of research areas including: system design and development, performance modeling and simulation, as well as component fabrication and stack assembly. A computer software program (e.g., INER-SOFC) capable of performing electrochemical and thermal performance analysis was used to analyze various operational conditions and designs. A power demonstration station based on SOFC is now in the planning stage.

Local Industry Activities

Since private industries are concerned about near-term commercialization, all companies involved in fuel cell development are working on PEMFC-type products, as DMFC and SOFC face more technological challenges. Nevertheless there are indications that a few Taiwanese firms are exploring the possibility of using DMFC for 3C applications.

So far, there are probably only two manufacturers past the prototype stage; that is they have a system or subsystem available for sale: Asia Pacific Fuel Cell Technologies, Ltd. uses hydride-alloy for pure H_2 storage and Tatung Group uses methanol as a hydrogen source. The former is promoting its system for electric power generation as well as for electric scooters, while the latter company concentrates on stationary power application. A new company named Antiq Technologies has developed a new DMFC prototype product. A more detailed description of these three firms is provided below to offer a closer look at the existing engineering capability in Taiwan.

One particularly noteworthy point is that besides these firms working on fuel cell technologies, Taiwan has a fledgling zinc air battery industry. There are at least two manufacturers—eVionyx and Century Zinctec Electric (described below)—working vigorously to get their zinc air battery products marketable. Zinc air can be regarded as a simplified derivative of fuel cells. At the cathode it uses air as fuel just like a conventional fuel cell. However, at the anode, it uses metallic zinc instead of hydrogen as a fuel, thereby eliminating the problems of hydrogen handling and reformer operation. Although it has its own technological problems, zinc air batteries can be considered fuel cells in a broad sense. The technology is well suited for countries like Taiwan with medium-level technology capability. This observation on air zinc batteries highlights that while Taiwan may never be a major player in fuel cell business it can find a niche in special-type fuel cell subsystems, particular applications or original equipment manufacturer (OEM) operations.

Since it is well recognized that the establishment of a fuel cell industry involves complex coordination among various government departments, research institutes and industries, the Taiwanese government encouraged the creation of an alliance of various parties from the public and private sectors, which was called the Taiwan Fuel Cell Partnership, which is also described below.

The largest local gasoline producer in Taiwan, China Petroleum, is interested in the hydrogen supply and distribution business since it has large number of gas stations available. This company also has experience handling natural gas. Another private firm, San-Fu, which is partially owned by Air Products, is also involved in the development of H2-storage canisters and related technologies. Other firms that supply material or components for fuel cells have also emerged, forming a stronger base for fuel cell industry in Taiwan—two such firms include: (1) Yonyu Applied Technology Material Company for carbon material and (2) Green Hydrotec for oxidation catalyst and hydrogen purification.

Taiwan Fuel Cell Partnership (TFCP)

Taiwan Fuel Cell Partnership (TFCP), formed in July 2001, carries out the mission of the Executive Yuan's Fuel Cell Research and Development Society to promote and develop the fuel cell industry in Taiwan. The EPA and Bureau of Energy both help fund the Partnership. The Partnership unites industry, government agencies, and academic and research centers to help promote and develop fuel cell technology and industry in Taiwan.

TFCP has appointed a steering committee—made up mainly of representatives of government departments—to supervise its general operation. The organization consists of the Secretariat and Staff Unit, and mission-oriented Policy Working Units. The current working units and their objectives are the outlined in Table 5.

Under the support of relevant government departments and industries, TFCP has established a Taiwan Fuel Cell Information website (see list at end of paper), which sends relevant reports via email and organizes fuel cell discussions and conferences to promote industrial research and development exchange. TFCP also invites many experts and academics to discuss with governmental agencies issues related to the future policies and directions of the Taiwan fuel cell industry. TFCP recently started to focus on the educational activities in primary and secondary schools, in hopes of broadening the knowledge of fuel cells within the general public. Besides developing and promoting the fuel cell industry, TFCP hopes to engage in activities in the international market to help promote Taiwan's fuel cell industry.

Table 5. Current Policy Working Units within the Taiwan Fuel Cell Partnership

Units	Member Parties		Objectives
	Main	Secondary	
Fuel Unit	Chinese Petroleum corporation	BOC LienHwa Industrial Gases Company, Ltd.	Development of logistics and policies for supply of fuel cell energy.
Fuel Cell Unit	Institute of Nuclear Energy Research	Tatung Company	Research & development of fuel cells. Exhibition and promotion of fuel cell applications.
Generator Unit	Taiwan Power Company	Materials & Electro-Optics Research Division of Chung-Shan Institute of Science and Technology	Research & development of generators. Marketing and promotion.
3C Application Unit	Materials Research Laboratories of ITRI	H Bank Technology Inc.	Research & development of 3C applications. Marketing and promotion.
Motor Vehicles Unit	Materials Research Laboratories of ITRI	Asia Pacific Fuel Cell Technologies, Ltd.	Research & development of motor vehicle fuel cell products. Marketing and promotion. Development of policies and standards.
Regulations and Testing Unit	Energy and Resources Laboratories of ITRI	Automotive Research & Testing Center	Setting of regulations and standards for fuel cell products (e.g., fuel cell motors & 3C products). Testing of fuel cell products.
Industry Promotion Unit	Taiwan Institute of Economic Research		Analysis of fuel cell market (e.g., fuel cell motors & 3C products). Development of marketing for fuel cell industry.
Academic Unit	Mingdao University	Taiwan Institute of Economic Research	Research of fuel cell theory and techniques. Marketing of the research.
Policies Working Unit	Taiwan Institute of Economic Research		Gathering of opinions of all units to advise the government on fuel cell development strategies.

Tatung Group

The Heavy Power Division of Tatung Group (which in 2004 had a revenue over 7 billion USD) is the biggest, and also the oldest, manufacturer of heavy electric products in Taiwan, specializing in traditional diesel power generators with high voltage and large capacity. Motivated by environmental concerns and the need to expand business, in 2001 Tatung started R&D in backup power, especially fuel cells for stationary application.

Closely working with ITRI, the Tatung Fuel Cell team has developed a range of multi-fuel cell products including customer designed fuel cell stack 1~5 KW, 1 KW & 5 KW converter with inverter module, 1 KW backup system of fuel cell power generator, and 2KW methanol fuel processing system. Tatung will continuously work to develop more compact, efficient, durable, and low cost fuel cell products for niche markets in the near term.

In the 2004 Fuel Cell Seminar held in San Antonio, Texas, Tatung exhibited a newly developed 1 kW inverter and attracted some potential customers. This inverter provides good performance for applications in the fuel cell system at a quite reasonable price. At present, Tatung is working hard to expand the capacity of this inverter to 5 kW. Their products are usually much more compact in design than other similar products, which is another very attractive feature that should help them break into international markets.

Asia Pacific Fuel Cell Technologies, Ltd.

Asia Pacific Fuel Cell Technologies, Ltd. (APFCT) was incorporated in March 2000 in Taiwan by Dr. Jefferson Yang and his core team. Initially, Dr. Yang targeted the 3C or portable fuel cell applications. However, after completion of a feasibility study of fuel cell power for scooters, he was convinced of the potential for PEM fuel cell energy to revolutionize this light mass transportation vehicle and its potential to contribute to a cleaner environment in the Asia Pacific region. APFCT was then formed in Taiwan with the stated mission of promoting early commercialization of fuel cell technology and its application to small two-wheeled vehicles.

Since the company's founding, APFCT has dedicated its efforts to the acquisition and advancement of fuel cell technologies for scooters. In June 2001, the Taiwanese government awarded APFCT an R&D grant for "Preliminary Study in the Application of Fuel Cell Technologies to Scooters," which was successfully completed in January 2002. During this period, APFCT carried out fuel cell scooter development prototypes ZES II, ZES II.5 and ZES II.6. As a specific accomplishment of this study grant, ZES II.6 was the world's first publicly known fuel cell scooter tested and certified by a government established testing laboratory.

In August 2002, APFCT was granted a project in "Development of Proton Exchange Membrane Fuel Cell Stack Applications" by the Industrial Development Bureau (IDB) under its Leading Product Development Project program. This important grant exemplified the Taiwan government's interest and support of fuel cell technologies. This project was concluded in July 2004. APFCT successfully completed the design of the fuel cell system and demonstrated the world's first automated fuel cell volume production system. This automation production system is a milestone in the advancement of fuel cell technology and in its progress towards commercialization.

From 2002 through 2004, APFCT continued its advancement in developing a market-focused scooter with ZES III, ZES IV and ZES IV.5. These fuel cell scooters were exhibited at the annual international Fuel Cell Seminar and offered for a test drive. APFCT has plans to unveil ever-advanced fuel cell technology scooters at future shows.

In addition to fuel cell scooters, APFCT developed PEMFC systems that are being applied to lift trucks. In this area, APFCT is the exclusive provider of stacks and humidifiers to Cellex Power of Canada. The hybrid fuel cell power unit developed by Cellex was targeted for field trial at Wal-Mart warehouses in early 2005 and is moving well towards early commercialization. APFCT also has developed a hybrid system using its air-cooled fuel cell and humidifier unit and has successfully applied it to wheelchairs for Kurimoto Corporation of Japan. The fuel cell wheelchair can operate continuously for more than ten hours without refueling. APFCT and Kurimoto will jointly develop a new generation of integrated fuel cell wheelchair with target commercialization starting in 2006.

As early as 2005, APFCT was actively preparing a proposal to the Taiwan government for a project to perform a fleet demonstration of fuel cell powered scooters. The demonstration will involve scooters based on APFCT developed fuel cell power, on-board hydrogen fuel storage, and hydrogen infrastructure model. The goal will be to use the results from this project to validate, verify and refine fuel cell power technology for light mass transportation. This project could signify a major new milestone in the commercialization of fuel cell energy in Taiwan.

Antiq Technologies

Founded in 2003, Antiq is a new R&D company that is dedicated to the development of DMFC technology. Antiq is a design and engineering company that owns a patented technology for a component-like DMFC module which fits into a standard notebook computer optical drive bay and measures 190x128x30 mm and weighs 435 grams. The prototype uses a fuel cartridge filled with 10% methanol to produce a power output of 10 W. This device has a sandwich structure with printed circuit boards similar to those used by the electronics industry.

eVionyx Taiwan

eVionyx Taiwan, Inc. (EVT), co-founded in 1999 by Dr. Sadeg Faris of eVionyx, Inc. USA (EVI) and Dr. Cheng Ming Lee of Cheng Xin Technology Development Corporation in Taiwan, has adopted as its mission to commercialize the advanced metal fuel technology. EVT/EVI together hold more than 200 patent rights in metal fuel applications. EVT is pursuing a full spectrum of applications, such as transportation, power generation, power storage, military use, backup power system, portable electronic devices, and power tools. EVT is committed to key components production, product design, metal fuel modules manufacturing and metal fuel regeneration. EVT established its mass production site in Chung-Li, Taiwan in 2001. Now, the Chung-Li factory has facilities to: (1) manufacture all key components, such as air cathode, metal fuel and solid state membrane; (2) produce various types of zinc metal fuel modules as power sources for portable devices and transportation; and (3) simulate road-test in a Roller Bench Lab for e-bike, e-scooter and, electrical vehicles.

EVT has successfully developed a variety of portable power supplies, including long shelf life reserve power products; a portable AC power source; portable long-service lamp sets; multifunctional light sets; a high performance, one-time use zinc air battery for charging; and an environmentally benign reusable D size battery. EVT also is developing a moveable energy storage system together with Taiwan Power Research Institute (TPRI), designed to test the feasibility of applying metal fuel technology as energy storage for renewable power stations.[3]

In the transportation sector, EVT had passed a series of tests in drive range, grade-climb, acceleration rate and total weight; and was elected to participate the 2003 "Public On-Road Ride & Drive of Advanced High Efficiency E-Scooters" program, sponsored by the Industrial Development Bureau (IDB). In a three-month period, EVT had up to ten e-scooters all equipped with zinc-air fuel cells run on the road (with a range of 100 km and with 3 kW power). The data collected so far confirmed that EVT's e-scooter has strong potential for commercial application. EVT/EVI is developing a hybrid system of Ni-Zn battery and zinc air fuel cell for a total electric, zero emission vehicles.

Century Zincatec Energy Inc

Zinc air fuel cell batteries can be seen as an economical fuel cell battery. In Taiwan, Century Zinctec Energy Inc. (CZEI), with the support of Advance Nanopower Inc., has made a breakthrough to overcome the problem of insufficient power at fast discharge in such batteries. These achievements demonstrate the potential of zinc air fuel cells as the power source for vehicles. At present, the current density of discharge in these batteries can reach 370 milliamps/cm^2.

CZEI is launching field tests of buses and lightweight automobiles equipped with zinc-air fuel cell battery in cooperation with international car manufacturers. The CZEI zinc-air fuel cell battery operates under atmospheric pressure and needs no pressure balance design, which makes the construction of the battery system simpler and cheaper. With these features, the zinc-air battery can be used as main power source for the 150-180 kW electric buses. In 2005 the company plans a field test of the zinc-air fuel cell battery in mid-size electric buses.

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[3] If the test shows positive results and proves to have less energy capacity loss, the facilities will soon be scaled up to serve a full-size windmill farm.

SUMMARY OF TAIWAN'S FUEL CELL R & D

The above review of the general research and policy activities supporting fuel cells underscores two major conclusions on this area of research:

1. Although Taiwan is small in size, the fuel cell R&D program is quite balanced and covers basic research in the academic sphere, applied research in the national laboratories, and product development in the industry.
2. The manufactures are aggressive in pursuing commercialization of fuel cell technologies. Some firms like Tatung have fully exploited its inherent strength in power electronics and control devices and already developed niche markets for its inverter module. Others like Asia Pacific and eVionyx Taiwan obtained core technology from abroad and designed specialized products. Thus, while every company is still struggling in the developing stage, some progress has already been made in creating marketable products and these firms are gaining experience very quickly.

FUEL CELL DEVELOPMENT & COMMERCIALIZATION IN NORTH AMERICA, EUROPE, AND JAPAN

Hydrogen and fuel cell transition studies are under way in at least 22 countries, and in most cases the analysis is supported by government investment. In the United States, for example, Breakthrough Technologies, Inc. estimates that the budget for fuel cell research, demonstration, purchase and installation in 2005 exceeds $400 million overall when state and federal support programs are combined. This investment is matched more than two to one by private investment. Substantial investments are envisioned in Europe and Japan, with significant programs in Germany, Canada, Singapore, Korea, Australia, China, and a growing number of other countries. Some examples of these international programs are listed below[4] and in Table 6.

● The European Community's "Sixth Framework" research program in energy has a budget of €2 billion. This amount must support renewable energy research as well as hydrogen and fuel cells.
● The Canadian government has announced a five-year, $350 million fuel cell program.
● Japan's annual investment in fuel cells and hydrogen is estimated at ¥30 billion yen, and is coupled with commercialization benchmarks out to 2030.
● The German national government and many German states have fuel cell programs, estimated at €8 ti €10 million annually.
● Public sector fuel cell investment in Korea is estimated to reach $586 million between 2004 and 2011.
● Many countries are pursuing collaborative fuel cell activities through the International Energy Agency as well as the International Partnership for a Hydrogen Economy.

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[4] *Source: Hydrogen and Fuel Cells*, IEA, Paris, 2004, supplemented by our estimates

Table 6. Selected Vehicle Research and Demonstration Projects

COUNTRY	FUNDING
Canada	
Canadian Transportation Fuel Cell Alliance	CAN$23 million (Canadian Government) to demonstrate fueling options for fuel cell vehicles
Hydrogen Early Asopters ("h2EA") Program	CAN$215 million (Canadian Government) for new concepts, including hydrogen highways
Fuel Cells Canada Hydrogen Village Partnership	Demonstration of hydrogen infrastructure in Toronto
Vancouver Fuel Cell Project	CAN$5.8 million over 3 years
Hybrid Fuel Cell Transit Bus Project (with Hydrogenics Corporation)	CAN$8 million (Natural Resources Canada: CAN$2 million in Phase I, CAN$1 million Phase II. Hydrogenics and its partners are contributing the remainder)
China	Chinese government pledged $20 million a year for 5 years to FCV research; Chinese Academy of Science to invest $12 million over 3 years on hydrogen technology; Global Environment Facility will provide $12 million for fuel cell bus development, national and local governments will provide $20 million, with $4 million pledged from private companies
Europe	
European Union (EU)	€2.8 billion on hydrogen by 2015; €500 million by 2007; €1.2 billion in 2007-2012
CUTE (Clean Urban Transport for Europe)	EU is contributing €18.5 million to demonstrate fuel cell buses and fueling infrastructure in nine cities (3 buses in each city)
France	€40 million over five years for Clean Vehicles; €5.8 million allocated to fuel cells
Germany	~€55- €60 million in combined federal and state funding for power generation and vehicle development and demonstration
Italy	~€15 million annually, proposed to double to ~€30 million annually for the next three years
Iceland	
Ecological City Transport System (ECTOS)	Demonstration of three fuel cell buses; hydrogen infrastructure activities. ~€9.5 million, €2.8 million from EU, ~€6.7 million from the commercial partners (Shell, VistOrka hf, Norsk Hydro, and DaimlerChrysler)
Japan	
Japan Hydrogen & Fuel Cell Demonstration Project	Multi-company road demonstration. Japanese government contributed ¥2 billion in 2002 and ¥2.5 billion in 2003
Methanol Fuel Cell Vehicle Project	Ministry of International Trade and Industry will contribute up to ¥300 million (of the ¥1 billion project cost)
United States	
Freedom Car/Hydrogen Fuel Initiative	Will invest total of $1.7 billion to develop hydrogen fuel cells, hydrogen infrastructure, and advanced automotive technologies
National Fuel Cell Bus Technology Initiative (NFCBTI)	Proposing to allocate $150 million in U.S. federal transportation funding for fuel cell bus development and deployment
California Fuel Cell Bus program	Program budget is $18,450,000 for a total of seven buses in three jurisdictions
World Bank/Global Environment Facility	Bus demonstrations in Brazil, China, Egypt, India, Mexico. GEF commitment as of December 2003: $24.2 million

Source: *Fuel Cell Vehicles 2003*. Breakthrough Technologies Institute, Inc., Washington DC, 2004

The Vehicle Market

Although various types of fuel cells and applications are being developed, the largest candidate market is fuel cell vehicles (FCVs). Table 7 outlines fuel cell types and the status of their application worldwide, which highlights the wide range of technologies and markets in which Taiwan might participate. Ballard demonstrated the potential of fuel cells in vehicles in the late 1980s. Many companies including GM, Toyota, Ford, and Daimler-Chrysler all quickly went into developing FCVs either independently or in collaboration with other companies. The initial goal was to use hydrocarbon liquid fuel to comply with the existing gasoline distribution system. However the technical difficulty of operating an on-board reformer has forced many to consider using pure hydrogen as fuel although it has its own problems. The phenomenal success of Toyota's Prius hybrid cars further enlightened many producers about the potential of a hybrid model as an intermediate product. Most of the fuel cells developed for these vehicles are in the 35kW and above range. So the niche market for Taiwan is either to supply components for these products or develop fuel cells below 20kW for small vehicles.

Table 7. Fuel Cell Types and Status of Applications Worldwide

Fuel Cell Type	*Electrolyte*	*Operating Temperature*	*Applications*	*Status*
Phosphoric Acid	Liquid phosphoric acid	~450C	Power generation, cogeneration	Commercial sales at premium prices ~280 units in the field
Molten Carbonate	Carbonate salt mixtures	~625C	Power generation, cogeneration. Potential for hybrid configurations with turbines	Initial sales at premium prices
Solid Oxide	Nonporous ceramic compounds	~800-1000 C	Power generation, cogeneration, potential for residential and vehicle applications. Potential for hybrid configurations with turbines	Demonstrations in residential applications and power generation/ cogeneration applications.
Alkaline	liquid potassium hydroxide	~50C	Power generation, specialty applications	Sales in specialty markets
Proton Exchange Membrane (solid polymer)		~65C	Backup power, small distributed power, residential, vehicles, battery replacements	Stacks are commercially available in education markets; initial sales in backup power and small portable power markets. Extensive demonstrations in vehicles of all kinds. Demonstrations in residential applications
Direct Methanol (solid polymer)		~65c	Backup power, small distributed power, residential, vehicles, battery replacements	Nearing initial sales in battery replacement markets

FUEL CELLS IN CHINA AND OPPORTUNITIES FOR TAIWAN

Although China has its own oil reserves, it has been unable to meet its ever-increasing petroleum demand and started importing oil in 1994. The government realized this strategic weakness and ten years ago initiated vigorous research and development into alternative energy sources. Fuel cell development especially for transportation applications has been one of the major programs.

The Chinese government began supporting electric vehicle R&D at universities in the early 1990s, mainly emphasizing battery technology and electric motors. Tsinghua University in Beijing has played a leading role in that it is in charge of coordinating the national research agenda. They soon learned that such a major enterprise involving complex infrastructure establishment and multiple-technology coordination needs early and intensive involvement from industries. Thus in the second stage of the national research work, automobile manufacturers and other related industries became more active and received funding from the government. Academic research in the clean vehicle area has expanded considerably due to the Tenth Five-Year Plan (2001-2005) in which China's Ministry of Science and Technology (MOST) approved a 880 million Yuan ($106 million) R&D program to develop advanced hydrogen technology, hybrid-electric, and fuel cell vehicles. Among more than 30 related institutes, the Dalian Physicochemical Institute is one of the foremost research laboratories for fuel cell research. They are aiming to develop a membrane that can compete with Nafion membrane, the industry standard for PEM systems.

Besides two major state-funded research programs that support basic research applicable to fuel cells and the ongoing academic research on fuel cell vehicles, since 2000 the government has launched several study projects to address hydrogen and fuel cell issues specifically:[5]

(1) *Fundamentals of Large-scale Production, Storage and Transportation of Hydrogen and the Related Fuel Cells (2000-2005).* Led by MOST this project ten research areas address problems related to hydrogen production, storage, application, and standards.

(2) Basic Research of Hydrogen Production in Scale Using Solar Energy (2003-2008). Led by MOST this project contains six subprojects that address principles and theories for constructing stable reaction systems for continuous hydrogen production. Other hydrogen and fuel cell technology projects that have benefited from the funding boost in the Tenth Five-Year Plan include:

1. *Post-Fossil Thematic Project on Hydrogen Technology*
2. *Post-Fossil Thematic Project on High-Temperature Fuel Cell Technolgoy (2001-2005)*
3. *Target-Oriented Key Project on Electric Automobile (2001-2005)*
4. *Strategic Study on China's Sustainable Energy Development (2003-2004)* carried out by China's Academy of Sciences that includes two important subprojects on fuel cells

One major boost to fuel cell research came from the fact that China will be the host of the 2008 Olympic Games. Beijing's air quality is far from being acceptable, therefore the central government and municipal

[5] Much of the information in this section is drawn from *IPHE Country Paper—China.* (2004): http://www.iphe.net/china.htm

authorities are taking every measure to improve it. One of the many ambitious plans is to have 20,000 zero-emission busses on Beijing's streets by 2008. This kind of national effort would certainly make China one of the major green energy giants within ten years. One promising project preparing the city for the Olympics is a collaboration among MOST, Global Environment Facility, and the United Nations Development Programme in a $32 million project to catalyze the cost-reduction of fuel-cell buses for public transit applications in Chinese cities and stimulate technology transfer activities by supporting major demonstration projects of these busses and hydrogen fueling infrastructure in Beijing and Shanghai. The project aims to use the 2008 Olympics to showcase these fuel cell busses to the Chinese public and the world.

In its report to IPHE[6] China indicated a goal to direct the country towards a hydrogen economy by the mid-21st century. To achieve this long-term goal, in the report the Chinese government listed a series of necessary technological benchmarks it hopes to achieve:

● 2008 establish technical platform for PEM fuel cell and relevant vehicle power system, improving core technologies through commercial demonstration;
● 2015 market entry of hydrogen-fueled dynamic system for PEM-fuel cell vehicles;
● 2020 introduce large-scale industrial use of hydrogen in more than 10 key cities and carry out commercial demonstrations of hydrogen production and storage technology; and,
● 2040 set up national hydrogen infrastructure based on large-scale hydrogen production technology with multi-feedstock and zero carbon dioxide emissions, which will help support the commercialization of fuel cell vehicle systems.

While these targets may seem ambitious, China has in fact already had some remarkable results in fuel cells and built a solid foundation. The sales of electric-bikes have increased over one million every year for the past three years. The government also set up a national EV testing park at Shantou in southern China, which accepts nearly developed vehicles for short- or long-term testing. Car manufacturers like Toyota and GM have sent new EV models to this park in Shantou.

The willingness of people to test new devices is also important for the development of fuel cells. The Chinese government and citizens are coming to acknowledge that the extreme air and water pollution pose serious threats to economic growth in the country. Governmental support of alternate energy sources has been increasing as the country experiences more energy shortages—for example in the summer of 2004 many coastal cities experienced frequent brown outs, forcing many factories to decrease their production. In addition to significant infrastructure investment into natural gas development, the government also has been supporting pilot wind farm projects and solar heating. Solar heating panels are becoming more common in both rural and urban areas. Almost all new apartments are equipped with

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[6] *IPHE Country Paper—China.* (2004): p. 8: http://www.iphe.net/china.htm

sensors to control lighting automatically.

Should fuel cell products of some form find a market in China, Taiwan is in a very good position to supply key components especially in electric control since China is still relatively weak in electronics manufacturing and many modern plants are owned or partially owned by Taiwan companies. The combined fuel cell market of China and Taiwan and the strength of Taiwan electronic manufacturers could very likely lead to one of the first fuel cell commercialization cases.

RECOMMENDATIONS

Dr. Michael Binder noted in his opening address for the 2004 Fuel Cell Seminar: "Right now, the fuel cell community is in desperate need of a commercial success." Taiwan could potentially play a useful role in answering his call for near-term commercialization of fuel cell technology. Taiwan with its inherent energy handicap has always been, and will continue to be, active in developing any transportation substitute for ICE vehicles and any clean power generation technology. In addition, Taiwan is renowned for its manufacturing capability and is especially suitable for international collaboration to transform new technology into low-volume products at a reasonable price in the development stage. As outlined in the descriptions above, Taiwanese industries also have shown some encouraging results in converter/inverter component production and kw-range PEMFC module. However, much more effort still is called for from the government, industry, and research sectors. This paper concludes with a discussion of the four core problems in fuel cell development in Taiwan, along with recommendations on how to remedy these shortcomings.

Problem 1: Insufficient testing, validation and promotion facilities.

Fuel cells represent an emerging industry. Numerous codes, regulations and standards need to be set up to help this industrial sector thrive. The general public also needs to be educated in the form of direct use experience in addition to information obtained from published material or other news media channels. Since most of the companies in Taiwan are in the medium to small range, they cannot handle all these necessary procedures by themselves. We have witnessed many failure cases of immature green-energy products developed by local manufacturers, which not only is a loss of investment but also erodes the confidence and enthusiasm of the general public.

Recommendation 1:

The government can choose an industrial park and designate it a "Green Energy Science Park." This park could greatly enhance Taiwan's image in environmental improvement and clean energy development. It could also serve both as a new product validation zone and an education/promotion area. Besides fuel cell based generators and vehicles, the park could also accommodate other energy-related technologies like solar-cell devices, EV, and any hybrid products. Special working groups could then be established to design related code and standards based on international information and local needs and experience.

The central government could also provide incentives for local governments to establish regional demonstration projects. For instance, an FCV program coupled with the Kaohsiung subway system that is currently under construction could greatly reduce the notorious air pollution in southern Taiwan.

Problem 2: Insufficient coordination among government agencies, private industries, national laboratories and academia.

Professors in Taiwan receive funding for fuel cell research mainly from the NSC to carry out research in areas such as synthesizing new catalyst and polymeric material, and flow channel simulation. These projects are of individual academic interest, loosely coordinated by the NSC. The interactions between universities, national laboratories, and industries are sporadic and lack a consistent mechanism. The funding for the national laboratories is chiefly from MOEA and little governmental support is specifically addressed to development of energy-related technologies for industries. So the government's current funding priority is first to support the universities, than the laboratories, and last—receiving little support—are industries. This neglect of support of industry certainly constitutes one of the major obstacles to realizing any near-term fuel cell commercialization in Taiwan. Even companies in the United States or Japan that are much larger than their Taiwan counterparts still need support from their governments. If the priority of fuel cell funding could be reversed in Taiwan, the industries would not only receive badly needed funding from the government but also subcontract to national laboratories and universities, so the interactions and research networks would be more coordinated and enhanced, and yield relevant results.

Recommendation 2:

The R&D activities of all institutions should be more closely organized and a large portion of funding should be allocated to mission-oriented topics recommended by the industries so that local manufacturers can get direct technology support from the university and research centers. This can be effectively implemented either by establishing a national project or simply by strengthening the existing coordination channels between NSC, MOEA, and EPA.

The Bureau of Energy (BE) could allocate special funds for R&D for Taiwanese industry in the same way as the U.S. Department of Energy annually sponsors numerous projects within American companies. There is no apparent legal barrier for BE to do so since other divisions of MOEA already have had similar programs. However, MOEA's existing programs are not for energy technology, so a special program for energy R&D for the local industry seems to be timely. Development for special applications for niche markets should be especially encouraged by government support in order to build up confidence and experience for future development of large-volume items.

Problem 3: Lack of goal for near-term commercialization based on Taiwan's ability and market.

It has been argued that since a total replacement of combustion-based industry by fuel cells may be the ultimate goal, any intermediate successful product is not the final solution and can only serve to lengthen the life of the existing industrial structure. That is why major American automobile producers have concentrated their effort on fuel cell vehicles. However the phenomenal success of Toyota Prius hybrid car significantly changed their strategy. Taiwan should devote a part of their resources to technology that can lead to near-term commercialization based on existing capability locally available. Especially in the case of Taiwan, duplicating the fuel cell R&D activities being carried out in the United States and Japan is actually a waste of precious resources available for fuel cell development in Taiwan.

Recommendation 3:

A broad range of technologies for clean energy and their possible combinations should be included and coordinated. The goal of fuel cells is to supply a substitutive and clean energy, so every other technology aiming towards that goal also should be welcomed. The fuel cell enthusiasts therefore need not look upon other clean energy technologies with hostility. The gradual acceptance by the general public to shift from conventional power generation and transportation methods to some substitutes needs cooperative efforts from all clean energy developers. Any success from any specific technology to penetrate into a particular market is good news for all, since these individual successful cases will lead to wider support for the clean energy community as a whole from the public and government. Commercial fuel cells would enhance the capability of most clean energy technologies. The existing R&D programs in Taiwan cover all major fuel cell types including PEMFC, DMFC, and SOFC. However, since the funding is limited, the competition is intense and leaves little room for other items of near-term potential. So a certain fraction of funding should be specifically allocated for R&D pertaining to near-term commercialization of any clean energy technologies.

Problem 4: Insufficient international collaboration.

If fuel cells become a commercial success in the future, Taiwan should realistically position itself as a regionally important participant rather than a global major player. The existing program assumes the local manufacturers can provide competitive components and skills at every level, which is unrealistic and risky. Taiwan's local automobile industry has a history over 30 years and is very competitive. The locally assembled cars have good performance and capture most of the domestic market. Yet most of the engines and some others components are imported. Fuel cell development should learn from the automobile industry and focus on selective areas. Increased cooperation with international firms can help identity Taiwan's weakness and strengthen the fuel cell industry.

Recommendation 4:

Taiwan can and should better utilize its strength in manufacturing capability and quick adaptation for international cooperation. The government can partially support any collaborative project between local firms and foreign counterparts. The assistance from the government can speed up cooperative activities especially in the beginning stage since most of the firms are relatively small and do not have worldwide reputation or international networks. The government can use its information network to promote cooperation.

This kind of cooperation is a win-win situation in the sense that foreign companies can fully utilize Taiwan's cost-down specialty to reduce development cost and to facilitate earlier commercialization while the local firms can learn through those collaborative works and improve their capabilities.

ACRONYMS

APFCT	Asia Pacific Fuel Cell Technologies, Ltd
BE	Bureau of Energy
CZEI	Century Zincatec Energy Inc.
DIT	Department of Industry Technology
DMFC	Direct Methanol Fuel Cell
EPA	Environmental Protection Agency
ERL	Energy and Resources Laboratories of ITRI
EV	Electric Vehicle
EVI	eVionyx Inc. USA
EVT	eVionyx Taiwan, Inc.
FCV	Fuel Cell Vehicle
ICV	Internal Combustion Vehicle
IDB	Industrial Development Bureau
ITRI	Industrial Technology Research Institute
MEA	Membrane Electrode Assembly
MOEA	Ministry of Economic Affairs
MRL	Materials Research Laboratories of ITRI
NSC	National Science Council
PAFC	Phosphoric Acid Fuel Cell
PEMFC	Proton Exchange Membrane Fuel Cell
SOFC	Solid Oxide Fuel Cell
TFCP	Taiwan Fuel Cell Partnership

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BIOGRAPHIES

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Bob Rose is founding executive director of the Breakthrough Technologies Institute (BTI), an independent nonprofit organization dedicated to promoting advanced environmental and energy technologies from the perspective of the public interest BTI's fuel cell education program, Fuel Cells 2000, was launched in 1993 and is internationally recognized. Rose also is founding executive director of the U.S. Fuel Cell Council, the business association for the fuel cell industry. Founded in 1998, the council has more than 120 members. Rose is the author of Fuel Cells and Hydrogen: The Path Forward*, which proposes a public-private partnership to develop and commercialize fuel cells and a supporting hydrogen infrastructure. He has many other writing and speaking credits and is a regular media source. He can be reached at: brose@fuelcells.org*

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