Review Article in subject of Fuel Cell, Technologies and Prospect

Mousa Meratizaman[1], Farshad Torabi[2]

[1]PhD student, Mechanical Eng. Faculty, K. N. Toosi University of Technology, meisam_463@yahoo.com

[2]Assistant Professor, Mechanical Eng. Faculty, K. N. Toosi University of Technology, *ftorabi@kntu.ac.ir*

Abstract

Ever increasing energy consumption, rising public awareness for environmental protection and higher prices of fossil fuels have motivated many to look for alternative/renewable energy sources. Fossil fuel resources are limited and are expected to end early in the next century. In this situation small-scale power generation systems such as wind turbines, solar cells, micro-turbines and fuel cells can play an important role in meeting consumer demands for "greener" energy. In this article firstly, different types of fuel cell technology is described, secondly the prospect of fuel cell in the word is discussed. Finally, the long term program of fuel cell in Iran will be considered.

Keywords

Fuel cell, Prospect, Different technologies of fuel cell, Newest of fuel cell in Iran

Introduction

A fuel cell is simply an electricity generation device that uses hydrogen as a feedstock, along with oxygen from the air, to produce electricity. The fuel cell releases only water and heat as byproducts and releases no gases, greenhouse or otherwise. Fuel cells possess many key advantages, including high efficiency, quiet operation, and clean operation with no greenhouse gas emissions. In addition, fuel cells can be used in a wide range of applications, including small electronic devices, vehicle transportation, building power and backup and utility-grade power generation. The main disadvantages are cost and how to supply the hydrogen fuel. The following is a summary of the advantages and disadvantages of fuel cells [1, 2].

Advantages:

- No pollution. Fuel cells use only hydrogen and oxygen as inputs and dispel only water and heat, which are all natural elements.
- Greater efficiency. Energy efficiency is defined as the percentage of energy that can be extracted from a given fuel source and turned into electricity. High temperature fuel cells have efficiencies ranging from 32 percent to 47 percent and Low temperature fuel cells have a much wider range of efficiencies, from 25 percent to 60 percent
- Backup and distributed power. A building owner can install a fuel cell at a building site (outside or inside), thus providing an electricity generation source that is independent of the grid. This protects the fuel cell owner from grid fluctuations and blackouts and also from the rising price of electricity.
- Cogeneration as an enhancement to efficiency. High temperature fuel cells generate a lot of heat as a byproduct. Cogeneration refers to capturing and using this heat. This greatly increases the energy efficiencies associated with high temperature fuel cells, which can achieve efficiency rates of nearly 85 percent.
- Silent technology. Fuel cells operate silently, which means they do not cause noise pollution and that they are suitable for use indoors and in residential areas outdoors.
- Remote operation. Fuel cells can run independently in remote locations off-grid with only hydrogen provided as a fuel, which provides a source of electricity where the grid may not be available.
- Electricity can be stored. Fuel cells allow for energy to be stored and reserved for later use. Excess electricity can be used to create hydrogen through electrolysis, and that hydrogen can then be stored and used later by the fuel cell when the electricity is needed again

Disadvantages:

- High cost. Fuel cell technology for some applications (though not all) is still in the developmental stage. Production costs at various stages need to be significantly reduced before large-scale manufacturing can occur. In addition, the construction of a fuel cell can use expensive materials, some of which, such as platinum, are actually getting more expensive.

- Hydrogen production, delivery and storage. Hydrogen is not easy or inexpensive to produce, store, or transport. Hydrogen gas in its pure form is flammable and requires special handling. Hydrogen gas is also very light and must be compressed for transportation and storage.

- Production of hydrogen can pollute. Hydrogen used in fuel cells can be produced through two processes: electrolysis (splitting of water into hydrogen and oxygen) or reformation of hydrocarbons such as natural gas. Electrolysis is pollution-free, but is still prohibitively expensive today. Reformation of hydrocarbons such as natural gas, which is the main technology used at present, pollutes the environment through the release of CO2, although the pollution is less than burning the hydrocarbons since hydrogen reformation is a more efficient process.

- Perceptions on reliability, durability and safety. Fuel cells are a new technology so their reliability and durability have not been statistically proven, though some claim 99.9999 percent reliability. Long-term reliability records are limited to the relatively few devices currently in operation, which are mostly in controlled environments and not exposed to real world problems. There are also questions regarding the safety of hydrogen as a fuel, since it can be extremely flammable when produced at high purity and concentration levels [3].

As mentioned earlier, a fuel cell converts hydrogen and oxygen into electricity, releasing only water and heat as byproducts. There are no moving parts in a fuel cell and nothing is burned. As can be seen in Figure 1, an anode is used to split hydrogen atoms into positively and negatively charged parts, which are then sent across to the cathode through different paths. The negatively charged electrons generate electricity, and when the hydrogen molecules are combined with oxygen at the cathode, water and heat are produced.

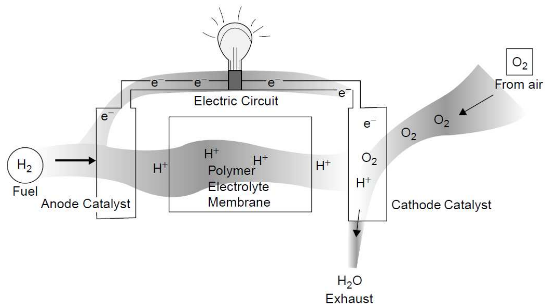

Fig 1. A sample model for Fuel Cell

Types of Fuel Cells:

The different types of fuel cells can be classified by two attributes:

1. The temperature at which the fuel cell operates

2. Whether the fuel cell is supplied directly with hydrogen or with an intermediate fuel supply that contains hydrogen

Table 1 classifies the various types of fuel cell technologies by the two characteristics explained in the previous section, that is, temperature and hydrogen reformer type. It should be mentioned that the "external reformer" fuel cells require the delivery of hydrogen, while "internal reformers" use intermediate products such as natural gas or methanol [4].

Table 1. Classification of Fuel Cell Types

	High Temperature	Low Temperature
Internal Production of Hydrogen	Molten Carbonate Fuel cell (MCFC)	Direct Methanol Fuel cell (DMFC)
	Solid Oxide Fuel cell (SOFC)	Direct Liquid Fuel cell (DLFC)
	Protonic Ceramic Fuel cell (PCFC)	Zinc-Air Fuel cell
		(ZAFC)
		Regenerative fuel cell (REFC)
External Reformer of Hydrogen	Phosphoric Acid Fuel cell (PAFC)	Proton Exchange Membrane Fuel cell (PEMFC)
		Alkaline Fuel cell (AFC)

PEM Fuel Cells:

PEM stands for proton exchange membrane or polymer electrolyte membrane. The PEM fuel cell is typically used for smaller scale uninterruptible power supplies (UPS) and for remote power for instruments or lighting. The UPS systems based on PEM fuel cells have higher reliability than other types of UPS systems, but the PEM based UPS systems are also a bit more expensive than competing battery technologies. Among various fuel cell applications, fuel cell vehicles are regarded as the potential largest market in the world. The majority of automakers such as GM, Toyota, Nissan, Ford, and Daimler-Chrysler devoted greatly into developing fuel cell passenger cars either independently or in collaboration with other companies. Most of these companies used PEM fuel cell in their products so the best choice for transportation sector is PEM fuel cell up to now. The commercialization of fuel-cell powered vehicles is still a long way away, after 2015 according to the Department of Energy (DOE). Furthermore, PEM cells require an external reformer of hydrogen, meaning that a suitable hydrogen delivery and refueling system needs to be present to provide fuel for the vehicles. Ballard Power Systems is involved in the development of PEM cells for transportation, while Plug Power [5].

DMFC and DLFC Fuel Cells:

Direct methanol and direct liquid fuel cells, as pictured in Figure 2, are small, low-temperature fuel cells that are on the verge of being commercialized for use in microelectronic devices and portable power supplies that can supply electricity for a camping trip, to recharge cell phones on-the-go, or to be carried by the military to power their increasing amount of electrical equipment. These fuel cells are ideal candidates for built-in, long-lasting “batteries” for small electronic devices such as cell phones, personal digital assistants (PDAs), or laptop computers. They can be disposable or rechargeable. They can be rechargeable with the replacement of the methanol or fueling liquid, although this presents somewhat of a challenge in terms of design and consumer usage. Toshiba, Medis Technologies and Mechanical Technology work with these types of fuel cells.

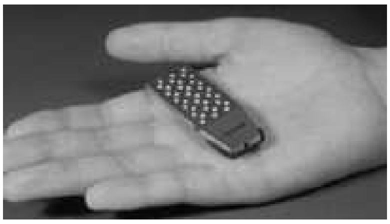

Fig 2. Direct Methanol Fuel Cell

MCFC Fuel Cells:

Molten carbonate fuel cells operate at temperatures ranging from 1,100 degrees Fahrenheit to 1,300 degrees Fahrenheit. They contain an internal reformer of hydrogen, thus they can work with almost any hydrogen-based fuel, including natural gas, propane, landfill gas (methane), and synthetic coal gasification products. Due to their high efficiency and large output capacity, they are used as backup power for the megawatt market, which comprises large hotels, hospitals, and wastewater treatment facilities. These fuel cells are the main candidates to supply the multi megawatt market, which includes backup power for central-station power grids. They are still expensive to produce, but research continues on trying to cut costs to more competitive levels. Fuel Cell Energy is the main company that works with molten carbonate fuel cells.

Protonic Ceramic fuel cell:

This new type of fuel cell is based on a ceramic electrolyte material that exhibits high protonic conductivity at elevated temperatures. PCFCs share the thermal and kinetic advantages of high temperature operation at 700 degrees Celsius with molten carbonate and solid oxide fuel cells, while exhibiting all of the intrinsic benefits of proton conduction in PEM and phosphoric acid fuel cells. The high operating temperature is necessary to achieve very high electrical fuel efficiency with hydrocarbon fuels. PCFCs can operate at high temperatures and electrochemically oxidize fossil fuels directly to the anode. This eliminates the intermediate step of producing hydrogen through the costly reforming process. Gaseous molecules of the hydrocarbon fuel are absorbed on the surface of the anode in the presence of water vapor, and hydrogen atoms are efficiently stripped off to be absorbed into the electrolyte, with carbon dioxide as the primary reaction product. Additionally, PCFCs have a solid electrolyte so the membrane cannot dry out as with PEM fuel cells, or liquid can't leak out as with PAFCs.

SOFC:

The SOFC’s are basically high temperature fuel cells. The SOFC produces electricity at a high operating temperature of about 1000 ^{0}C. The main advantages of the SOFC is that they are operated at high efficiency of 50–60% and a separate reformer is not required to extract hydrogen from the fuel due to its internal reforming capability. Waste heat can be recycled to make additional electricity by cogeneration operation. One type of SOFC uses an array of meter-long tubes, and other variations include a compressed disc that resembles the top of a soup can. Tubular SOFC designs are closer to commercialization and are being produced by several companies around the world. SOFCs are suitable for stationary applications as well as for auxiliary power units (APUs) used in vehicles to power electronics [6].

Phosphoric Acid fuel cell:

Phosphoric acid fuel cells are commercially available today. Hundreds of fuel cell systems have been installed in 19 nations - in hospitals, nursing homes, hotels, office buildings, schools, utility power plants, landfills and waste water treatment plants. PAFCs generate electricity at more than 40% efficiency and nearly 85% of the steam this fuel cell produces is used for cogeneration this compares to about 35% for the utility power grid in the United States. Phosphoric acid fuel cells use liquid phosphoric acid as the electrolyte and operate at about 450°F. One of the main advantages to this type of fuel cell, besides the nearly 85% cogeneration efficiency, is that it can use impure hydrogen as fuel. PAFCs can tolerate a CO concentration of about 1.5 percent, which broadens the choice of fuels they can use. If gasoline is used, the sulfur must be removed.

Zinc-Air Fuel cell:

In a typical zinc/air fuel cell, there is a gas diffusion electrode (GDE), a zinc anode separated by electrolyte, and some form of mechanical separators. The GDE is a permeable membrane that allows atmospheric oxygen to pass through. After the oxygen has converted into hydroxyl ions and water, the hydroxyl ions will travel through an electrolyte, and reaches the zinc anode. Here, it reacts with the zinc, and forms zinc oxide. This process creates an electrical potential; when a set of ZAFC cells are connected, the combined electrical potential of these cells can be used as a source of electric power. This electrochemical process is very similar to that of a PEM fuel cell, but the refueling is very different and shares characteristics with batteries. The chief advantage zinc-air technology has over other battery technologies is its high specific energy, which is a key factor that determines the running duration of a battery relative to its weight.

Alkaline fuel cell:

Long used by NASA on space missions, alkaline fuel cells can achieve power generating efficiencies of up to 70 percent. They were used on the Apollo spacecraft to provide both electricity and drinking water. Alkaline fuel cells use potassium hydroxide as the electrolyte and operate at 160°F. However, they are very susceptible to carbon contamination, so require pure hydrogen and oxygen.

Regenerative fuel cell:

Regenerative fuel cells are attractive as a closed-loop form of power generation. Water is separated into hydrogen and oxygen by a solar-powered electrolyzer. The hydrogen and oxygen are fed into the fuel cell which generates electricity, heat and water. The water is then recirculated back to the solar-powered electrolyzer and the process begins again. These types of fuel cells are currently being researched by NASA and others worldwide.

Microbial fuel cell:

Microbial fuel cells use the catalytic reaction of microorganisms such as bacteria to convert virtually any organic material into fuel. Some common compounds include glucose, acetate, and wastewater. Enclosed in oxygen-free anodes, the organic compounds are consumed (oxidized) by the bacteria or other microbes. As part of the digestive process, electrons are pulled from the compound and conducted into a circuit with the help of an inorganic mediator. MFCs operate well in mild conditions relative to other types of fuel cells, such as 20-40 degrees Celsius, and could be capable of producing over 50% efficiency. These cells are suitable for small scale applications such as potential medical devices fueled by glucose in the blood, or larger such as water treatment plants or breweries producing organic waste that could then be used to fuel the MFCs.

Prospect of Fuel Cell in Selected countries

Australia:

- Australian Government launched Hydrogen Roadmap in 2008, with a vision to ensure that well informed and credible decisions be made by 2020 [7].
- One goal was to establish an advocacy group.
- Australian Association for Hydrogen Energy (AAHE) launched in Sydney, 6 September 2010
- The government will consult with AAHE to explore possibilities for progressing hydrogen as a technology for integrating into Australia's energy mix.

- Potential uses for hydrogen in Australia are: Energy storage for network support, Refining, Alternative energy carrier
- Universities conduct research largely funded through the Australian Research Council national competitive grants program
- The Government laboratory CSIRO maintains a watching brief on technology developments, provides independent advice to Government, and conducts a limited amount of targeted strategic research in hydrogen technologies
- Ceramic Fuel Cells Limited is developing SOFC products and technologies and Hydrexia P/L is developing novel magnesium-based hydrogen storage technologies
- According to National Hydrogen Study in all scenarios the transport sector has the largest demand for hydrogen, whereas the demand from the portable appliance sector is minimal even in the most optimistic scenario. Table 2 shown this information [8].

Table 2. Calculated hydrogen demand by scenario (million m^3)

Market segment	2030			2050		
	1	2	3	1	2	3
Appliances	26	10	3	56	22	6
Transport	15034	9025	6020	29585	16912	9309
Distributed Generation	2942	1765	588	12409	8272	2482
Total	18002	10800	6611	42050	25206	11797

- Fuel cells have a place in Australia for large-scale stationary and distributed generation, to cover problems of losses through the electrical transmission and distribution system. This may be driven by a carbon tax.
- Near-term applications for FCs are growing – strong business cases can be made for use in forklifts; domestic CHP; reduction of local pollution in big, industrial cities; back-up power; mining; provision of high-quality ('digital quality') power.
- Fuel cells are inevitable because the United States, Europe and Japan are investing in them, whether Australia jumps on board or not [9].

Brazil:

R&D program for hydrogen and fuel cell

- The program is based on network projects in five areas [10]:

1. Hydrogen production
2. PEM fuel cells
3. SOFC fuel cells
4. Systems, integration and engineering
5. Utilization, Applications and use

- Over 40 Research groups from Universities and Research centers are involved in these activities.
- Public investment in these projects are according to Table 3:

Table 3. Pubic investment on Hydrogen and Fuel cell in Brazil

Area	Investment (Million US $)
Hydrogen Production, Purification and Storage	6.7
Fuel cell	15.6
System, Integration and Engineering	6.4
Total	28.7

- One of project in the field of fuel cell and hydrogen which run in Brazil is Network of Hydrogen Production for Fuel Cells. The objective Objectives of this project is integrated development and evaluation of several technologies for hydrogen production from different feedstock (ethanol and biomass) and natural gas. The First fase of this project will be concluded in 2010. Project is suported by FINEP (Research and Project Financing Agency) of Ministry of Science and Technology about U$ 2.700.000 and the

Partnership of project is Research groups from Universities and Research Centers

- Another project which run in Brazil is fuel cell bus. Hybrid dual system (2 fuel cell with 85Kw power). The hydrogen is supllied by an electrolyze fuel station in Sao Paulo. Figure 3 shown this bus.

Fig 3. Hybrid fuel cell in Brazil

Canada:

Canada's hydrogen and fuel cell technology sector is a clean energy success story. As a recognized leader in the global hydrogen and fuel cell industry, the sector continues to enhance Canada's science and innovation capacity through landmark product deployments and intensive R&D investments. From 2003 to 2008, the government of Canada supported the hydrogen and fuel cell sector through the Hydrogen Economy Program. Today, no such program exists. The Canadian Hydrogen and Fuel Cell Association calls on the government of Canada to renew hydrogen and fuel cell funding by adopting recommendations contained in the CHFCA's 2010 Budget Submission (see next page). Here are 10 reasons why [11].

1. Increase innovation based jobs in Canada
2. Boost clean energy R&D by the private sector in Canada
3. Accelerate commercialization of hydrogen and fuel cell technologies today
4. Achieve significant return on public investment in clean energy
5. Strengthen Canada's automotive future
6. Reduce the impact of climate change and improve air quality
7. Enable an integrated clean energy system in Canada
8. Implement recommendations of key government of Canada reports
9. Deploy near-zero emission transportation options in Canada
10. Level the global playing field

Hydrogen and fuel cells are important clean energy technologies that help Canada achieve its greenhouse gas and pollution reduction goals. For example, fuel cell- powered buses that run on hydrogen derived from renewable power offer a 62% reduction in GHG emissions on a well-to wheels basis compared to diesel buses. Figure 4 shown emission production.

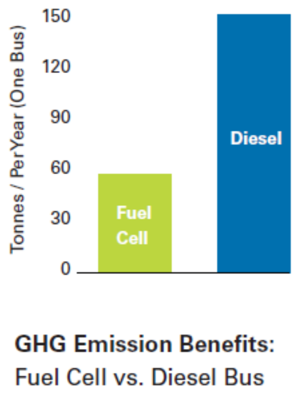

Fig 4. Emission production in fuel cell and diesel bus

Types of organization which involved in Canadian fuel cell projects are according to below [12]:

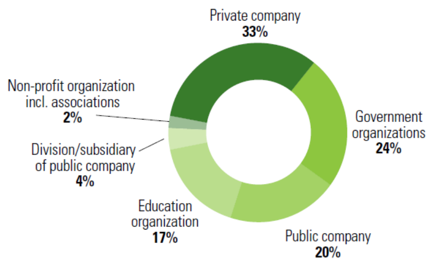

Fig 5. Company type in fuel cell sector

Corporate organizations, including public and private companies and subsidiaries, represented 57% of total responses. Government organizations accounted for almost a quarter of respondents (24%), with education organizations, and non-profit organizations including associations representing the remaining 19% of respondents.

Areas of Expertise:

The main area of expertise was research organizations (17%). Hydrogen production, along with policy development and program administration each represented 13%, followed by fuel cell developer or manufacturer (9%). Commercialization support and education, safety and training each represented 8% of industry expertise. Supplier to developer or manufacturer, systems integrator, and professional services provider each occupied 6% of industry expertise. Each of the remaining areas of industry expertise accounted for less than 6% of overall responses. The 'other' area of expertise category (5%) included hydrogen fueling infrastructure and testing. Figure 6 shows these categories [13].

Fig 6. Area of experience in fuel cell and hydrogen sector

Technology Focus:

The technology focus for 42% of organizations was on Proton Exchange Membrane (PEM) fuel cells followed by hydrogen production at 25% (see figure 7). Solid oxide and hydrogen storage each represented 8% of technology focus, followed closely by hydrogen distribution at 7%. The 'other' area of technology focus (5%) included hydrogen safety codes and standards, hydrogen internal combustion and fueling infrastructure.

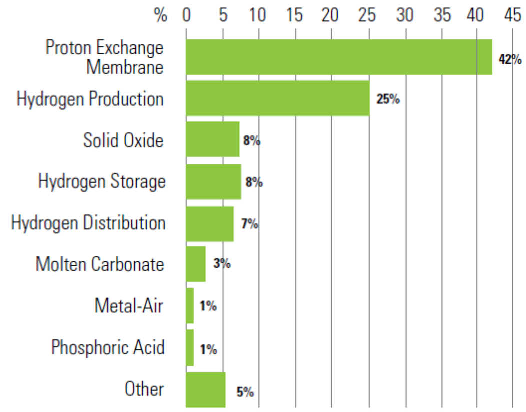

Fig 7. Technology focus in Canadian fuel cell activities

China:

Hydrogen-Fuel Cell Vehicle Development in China

The Chinese program in fuel cell and hydrogen consist of these parts [14]:

- Sustainable Development Energy and Environmental Problems in China

Total primary energy consumption in China in 2004 reached 1386.2 million tons oil equivalent, accounting for 13.6% of global consumption as the second largest consumer of energy in the world behind the U.S. (22.8%). Coal and oil consumption provide the major source of air pollution in China .China is the second largest emitter of CO2 in the world, making up roughly 13% of global emission.

- Sustainable energy for transportation system

In 2004 the vehicles production volume in China was 5.07 M units, and number of vehicles in operation reached 27 M units. There were only 20 vehicles per 1000 people. Based on a study, china annual vehicle demand will reach 9 million units by 2010, and about18 million units by 2020. The registered vehicle in China will be 120-150 million units by 2020, roughly average 100 vehicles per 1000 people. Oil cannot be expected as energy for sustainable transportation system due to its un-renewable. Renewable primary energy cannot be used as vehicle fuel directly. Three second energy carriers are recognized as the most promising sustainable "fuels" for vehicles Biomass fuel, Electricity, Hydrogen. Fuel cell stacks power density improved by 20 times. Size and weight of fuel cell engine can be integrated in vehicle, nearly equal to diesel level.

- Hydrogen-Fuel Cell Vehicle development in China

China have paid attention on PEMFC R&D since 90's, main researchers include [15]:

1. Dalian Institute of Chemical and Physics
2. Chinese Academy of Sciences
3. Beijing Fu Yuan Pioneer New Energy Material Co., Ltd
4. Shanghai Sun Li High Technology Co., Ltd
5. Beijing Lu Neng Power Sources Co., Ltd

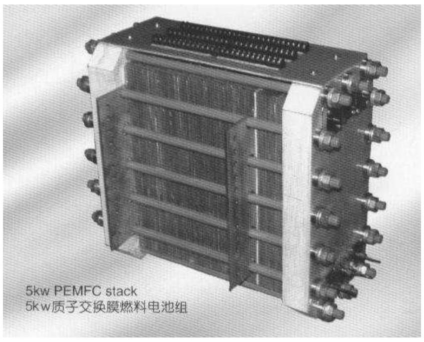

Fig 8. 5 kw stack PEMFC which produced in China

Fuel cell bus is one of the effective projects in fuel cell sector in China. Buses are used by many people and can become an effective tool to advertise environmental protection and sustained development concepts. It also performs as a "moving classroom" teaching people about new transportation technologies and their advantages through their real experience. Figure 9 shows Chinese fuel cell bus [16].

Fig 9. Chinese fuel cell bus

Fuel cell systems, fuel cell sedans and city buses are listed in "High Technologies Development" 5 year plan (2001-2005). The Ministry of Science & Technology of China contributed 106 million USD dollar towards support for battery-power, hybrid and fuel cell electric vehicle R&D and demonstration during the 10th 5 Year Plan (2001-2005).

In 2004 correspondents survey of bus production showed that Regarding larger potential market and lower cost of labor and material, if fuel cell propulsion system and bus production are localized in China, it will be competitive in the future.

After fuel cell usage in transportation sector, distributed power generation is the most attractive application of fuel cell in china. China have program to use 86 percent of SOFC in their distributed power generation program.

France:

France government spent 55 Million US$ on hydrogen and fuel cell in 2008 [17].

Past initiatives for Fuel Cell and Hydrogen in France:

1. PACO network (1999-2005)

- Coordinated by CEA and ADEME
- Missions: define research priorities and fostering R&D

2. PAN-H program (2005-2008)

- Coordinated by the National Research Agency (ANR)
- Objective: funding of R&D
- Outputs: 73 projects involving 420 organizations, for a total budget of 83 M€

3. H-PAC program (2009-2010)

- Coordinated by the National Research Agency (ANR)
- Objective: funding of R&D
- Priorities:
    1. Low and high-temperature electrolysis
    2. Hydrogen storage
    3. Stationary applications
    4. Early markets
    5. Renewable energy management
    6. Mobile applications including transport

Current initiatives: towards a Fuel Cell and Hydrogen industry in France

1. On-going initiatives towards a green economy

- Strategic sectors for a green economy » report (March 2010): the hydrogen and fuel cell sector was identified among others such as renewable energy, biofuels, smart grids, energy storage…

- Workshops with research and industry players and other stakeholders: draft an implementation plan for the development of the fuel cell and hydrogen industry in France

2. Funding of large-scale demonstration projects through the « Investissements d'Avenir » program

- Funding of pre-industrialization projects between 2010 and 2015

- « Transport of the Future »: 1 billion Euros

- « Low-Carbon Energy and Green Chemistry »: 1.6 billion Euros

- Hydrogen and fuel cells solutions : a candidate among other technologies

Road Map of Hydrogen and Fuel cell in France [18]:

Step 1:

During 5-7 years and with 300 million US$, research and development in hydrogen and fuel cell technology

Step 2:

During next 10 years and with 350 million US$, research and development and start to industrial activities

Step 3:

During next 10 years and with 500 million US$, research and development and 6 demonstrations projects

Japan:

Japan's fuel cell industry has been aggressively pursuing research and envelopments into phosphoric acid fuel cells and practical fuel cell vehicles, as well as polymer electrolyte fuel cells, which are nearing practical application. Few Japanese firms are in the market, so products are procured worldwide. However, Japanese firms are making efforts to add value and cut costs for their own products under development. The market is expected to grow as technology advances, and deregulation and government assistance progress [19].

Figure 10 shows the fuel cell industry and situation of Japanese in each technology.

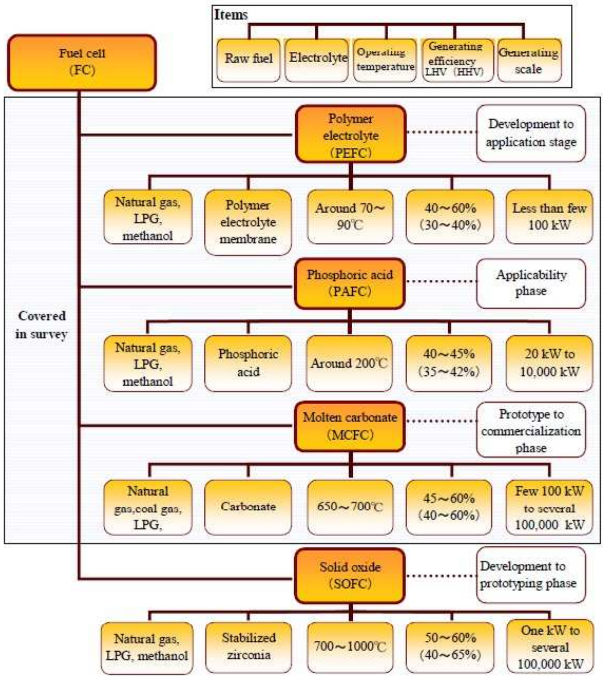

Fig 10. Fuel cell industry in Japan

Fuel cells are heralded as the next-generation source of clean, efficiently produced electricity. Research and development is progressing in Japan, where PAFCs and MCFCs are already in use. PEFCs for vehicles and other mobile applications, as well as for stand-alone systems for residential and commercial use, are now ready for practical application. It is highly likely that all types of basic fuel cells, including SOFCs, will be commercialized in the near future. In Japan, PEFC development began in 1992 as part of the Sunshine Project led by the Ministry of Economy, Trade and Industry (METI). R&D subsequently continued under the successor New Sunshine Project from 1993 through New Energy and Industrial Technology Development Organization (NEDO) programs. More specific projects regarding practical uses were implemented under the Millennium Project from 2000, including a program to begin development and testing in order to popularize fuel cells. METI began testing a few hundred stand-alone PEFC prototypes in 2005, and expects to put them into practical use soon. Possible uses for PEFCs include vehicles and small stand-alone power systems. Size reductions have been proven possible without any substantial loss of efficiency. Such systems are nearing practical use. Development of PAFCs began in 1981 with the decision to produce cells similar to those developed already in the U.S. under the Moonlight Project of the Agency of Industrial Science and Technology (now the National Institute of Advanced

Industrial Science and Technology). Development continued under the New Sunshine Project until 1997. Work is now focused on commercialization [20].

The MCFC conducted basic research from 1981 to 1986, and then shifted to research into a 100-kilowatt stack (see Glossary) from 1987 to 1994. System testing was conducted from 1994 to 1999, and from 2000 to 2004 development focused on practical uses. Like PAFCs, research on MCFCs began under the Moonlight Project. The MCFC Research Association guided efforts from 1988. Development by individual companies currently ranges from testing to practical applications. Figure 11 to 16 show the fuel cell market in Japan for PEFC, PAFC and MCFC during 2004 to 2010 [21].

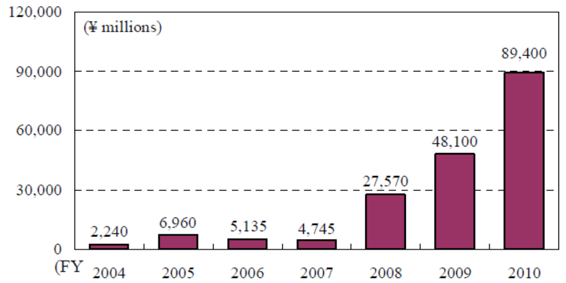

Fig 11. PEFC growth market trend

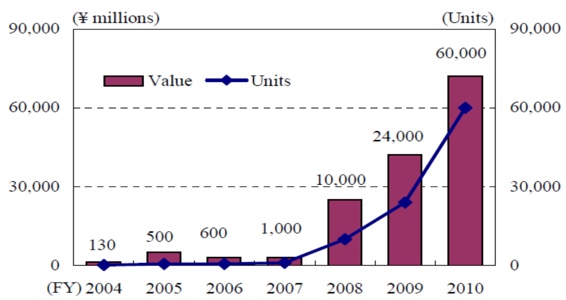

Fig 12. Residential PEFC growth market trend

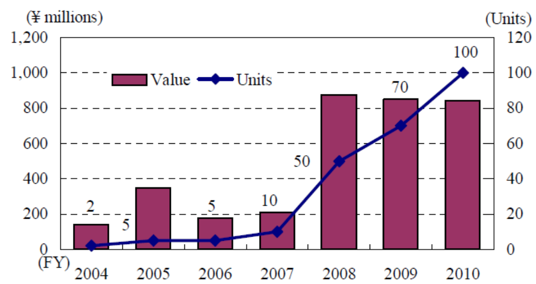

Fig 13. Commercial/ Industrial PEFC growth market trend

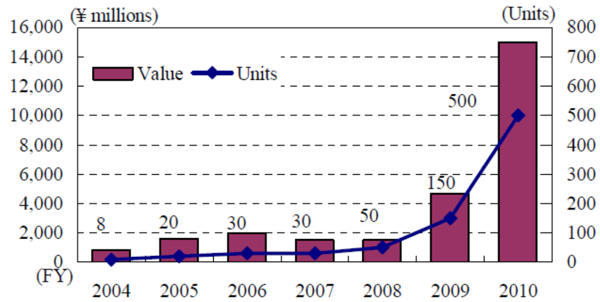

Fig 14. Mobile PEFC growth market trend

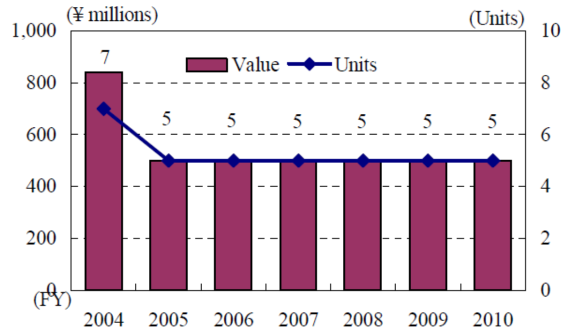

Fig 15. PAFC growth market trend

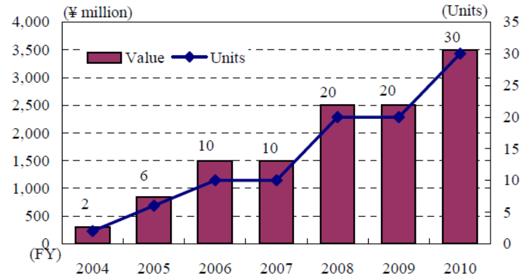

Fig 16. MCFC growth market trend

Among application of fuel cell in Japan, vehicle industry is more power full. The following figure shows companies which involved in Japanese fuel cell vehicle industry and their share percents.

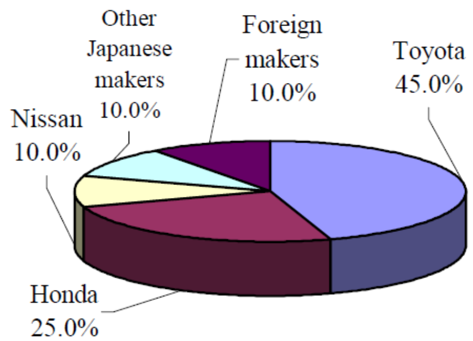

Fig 17. Fuel cell vehicle industry in Japan

Policies

- Agency for Natural Resources and Energy

The Strategic Council for Fuel Cell Applications, which advises the Natural Resources and Energy Agency director general, is calling for fuel cells to account for something less than 1% for all electric power nationwide and 0.1% of all vehicles owned by 2010. Because these systems are an integral part of policies for global-warming and environmental issues, efforts are being implemented in both the public and private sectors [22].

- Ministry of Economy, Trade and Industry

This ministry is central to the development of fuel cells in Japan. It allocated ¥142.3 billion in its 2005 budget for science and technology promotion, with fuel cells accounting for ¥35.4 billion, or around 25%. Policies on elemental technology development/testing/prototyping, legal/regulatory liberalization and international standards are among the wide-ranging measures being developed with the Natural Resources and Energy Agency. NEF's large stationary PEFC demonstration project was one of the major programs in 2005. In addition, support for the development of new technologies was provided through NEDO and the National Institute of Advanced Industrial Science and Technology.

- Ministry of Environment

This ministry's role will expand as fuel cells gain wider adoption. Current activities are limited to promoting increased awareness of fuel cells.

- Ministry of Land, Infrastructure and Transport

This ministry has participated in certain trials and prototyping since it oversees roads, public transportation, housing and other infrastructure. Besides implementing a project to promote fuel cell vehicles, it also decided to fund a project to promote the development of hydrogen-fueled fuel-cell cogeneration systems for housing complexes.

USA:

In Hydrogen production sector American government has comprehensive program. Funding for hydrogen production in the FCT Program is increasingly focused on early development, long-term, renewable pathways such as PEC, biological, and solar-thermochemical hydrogen production. This trend is expected to continue in FY 2012 with a $17.5 million request, when projects focused on separations will have ended. Hydrogen production R&D efforts in FE continued to focus on development of separation membranes and catalysts for hydrogen from coal. Emphasis in FY 2011 was on demonstration of performance through long-term bench scale and slip stream tests. In FY 2011 and FY 2012, hydrogen delivery activities in the FCT Program are focusing on reducing pipeline and forecourt compression cost, increasing tube trailer capacity, and identifying viable low-cost early market delivery pathways. A chart showing sub-program funding for FY 2011 and 2012 (requested) [23].

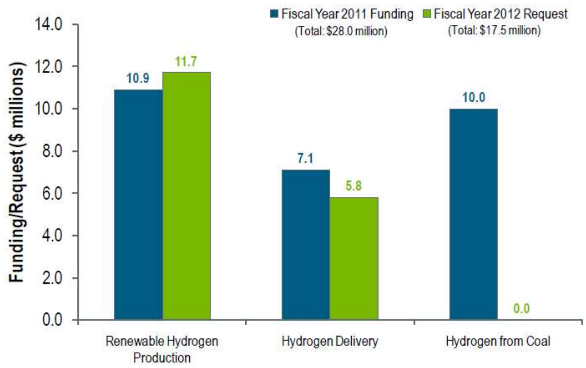

Fig 18. Hydrogen production fund in American H_2 program

USA government reasons to investigate in Hydrogen as a clean fuel are according to below:

- Hydrogen can increase America's energy security.

Vehicles operating on hydrogen can dramatically reduce their nation's dependence on oil and significantly reduce tailpipe emissions. Hydrogen offers a potential means to store and deliver energy from abundant, domestically available resources while reducing their nation's carbon footprint [24].

- Hydrogen is the most abundant element on Earth.

However, it does not exist naturally in its molecular form. It must be produced from other sources or "feedstocks" such as water, biomass, or fossil fuels. The technologies for producing pure hydrogen from these feedstocks also require energy to power the production process.

- Researchers are working to produce hydrogen economically from diverse sources.

Sustainable production technologies offer exciting possibilities for the future. Meanwhile, hydrogen produced from fossil fuels (like natural gas) can help to build early markets and infrastructure. The ability to generate hydrogen from a variety of feedstocks using diverse energy sources makes hydrogen a particularly promising energy carrier.

- Collaborative partnerships are accelerating technology advances.

By working together, government and industry can expedite progress in improving the efficiency and economics of hydrogen production. The FreedomCAR & Fuel Partnership brings together the U.S. Department of Energy (DOE), the major U.S. car manufacturers, energy companies, and utilities in advancing research and development (R&D) to enable high-volume production of affordable hydrogen-powered vehicles and their supporting infrastructure. The Partnership's Hydrogen Production Technical Team has identified the R&D needs for seven key hydrogen production technologies in the Hydrogen Production Roadmap: Technology Pathways to the Future [25].

Fuel Cells Funding by Technology:

The Fuel Cells sub-program received $43 million in fiscal year (FY) 2011 and approximately $45.5 million is requested for FY 2012. The sub-program continues to focus on reducing costs and improving durability with an emphasis on fuel cell stack components. The funding profiles for FY 2011 and the FY 2012 request are very similar, with some projects in membranes and bipolar plates ending in FY 2011.

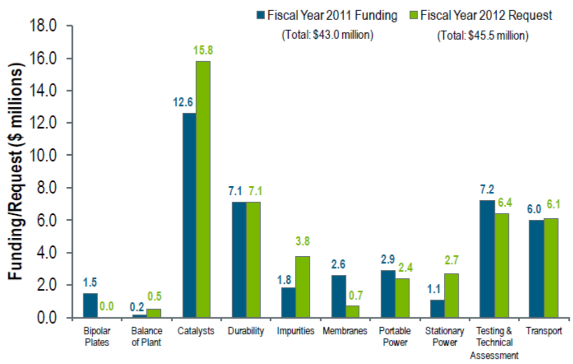

Fig 19. Fuel cell Funding in USA

Some of these projects are according to below [26]:

1. Advanced Cathode Catalysts and Supports for PEM Fuel Cells
2. Highly Dispersed Alloy Catalyst for Durability
3. Durable Catalysts for Fuel Cell Protection During Transient Conditions
4. Extended, Continuous Platinum Nanostructures in Thick, Dispersed Electrodes
5. Nanosegregated Cathode Catalysts with Ultra-Low Platinum Loading
6. Contiguous Platinum Monolayer Oxygen Reduction Electro catalysts on High-Stability, Low-Cost Supports
7. Polymer Electrolyte Fuel Cell Lifetime Limitations: The Role of Electro catalyst Degradation
8. Manufacturing Cost Analysis of Fuel Cell Systems
9. Transport Studies Enabling Efficiency Optimization of Cost-Competitive Fuel Cell Stacks

Most of these projects are about catalyst and PEM fuel cell and shown that these subject are the most important issue in fuel cell convince in USA.

National Renewable Energy Laboratory (NREL) supported number of projects in combination of renewable energy and hydrogen production and fuel cell. Figure 20 to 24 are shown these projects [27].

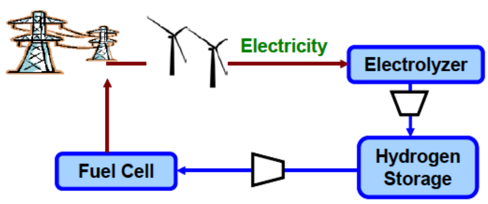

Fig 20. Wind energy in combination with fuel cell system

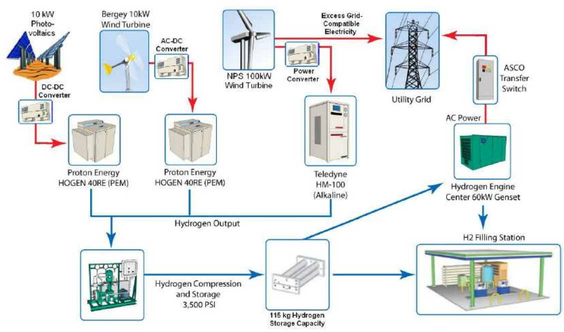

Fig 21. Overall wind to Hydrogen and fuel cell system

Fig 22. Fuel cell vehicle which fueled by solar panel and water electrolyzer

Fig 23. Membrane production for PEM fuel cell

Fig 24. Fuel cell hybrid bus

Prospect of Fuel Cell in Iran

Fuel cell is one of the wide spread scientific fields with a variety of applications. It's industrial, economical, and social effects are enormous. The organizations and universities which are working in this field in Iran are as follows [28]:

1. Iran Renewable energy Organization
2. Tarbiat Modares University
3. Sharif University of Technology
4. Iran Science and Technology University
5. Khaje nasir University
6. Research center of Jihad Esfahan
7. Iran Khodro Company

Since minor and unfocused activities will not lead to fuel cell technology, it is essential to achieve to a unique policy for collimating these activities with resource management strategies. For these reasons and also developing of fuel cell technology in Iran, the "Fuel Cell Steering Committee" was established in February, 2002.

National Strategy of Iran Fuel Cell, Technology Development:

Major goals

- Design, production and promotion of strategic fuel cell technology in competitive national and international markets with considering priorities of demand market.
- The extending and developing of investment in strategic fuel cell production industry and its key technologies and focusing on private section role, competitive advantages, entrepreneurship and export approach (mobilization of supply side).
- The creating and developing of application and exploiting capacities of strategic fuel cell technology in Iran and overseas by creating and by using mechanisms such as calculating real costs of energy production, developing niche markets in Iran and enacting required laws and regulation(mobilization of demand side)

Major policies

- The maximum using of capabilities and indigenous competences especially in private sector focused on supportive role of the government.
- Centralization in policy making with national and supra division approach and coordination and systematic administration focusing on international cooperation, interaction and partnership in developing strategic fuel cell technology systematically.
- Coordination with major strategies and measures of energy sector and renewable energies in the country.
- Development of exploiting fuel cells in the country and applying in economic and production sections

Strategies

- Development of strategic fuel cells technologies of "Proton Exchange Membrane Fuel Cell (PEMFC)" and "Solid Oxide Fuel Cell (SOFC)", and their key technologies5 through basic, applied, and developing researches.
- Development of technologies related to natural gas reformers into hydrogen, and hydrogen storage.
- Helping to create and develop domestic markets, and to penetrate into international markets of fuel cells with application in transportation and electricity production with beginning from early markets of residential electrical generators powered by Proton Exchange Membrane Fuel Cell (PEMFC).
- Development and completion of fuel cell National Innovation system in Iran.

Short term Program:

Goal: policy making, research and development activities, rising awareness and technology promotion

- Establishing fuel cell development council
- Formulating and suggesting rules and regulations related to support fuel cell technology development in Iran.
- Facilitating scientific, corporation and non government organizations foundation supporting fuel cell technology development.
- Foundation and operation of fuel cell technology development with related legal permissions.
- Foundation of supportive fund for fuel cell technology development independent or from supportive fund for energy efficiency and renewable energies with relevant legal permissions.
- Mastering the design and integration of 5 KW Proton Exchange Membrane Fuel Cell (PEMFC) systems and manufacturing its prototype.
- Command over design and manufacturing of single cell and production of Solid Oxide Fuel Cell (SOFC) model.
- Command over design and manufacturing of natural gas to hydrogen reformer and manufacturing its prototype.
- Command over design and manufacturing of hydrogen storage tank and producing its prototype.
- Purchasing, installation and exploiting of some models of different fuel cell systems.
- Development of web sites and publication of news bulletins on fuel cell technology achievements in Iran and in the world.
- Continuity of strategic studies needed for fuel cell technology.
- Preparing action plans needed for operational actions.
- Employment and training of expert human resources to implement actions.
- Conducting joint educational courses with reputable international centers.
- Support of master and PhD theses on strategic fuel cells and fuel processing.
- Support of innovators and inventors achievements in fuel cell technology field
- Interaction with international technology consortia
- Produce of designing and manufacturing software in strategic fuel cell and their key technologies
- Support of research projects in order to benefit from fuel cell in power plants as well as in transportation industries and industrial applications

Midterm Program:

Goal: continuing research and development activities raise awareness and promotion and establishment of essential infrastructures for technology development.

- Study and select an optimum system for fuel processing applies in automobiles
- Design and manufacturing of 10 and 25 KW Proton Exchange Membrane Fuel Cell (PEMFC) systems and manufacturing prototype applied in residential generators and transportation systems
- Design and manufacture Solid Oxide Fuel Cell (SOFC) models
- Formulating of manufacturing, distribution and formulation standards for hydrogen and fuel cell in

cooperation with the Institute of Standards and Industrial Researches of Iran (ISIRI) cooperation

- Establishing of fuel cell technology growth centers
- Developing supportive mechanisms for intellectual Property (IP) for innovations and inventions in fuel cell technology field in cooperation with Iran's Registration office for Documents and Estates.

Long term Program:

Goal: continuing research and development activities, raising awareness and promotion and initiate deployment of fuel cell technology.

- Production and application of Proton Exchange Membrane Fuel Cell (PEMFC) system in residential electrical generators proportionate with target market size.
- Production and application of Proton Exchange Membrane Fuel Cell (PEMFC) system in general and especial transportation systems.
- Design and manufacturing of 5 and 10 KW Solid Oxide Fuel Cells (SOFC)
- Implementation of optimization projects and decrease in final price of strategic fuel cells in order to achieve determined vision.
- Encourage various incentive mechanisms for economic institutes producing fuel cell and its related technologies.
- Tax free grant for strategic fuel cell and its related technologies, with legal permissions based on specific set of guidelines and regulations.
- Awarding financial bank facilities with proper investment condition needed for implementing developmental projects based on strategic fuel cell technology with relevant set of guidelines and regulations.
- Formulating guidelines for purchasing electrical power from private sectors which produce electricity via strategic fuel cell technology.
- Providing 90 Mega Watt decentralized electrical power from Iran power using fuel cell power plant till 2020.
- Formulating rules and regulations for using fuel cell in transportation systems.
- Manufacturing and exploiting one hundred public transportation vehicles in mega cities using Proton Exchange Membrane Fuel Cell (PEMFC) driving systems till 2020.

Conclusion

Hydrogen and fuel cell are one of reliable energy sources in the future. Hydrogen can be generated via fossil fuel and renewable energy. Because of these characteristics and other benefits of hydrogen and fuel cell which mentioned in the text, most of countries have special program to develop this technology. In most of these countries fuel cell is applied in transportation sector which is the most energy consuming sector. Zero emission vehicles helps to improve the quality of weather in crowded area of big cities. PEM fuel cell is the most popular type of fuel cell because of its special characteristics which can be used in transportation sector. After transportation, distributed power generation is in the next rank of fuel cell application. PEMFC and SOFC are the most popular fuel cell technology which used in this section. SOFC with the capability to use in cogeneration system has good prospect in power generation. In Iran according to Fuel Cell Development council the secretariat of fuel cell steering committee program PEMFC and SOFC are two type of fuel cell which recognizes to be suitable for the country. In some area Iranian program in fuel cell development is not complete. For example combination of renewable energy and hydrogen production and fuel cell is one of projects which most of developed countries have program for it, but in Iran this field is not considered.

References

[1] RICHARD W. ASPLUND, Profiting from Clean Energy, John Wiley & Sons, Inc, 2008

[2] Frederick J. Barclay, Fuel Cells, Engines and Hydrogen an Exergy Approach, John Wiley & Sons, Inc, 2006

[3] Andrei A. Kulikovsky, Analytical Modeling of Fuel cell, Elsevier, 2010

[4] Fuel Cell Handbook (Seventh Edition), EG&G Technical Services, Inc, 2004

[5] EUROPEAN COMMISSION, Hydrogen Energy and Fuel Cells A vision of our future, 2003

[6] Subhash C Singhal and Kevin Kendall, High Temperature Solid Oxide Fuel Cells: Fundamentals, Design and Applications, ELSEVIER, 2003

[7] The Hydrogen Technology Roadmap is available at: http://www.coag.gov.au/reports/docs/hydrogen_technology_roadmap.pdf

[8] Australian Government, National Hydrogen Study, 2003

[9] Department of Resources Energy and Tourism, STRATEGIC FRAMEWORK FOR ALTERNATIVE TRANSPORT FUELS, DECEMBER 2011

[10] SYMONE C. S. ARAÚJO, Road Map of fuel cell in Brazil, Ministry of Mines and Energy, Shanghai, China - September 2010

[11] Canadian Hydrogen and Fuel Cell Association, available online at: Web: www.chfca.ca

[12] Canadian Hydrogen and Fuel Cell Association, Canadian Hydrogen and Fuel Cell Sector Profile 2010.

[13] Canadian Fuel cell, commercialization Roadmap, March 2003

[14] Hydrogen-Fuel Cell Vehicle Development in China, Demonstration for Fuel Cell Bus Commercialization in China, 2006

[15] Chinese Hydrogen & Fuel Cell Activities in 2010-2011, Ministry of Science and Technology Tongji University, 2011

[16] Liangfei Xu, Jianqiu Li, Jianfeng Hua, Xiangjun Li, Minggao Ouyang, Adaptive supervisory control strategy of a fuel cell/battery-powered city bus, Journal of Power Sources 194 (2009) 360–368

[17] The French Hydrogen and Fuel Cell Roadmap, Plan towards a hydrogen economy in France, 2011

[18] Hydrogen Energy and Fuel Cells, A vision of our future, European commission, 2003

[19] Japan's Fuel Cell Industry, JETRO Japan Economic Report, April-May 2006

[20] Akira Maeda, Fuel Cell Technologies in the Japanese National Innovation System, September 2003

[21] Annual report, Energy in Japan 2010, Agency of Natural resources and energy

[22] Japanese sector, International Hydrogen and Fuel Cell Policy and Funding, Available Online: www.fuelcell200.com

[23] Kevin Chandler, Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration: First Results Report, NREL 2011

[24] K.W. Harrison, G.D. Martin, T.G. Ramsden, and W.E. Kramer, The Wind-to-Hydrogen Project: Operational Experience, Performance Testing, and Systems Integration, NREL 2011

[25] Darlene Steward and Mike Penev, Fuel Cell Power Model Elucidates Life-Cycle Costs for Fuel Cell-Based Combined Heat, Hydrogen, and Power (CHHP) Production Systems, NREL 2011

[26] Darlene Steward, Genevieve Saur, Mike Penev, and Todd Ramsden, Cost Analysis Highlights Hydrogen's Potential for Electrical Energy Storage, NREL 2011

[27] Hydrogen Production Roadmap Technology Pathways to the Future, FreedomCAR & Fuel Partnership Hydrogen Production Technical Team, 2009

[28] Fuel Cell Development council the secretariat of fuel cell steering committee, National Strategy of Iran Fuel Cell Technology Development