

Fuel Cell Technological Innovation System in Iran

Naser Bagheri Moghaddam¹ Morteza Zamanian²
Mahdi Sahafzadeh³ Mohammadsadegh Emamian⁴

1 Department of Management & Accounting, Allame Tabatabaee University, Tehran, Iran

2 Department of Economics, University of III Carlos de Madrid, Spain

3 Department of Industrial Engineering, Iran University of Science & Technology, Tehran, Iran

4 Department of Management & Economy, Sharif University of Technology, Tehran, Iran

(Email: nbagheri@tco.ir, mo.zamanian@gmail.com, sahaf@ind.iust.ac.ir,
smsemamian@alum.sharif.edu)

Abstract This article provides an overview of innovation processes have been taken in the field of Fuel Cell Technology (FCT) in Iran. Fuel Cell technology is a generic technology with wide variety areas of application in automobile and in energy production both for industrial and residential purposes and it is expected to have a large societal impact on the future society. In this article we review some of technology development frameworks including interactive and systematic models. Then concerning decision criteria such as considering role of the actors cooperating at national level and also their interactions and based on the National Innovation System (NIS) approach, an innovation survey has been drawn. Activities of main actors in development of FCT in Iran were monitored. By using this survey, we explore technological innovation in the field of FC technology. These innovation surveys try to deal with two challenges. Firstly, what characterized FC technology innovation in Iran? And secondly, how can numerous actors be maintained and duplication avoided in a NIS? Finally our concluding remarks of the innovation surveys is analyzing the role of government, industry and academia and their interaction and suggesting establishment of FCT development center.

Key words innovation system, fuel cell, national innovation system

1 Introduction

This paper discusses about technological innovation in the emerging field of Fuel Cells Technology (FCT) in Iran. Fuel cell (FC) technology is a generic technology with application areas such as automobiles, residential power generation and portable apparatuses. FC produces energy through chemical reactions between hydrogen and oxygen, and it is expected to have a large societal impact on the future society. FC and Hydrogen technology are interrelated technologies, so that important innovations in one of these fields have implications for the other.

Due to its emerging character, this technology has not been widely studied, especially not from an innovation standpoint. The development of FC in Iran has been pursued by government, university and industry centers since the early 1990s. The fuel cells currently being studied and developed can be largely divided into the following five types:

- (i) Polymer Exchange Membrane Fuel Cell (PEMFC)
- (ii) Solid Oxide Fuel Cell (SOFC)
- (iii) Phosphoric Acid Fuel Cell (PAFC)
- (iv) Alkaline Fuel Cell (AFC)
- (v) Molten Carbonate Fuel Cell (MCFC)

According to Iran FC National Strategic Plan, PEMFC and SOFC are received the greatest amount of attention for the country. PEMFC has technological characteristics such as low operating temperature (80 -100 C), higher energy density and fast startup time that make it appropriate for being used in transportation and portable applications. On the other hand, SOFC can be used for energy generation in power plant and Combine Heat and Power (CHP).

In this regard it is necessary to perform a complete innovation survey of FC technology development activities in Iran. So the research questions in this paper are as follows:

- (i) What characterized FCT innovation in Iran?
- (ii) How can variation be maintained and duplication avoided in a NIS? (Role of government, industry and universities)

In this paper section 2 discusses the methodology and explains how National Innovation System can be used to analyze the background of FC technology in Iran.

Section 3 presents the Innovation survey drawing upon different aspects of the Technological and National perspectives of NIS and discusses the role of government, industry and university in

developing FCT in Iran. Then we analyzed the innovation system with a focus on actor relations and interaction between them in developing FCT.

Finally section 4 presents our research conclusion and shows the Iranian fuel cell innovation system as a model.

2 Methodology

The main approach applied in this article is innovation survey according to NIS framework. Most countries use this approach for evaluating technological capabilities at national level. National innovation system is a conceptual tool to analyze the current knowledge economy because the approach deals explicitly with knowledge creation, distribution and utilization as the key components of analysis [1]. In essence, innovation is the ability to manage knowledge creatively in response to market-articulated demands and other social needs [8]. Innovation performance depends not only on how specific actors (e.g. enterprises, research institutes, universities) perform, but on how they interact with one another as elements of an innovation system, at local, national and international levels [8]. One of the common assumptions behind the different approaches to innovation systems is that elements of knowledge important for economic performance are localized and not easily moved from one place to another. A common assumption behind the innovation system perspective is that knowledge is something more than information and that it includes tacit elements. Important elements of knowledge are embodied in the minds and bodies of agents, in routines of firms and not least in relationships between people and organizations [3], [5].

It can be said that the recognition of the involving institutions in the process of national innovation development and the fact that how these institutions are interacting and interrelating toward main objectives, namely; generation, exploitation and diffusion of technological knowledge[10] are among the most important subjects of NIS. Therefore, the main characteristics of NIS are as following:

- (i) Create new knowledge
- (ii) Guide the direction of the search process
- (iii) Supply resources i.e. capital and competence
- (iv) Facilitate the creation of positive external economies (in the form of an exchange of information, knowledge, and visions)
- (v) Facilitate the formation of markets

One of the most important classifications of NIS functions is that of OECD that identifies seven main activities for NIS [8].

- (i) Policy formulation, coordination, supervision and assessment
- (ii) Performing R&D (basic, pre-competitive, applied)
- (iii) Financing R&D
- (iv) Promotion of human resource development and mobility
- (v) Technology diffusion
- (vi) Promotion of technological entrepreneurship
- (vii) Production of goods and services.

Also there are many NIS indicators with different approaches of measurement at national level. The identification of these indicators and their classification can show the level of each country's performance and capabilities in different relevant areas of innovation. There are different classifications regarding the NIS indicators. Each classification has its own particular function that may be used for analyzing the conceptual framework of NIS. There are many indicators for NIS that refer to generation, exploitation of technological innovation as main NIS indicators. According to [4] & [9], the main indicators of NIS have been classified into different sub- categories as follows:

- (i) Indicators relevant to creating and generating knowledge: R&D and Innovation: Human resources in science and technology: knowledge and skills; Patents; protecting and commercializing knowledge;
- (ii) Indicators relevant to technology diffusion: ICT as an enabler for the knowledge society; Knowledge flows and the global enterprise;
- (iii) Indicators of NIS related to exploitation of technological knowledge such as the impact of knowledge on productive activities.

In this paper we present innovation survey of FC technologies in Iran, based on the first group of indicators i.e. indicators relevant to creating and generating knowledge. Our main focus was on

identification of actors and their relations. So a questionnaire has been designed and sent to actors in FC technology. Meanwhile single interviews were conducted in some centers, using an unseen semi-structured questionnaire, derived from our research model (NIS functions).

Interviews, conferences and reports involving a broad spectrum of research centers or related institutions in Iran, including government research centers, universities and industry associations were conducted to understand the general context of fuel cell development. Also by interviews with companies active in development of fuel cell stacks, components and infrastructures, a big picture of the issues and drivers affecting FC development and commercialization was established.

Twenty active centers in FCT were selected. These include many of the most prominent centers engaged in development process of different types of fuel cells. During eight face-to-face interviews, interviewees were encouraged to talk freely about their experiences and perceptions of fuel cell development, with the schedule as a prompt. The main themes drew in questionnaire and discussed in the interviews were the following items derived from main functions of NIS:

- i. Origins and history of fuel cell development in the company
- ii. Position in supply chain, any partnering agreements, and markets addressing
- iii. Company innovation process and its application to fuel cell development
- iv. Critical customer/market issues
- v. Barriers (internal and external) to be overcome
- vi. Research and development and commercialization strategies, with future plans
- vii. General incentives and disincentives driving the industry (including the role of government)
- viii. Human resources (FC experts)
- ix. Publications (books, articles, thesis ...)
- x. Research & Development Projects and their costs
- xi. Hardware and tools especially use for FC technology development

3 Fuel Cell Innovation System in Iran

In Iran, first efforts for developing fuel cell technology initiated in the latest 1990's by Power Ministry which lead to exploit some PAFC prototypes.

The following factors are stimulating fuel cell developments which are driving innovation in this technology:

- i. Driver 1: Energy efficiency
- ii. Driver 2: Reduced environmental impact
- iii. Driver 3: Diversification of energy supply, and fossil alternatives.
- iv. Driver 4: Distributed power generation

In this part we analyses the role of three main actors influencing development of FCT in Iran.

3.1 The Role of Government

The crucial function of the government is the planning and framing of the development of technologies. Based on this function, the government should support the development of common platform technologies, high-risk basic technologies, and infrastructure building technologies by commissioning R&D to the private sector, providing aid to businesses, offering competitive funding to universities and public labs and implementing other forms of support. In Iran government engaged in both innovations policy implication (policy making) function and R&D function.

Government can use several types of policies to attain the goal of developing new technologies including science policy, technology policy and innovation policy. Science policy is the attempts of governments to strengthen the national science foundations. According to [5], science policy is "allocating sufficient resources to science, to distribute them wisely between activities, to make sure that resources are used efficiently and to contribute to social welfare". Technology policy refers to government support of technologies and sectors and especially science based technologies such as nuclear power, space technology, computers, drugs and genetic engineering (Ibid: 11).

Innovation policy is discussed in two versions. According to first version Innovation policy "puts the emphasis on non-interventionism and signals that the focus should be on framework conditions rather than specific sectors or technologies" (Ibid: 16) which emphasizes on education and R&D. The other version implies "that most major policy fields need to be considered in light on how they contribute to innovation" (Ibid: 17). Then innovation policy explains knowledge creation, diffusion and exploitation (commercialization) phases.

In Iran, the newly established Steering Committee of Fuel Cell (SCFC) is responsible for FC

development policy making. This committee is including presenters of some related ministries and institutions. SCFC has three main missions: Firstly monitoring international changes of FCTs, secondly policy making and facilitating for R&D activities and finally coordinating efforts made by institutions and organizations. However because of two reasons this committee wasn't successful in achieving its goals. Firstly not being supported by necessary requirements such as financial resources and sufficient authority, and secondly lack of a long term national strategic plan for FC development considering the role of all actors.

To decline this drawback, in 2007, SCFC has been reinforced by council of ministers and became an independent organization supported by enough authority and resources from government. After establishing this committee numerous national policies and programs approved by government and pursued by this committee which can be considered in two categories; "vertical" and "horizontal" policies which respectively refer to policies related directly to FC technology and policies related to secondary requirements of developing FCT such as research policies, human resource development policies, etc. In Iran, Most of legislated programs relate to horizontal policies.

According to Iranian political system the highest level policymaking position at national level is the leader of Islamic Republic of Iran. According to the Third Development National Plan which is approved by leader both vertical and horizontal FC innovation policies are emphatically mentioned which is an outstanding opportunity for developing this technology.

Also different paragraphs in national laws such as "Guidelines of Council of Ministries", paragraphs 2, 4, 5 and 6; "Guidelines of Science and Technology Development Committee", paragraphs 2, 4, 6, 14, 15; and the first paragraph "Executive Policies of Energy Sector" refer to FC innovation concepts such as research priority setting, facilitating R&D innovation and establishing intellectual property system.

According to various work break-down systems between public and private sectors, the role of government differs through various countries. In countries with powerful market mechanisms and private sectors, the role of government restricted to key policymaking and supporting private sectors by financial aids. On the other hand in many countries, government also undertakes the responsibility of establishing public research centers and directly holds their research activities. In Iran the government has entered R&D activities from 1999.

The list of governmental institutions and organizations involving in FCT in Iran is as follows.

- i. Isfahan Engineering Research Center
- ii. Karaj Energy & Material Research Center
- iii. Research Institute of Petroleum Industry (RIPI)
- iv. Iranian Research Organization of Science and Technology
- v. Iran New Energies Organization (SUNA)

In table 1 governmental activities is evaluated.

3.2 The Role of Industry

FC Technological development should fundamentally be supported by private sector research funding to be commercialized. Notably, development of primary automobile technologies—the overall system, fuel cell stacks, reformers, drive systems, and other technologies—is already in a state of competition. This is a domain in which the government should not intervene.

In the other direction, industry can play a vital role in assisting the government's formulation of long-term policies by offering recommendations on new needs related to both technological development and the support necessary for such development.

In Iran there are two industries involved in FCT, the automobile and gas industries. The main industrial companies engaged in this technology are as follows:

- i. Iran Khodro Co.
- ii. Taght Iran Kashan Co.
- iii. Asre Hydrogen Technology Co.
- iv. Arman Saba Sanat Fanavar Co.

In table 2 related activities of industrial companies are shown.

Table 1 Governmental R&D centers and their activities

ID	Activities Actors	FC Types					FC Components															Number of Responds		
		PEMFC	PAFC	AFC	MCFC	SOFC	Reformer	Electrolyzer	H ₂ Storage	Catalyst Supply	Control System & Instrumentation	Testing	YSZ	Membrane	GDL	FFP	MEA	Sensor/Valve /Piping	Design	Material	Other	PHD	MSc	BS
1	Esfahan Engineering Research Center																					-	7	1
2	Karaj Energy & Material Research Center																					3	2	-
3	Research Institute of Petroleum Industry (RIPI)																					6	7	4
4	Iranian Research Organization of Science and Technology																					1	-	-
5	Iran New Energies Organization (SUNA)																					4	4	4

Table 2 Industry R&D centers and their activities

ID	Activities Ac	FC Types					FC Components															Number of Responds		
		PEMFC	PAFC	AFC	MCFC	SOFC	Reformer	Electrolyzer	H ₂ Storage	Catalyst Supply	Control System & Instrumentation	Testing	YSZ	Membrane	GDL	FFP	MEA	Sensor/Valve /Piping	Design	Material	Other	PHD	MSc	BS
1	Iran Khodro Co.																					3	6	3
2	Taghtiran Kashan Co.																					21	22	23
3	Asre Hidrogen Technology Co.																					2	7	4
4	Arman Saba Sanat Fanavar Co.																					1	3	2

3.3 The role of Academia

Through government-funded basic research, universities and other research institutes can help the cause by seeking out technology seeds, illuminating the basic principles and the degradation process of fuel cells, creating materials databases, and making other contributions. They can further play an active role by creating partnerships with businesses and performing research commissioned by the private sector.

List of universities involved in the FCT research and development are as follows:

- 1) University of Tehran
- 2) Shiraz University
- 3) Khaje Nasireddin Tusi University
- 4) Tabriz University
- 5) Ferdowsi Mashhad University
- 6) Tarbiat Modarres University/ Ceramic Group
- 7) Tarbiat Modarres University/ Chemistry & Physics Science Dep.
- 8) Iran University of Science & Technology/ Material Engineering Dep.
- 9) Iran University of Science & Technology / Green Research Center
- 10) Sharif University of Technology/ Chemical Science Dep.
- 11) Sharif University of Technology/ Chemical Engineering Dep.

In table 3 FC research activities of different universities are shown.

Information sharing between government, industry, and academia

Seen in the light of technological strategies, fuel cell technology is distinctive for the fact that its associated elemental and system technologies span a broad range, and the fact that end use also comprises an assorted array of applications, including power generation for industrial, commercial, and residential use and automobiles. As a result, the challenges that must be overcome are likewise diverse, and thus all issues cannot be easily tackled by a single company or industry working on its own.

In order to successfully work toward fuel cell commercialization, all relevant industries and the government need to suitably divide their roles and engage in organic and systematic efforts in which the overall vision for R&D and market cultivation is shared by every player. It is obvious that the role of government should be descending in proper to increasing capabilities of private sector.

Unfortunately lack of an intellectual work breakdown system for Fuel Cell Research and Development activities leads to duplication between different actors.

Table 3 Universities and their activities

ID	Activities Actors	FC Types					FC Components															Number of Responds		
		PEMFC	PAFC	AFC	MCFC	SOFC	Reformer	Electrolyzer	H ₂ Storage	Catalyst Supply	Control System & Instrumentation	Testing	YSZ	Membrane	GDL	FFP	MEA	Sensor/Valve /Piping	Design	Material	Other	PHD	MSc	BS
1	University of Tehran	■		■									■									1	-	-
2	Shiraz University																					1	2	-
3	Khaje Nasireddin Tusi University			■																		2	4	-
4	Tabriz University	■											■									1	2	-
5	Ferdowsi Mashhad University							■			■											2	-	-
6	Tarbiat Modarres University/ Ceramic Group																			■		1	-	-
7	Tarbiat Modarres University/ Chemistry & Physics Science Dep.													■	■	■		■				2	8	-
8	Iran University of Science & Technology/ Material Engineering Dep.																					4	-	-
9	Iran University of Science & Technology / Green Research Center																	■				1	2	-
10	Sharif University of Technology/ Chemical Science Dep.																					1	3	-
11	Sharif University of Technology/ Chemical Engineering Dep.																					1	1	7

Currently, through these undertakings the government, industry, and academia share understanding on the following roadmap and crucial technological development challenges for FC commercialization, and on the manner in which they, the actors, are to divide their roles.

Statistic Triple Helix in which the sphere of government dominate other spheres and other spheres are separate from each other and do not collaborate, shows the current relationships of these 3 main actors in Iran. (Figure 1)

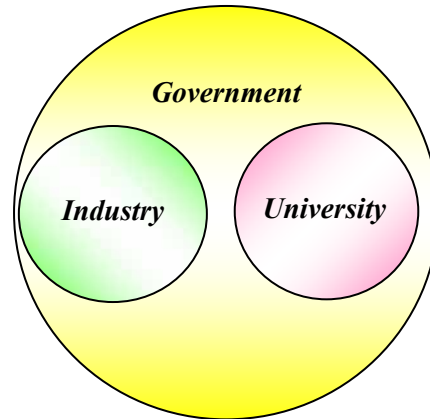


Figure 1 Statistic Triple Helix

Development of FC innovation system in Iran has been organizational problems. One of the most important current problem is undifferentiating between policy making, executing and monitoring organizations. Most of the effective organizations do these 3 functions simultaneously. In 2002 non-official and voluntary committee was established to coordinate the policies and strategies of FC development in Iran. Also in this committee some of ministries were present. Figure 2 shows the current states of organizations are engaged in FC innovation in Iran.

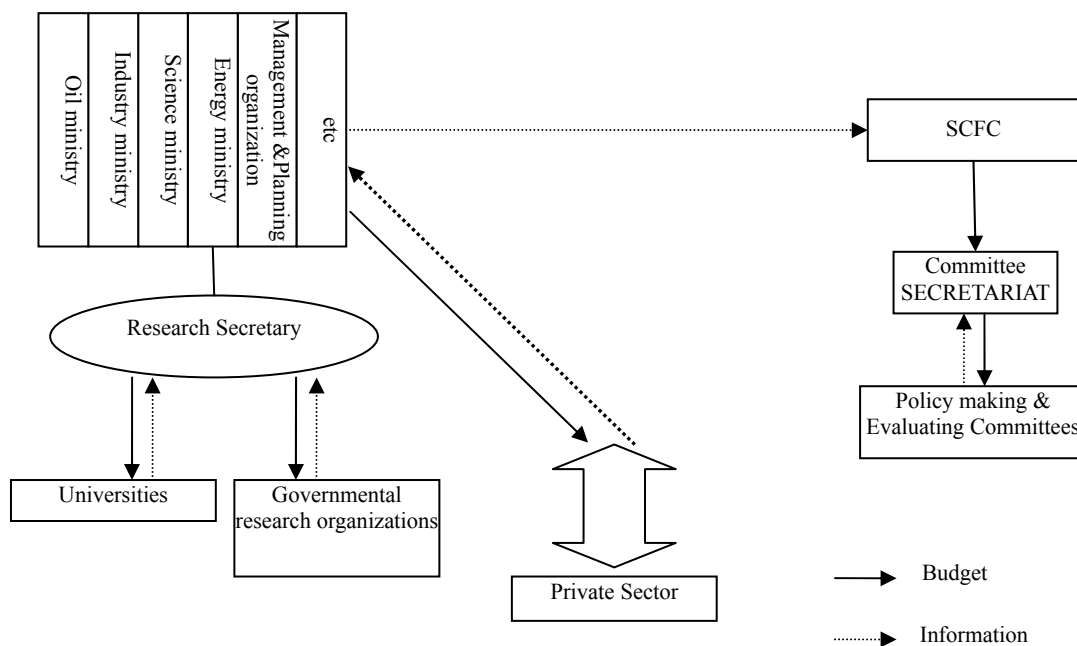


Figure 2 Organization of FC innovation policy making in Iran-Current state

As figure shows, some coordination has been done by this committee, but because another organization specifies the budget so the committee is playing the advisory role in the country. In this regard we suggest that, it should be a monetary linkage between this committee and other organizations to effect policies on them and have the legal place.

4 Conclusion

Considering the role of three main actors of National Innovation System in Iran, we identify three characteristics for this system. The role of government completely dominates the roles of industry and university. In this regard, government has a great share of FC innovative activities in Iran. Beside policymaking, government interferes in many R&D activities. It also supports other actors especially by financial aids. In current system the role of universities restricted to primarily teaching activities and there isn't any organic communication between them. Also the coordination between government and other actors is bureaucratic and to some extent it is a top-down communication.

In this respect we have two suggestions that can accelerate the development of FC technology in Iran.

(i) In order to avoid duplication between different actors, a work breakdown system of R&D activities should be defined between governmental research centers, university labs and industrial R&D centers.

(ii) Monitoring of activities and evaluating them should be pursued to ensure achieving desired progress rate, effectiveness of activities and also documentation of results. In this respect establishing a new national R&D center of FC technology is suggested. Policies of this center will be made by the board of directors elected from SCFC. Also one important mission of this center is pursuing the internal development of FC by focusing on PEM and SOFC technologies.

References

- [1] Chang Y., Chen M., Comparing Approaches to Systems of Innovation: The Knowledge Perspective, *Technology in Society*, 2004, 26: 17-37.
- [2] Economic and Social Commission for Western Asia (ESCWA), *New Indicators for Science, Technology and Innovation in the Knowledge- Based Society*, United Nation, 2003.
- [3] Edquist C., *Systems of Innovation- an Account of the State of the Art*, in Fagerberg J. (eds.), *Understanding Innovation*, Oxford University Press, 2004.
- [4] European commission, *European Innovation Scoreboard*, European commission, 2004.
- [5] Hendry, C., Harborne, P., Brown, J., *Fuel Cell Innovation: A Developing UK Industry? Working Paper Series*, Cass Business School, City University, 2004
- [6] Maeda, A., *Innovation in Fuel Cell Technologies in Japan: Development and Commercialization of Polymer Electrolyte Fuel Cells*, OECD/CSTP/TIP Energy Focus Group Report, November 28, 2003.
- [7] Niosi J., *National Systems of Innovation are "X-Efficient" (and X-Effective)- Why Some are Slow Learners*, *Research Policy*, 2003, 31:291-302.
- [8] OECD, *Managing National Innovation Systems*, 1999.
- [9] OECD, *TIP case studies in innovation*, 2002, available at <http://www.oecd.org/dataoecd/25/45/2495364.pdf>
- [10] OECD Case Study, *Innovation in Fuel cell and Photovoltaic industry in Korea*, available at: www.oecd.org/dataoecd/12/13/31967755.pdf
- [11] *Patents, Innovation and Policy: Fuel Cells and Related Hydrogen Technology in Norway 1990-2002*, Stian Nygaard Division of Innovation Lund Institute of Technology Lund University, Sweden, Paper for the 10th International J.A. Schumpeter Society Conference in Milan 9-12 June 2004
- [12] Salami, R., Mohammadi, M., *Developing a Conceptual Model of National Innovation System for Developing Countries Based on Technological Innovation Indicators*, University of Allameh Tabatabaei, Iran. Euromot 2006
- [13] Stones, R., *UK Innovation Survey, 2001*, available at: www.berr.gov.uk/files/file9673.pdf

* We should note that this research is done by support of "Bonyad Melli Nokhbegan" institute which supports elite Iranian students.