STRATEGIC ANALYSIS FOR A NOT-FOR-PROFIT RESEARCH INSTITUTE

by

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ABSTRACT

The National Research Council Institute for Fuel Cell Innovation (NRC-IFCI) (Vancouver, Canada) is a not-for-profit governmental institution. The NRC-IFCI is a leader in the research and development (R&D) of fuel cells, and maintains a leadership position in the Canadian fuel cell industry. The current economic recession has strongly affected the NRC-IFCI's targeted fuel cell and battery markets, and has required a re-evaluation of strategies. This internal and external strategic analysis provides alternatives for corporative development. The external analysis reviews such targeted markets as fuel cells and rechargeable batteries. The internal analysis evaluates fuel cell and battery development in terms of the resources, strengths and core capabilities in the value creation chain at NRC-IFCI. Alternatives are provided based on an evaluation of a modified research portfolio and external collaborations in order to increase NRC-IFCI business sustainability.

DEDICATION

To my son Mikhail and wife Elena, with love and respect

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List of Abbreviations

AFCC	Automotive Fuel Cell Cooperation
ARRA	American Recovery and Reinvestment Act of 2009
AES	Auger electron spectroscopy
BMW	Bayerische Motoren Werke AG
BD	Broomfield Designers Batteries Co.
B&K	Shanzben B&K Electronics Co. Ltd.
BYD	Build Your Dream Co. Ltd.
CCM	Catalyst coated membrane
DOE	U.S. Department of Energy
DEFC	Direct ethanol fuel cells
DMFC	Direct methanol fuel cells
FC	Fuel cell
FCV	Fuel cell vehicle
EEREO	Energy Efficiency and Renewable Energy
EDERO	Electricity Delivery and Energy Reliability
EURABAT	European Storage Battery Manufacturers
EV	Electric vehicle
GB	Giant Battery Co. Ltd.
GDL	Gas diffusion layer
GHG	Green house gas
GM	General Motors

H_2	Hydrogen
HEV	Hybrid electrical vehicle
HEC	Hydrogen environmental chamber
HQP	High qualified personnel
ICE	Internal combustion engine
IREQ	Institut de Recherche en Electricité du Québec
LANL	Los Alamos National Lab
LG	Lucky GoldStar
MEA	Membrane and electrode assembly
MAB	Metal-air battery
MBI	Matsushita Battery Industrial Co.
MCHP	Micro-combined heat and power
MNE	Multinational enterprise
NiMH	Nickel metal-hydride battery
NiCd	Nickel cadmium battery
NRC	National Research Council
OGD	Other government department
OEM	Original equipment manufacturer
ORR	Oxygen reduction reaction
PEMFC	Polymer exchange membrane fuel cell
PERD	Panel for Energy Research and Development
PHEV	Plug-in hybrid electrical vehicle

PRC	People's Republic of China
RSDT	Reactive spray deposition technology
R&D	Research and development
S&D	Science and development
SMEs	Small and medium enterprises
SOFC	Solid oxide fuel cell
TDP	Technology development program
TEM	Transmission electron microscopy
UPS	Uninterrupted power supply
UTC	United Technologies Corporation
USABT	U.S. Advance Batteries Consortium
VRLA	Valve-regulated design
XPS	X-ray photoelectron spectroscopy
ZAB	Zinc-air battery

1: INTRODUCTION

The National Research Council Institute for Fuel Cell Innovation (NRC-IFCI) (Vancouver, Canada) is a not-for profit governmental institution. It is one of the main architects of national policy in the field of fuel cell (FC) research and development (R&D). NRC-IFCI is the main supporter of the Canadian fuel cell industry. The high cost of key fuel cell components, such as platinum (Pt) based catalysts and Nafion membranes, and an undeveloped hydrogen filling station infrastructure for car fuelling, are the main barriers to widespread FC commercialization. Under these conditions, the U.S. and Canadian governments are re-evaluating national fuel cell policy, reducing investments in this area, and increasing their financial support of other clean energy sectors, such as rechargeable metal-air batteries and supercapacitors. Thus, NRC-IFCI needs to re-evaluate its current strategic plan taking these changes in market trends and national research policy into account. A significant reorganization of the NRC started in 2011 and focused on development of new strategic NRC flagship programs, and this has required substantial changes to NRC-IFCI's current business strategy and its alignment with the new NRC's vision and goals. However, prospective changes in IFCI's priority R&D directions are supposed to remain consistent with NRC-IFCI's FC core competency. This is crucial to support the Canadian high-tech fuel cell industry. For these reasons, the balance between prospective changes and retaining NRC-IFCI's current core competency is one of the challenges facing NRC-IFCI.

Demand for rechargeable metal-air batteries suggests good prospects for the diversification of NRC-IFCI business. These batteries have significant technical advantages. Metal-air batteries (MAB) are inexpensive to produce, have no explosive hazards, provide cheap power, and use no fossil fuel (Linden, Reddy, 2003). Additionally, metal-air batteries are a real substitute for the expensive Li-ion and NiCd batteries used in plug-in hybrid electric vehicles (PHEV/EVs). The development of MABs will be based on an already built FC facility.

The strategic analysis in this project provides a number of alternatives for NRC-IFCI strategic development. The current strategy requires re-evaluation due to the remaining challenges in the main targeted FC market. These market challenges include the high cost of FCs and long commercialization. The external analysis provides a review of the main targeted markets, such as fuel cells and rechargeable batteries, and market trends, an assessment of the competitive environment, and the estimation of future demand. The internal analysis evaluates the role of resources, strengths, and core capabilities in the value creation chain (for FCs and MABs). The evaluation of strategic alternatives provides suggestions for increased NRC-IFCI sustainability and competitive advantage**.** The analysis also includes a description of the implementation of the best alternative through the modification of NRC-IFCI's research portfolio and external collaborations.

2: OVERVIEW: INSTITUTE FOR FUEL CELL INNOVATION

Limited world supplies of fossil fuels, climate change, the demand for energy security and independence, economic development, and the necessity for efficient and reliable power require intensive development of fuel cells and solar batteries. The transition to alternative energy sources is a global trend. It is driven by increasing CO_2 emissions and climate change. The global fuel cell market, according to Energy Business Reports (Energy Business Reports, 2008), will generate more than $18.6 billion in 2013. The revenue is projected to increase to $35 billion annually, if the commercialization of polymer exchange membrane fuel cells (PEMFCs) for the auto industry is fully achieved.

Fuel cells (FCs) have promising technical advantages. Fuel cells are more reliable and require less maintenance than internal combustion engines (ICEs). FCs generate electricity and heat, chemically transferring energy in the process. FCs produce no emissions, are more than twice as efficient as internal combustion engines, charge quickly, operate across a wide temperature range, and work well with other renewable energy sources.

Fuel cells can be divided into five main types: alkaline (AFC), molten carbonate (MCFC), proton exchange membrane (PEMFC), solid oxide (SOFC), and phosphoric acid (PAFC) (Frost and Sullivan, 2008). NRC-IFCI focuses on the development of PEMFCs and SOFCs. The efficiency of a fuel cell vehicle (FCV) can reach the 60-70 mile per gallon (mpg) range, which is several times higher than that achieved by regular cars (with internal combustion engines). This alone promises to reduce gasoline demand and CO_2 emissions of up to 80% by 2050 (Energy Business Reports, 2008).

PEMFCs use a solid polymer exchange membrane, which is permeable to protons and does not conduct electrons. These fuel cells use hydrogen as fuel, which oxidizes on the anode to generate protons and electrons. The hydrogen ions pass through the membrane to the cathode as the electrons flow through an external circuit to produce electric power. On the cathode, oxygen (usually atmospheric) reduces and combines with the electrons and the hydrogen ions to produce water. The main applications of PEMFCs are residential power generators and FCVs. Compared to other types of fuel cells, PEMFCs generate more power for a given volume or weight of fuel cell. Canada currently invests at a high level in the development of PEMFCs, but not in their commercialization.

Solid oxide fuel cells (SOFC) are highly efficient, provide life-time fuel flexibility and emit fewer emissions than PEMFCs. SOFCs also work at higher temperatures (600-800^{o}C). The high temperature tolerance of SOFCs allows for the internal reforming of light hydrocarbon fuels. SOFCs use less expensive ceramic membranes (a solid oxide electrolyte) to conduct negative oxygen ions from the cathode to the anode, producing hydrogen or carbon monoxide following their oxidation. SOFCs are used primarily in stationary power stations.

2.2 Commercialization of Fuel Cells

Fuel cells are the expected long term dominant technology in automotive applications, portable electronic power packs, and residential power stations. PEMFCs are the leading technology in the fuel cell market. Ballard Power Systems Corp. successfully develops high temperature PEMFCs for residential and small stationary markets. The seven main world producers of fuel cell stacks, such as Ballard, Proton Systems, Nuvera, UTC, Toyota, Fuji Electric, and Arotech, supply PEMFCs for the most attractive market segment: fuel cell vehicles (FCVs). However, the popularity of other fuel cells is growing. This includes direct methanol and ethanol fuel cells

(DMFC/DEFC), solid oxide fuel cells (SOFC), phosphoric acid fuel cells (PAFC), and molten carbonate fuel cells (MCFC). UTC, Fuji Electric, and Elenco successfully improved phosphoric acid fuel cells. For example, UTC's PAFCs have achieved a lifetime of 80,000 hours. However, SOFCs are still in the research phase. Back-up and residential power stations are now the main focus of PEMFC and SOFC companies at this early stage of commercialization. Several large companies have been successfully developing DMFCs for portable electronics. Other significant segments of the fuel cell market include applications for transportation, and home and consumer products.

Japanese firms have made significant investments in the R&D of PEMFC and their commercialization. As a result, two out of every three fuel cell patent applications belonged to Japanese companies during the period between 1998-2004 (Green Autoblog, 2010). The Japanese domestic fuel cell market is predicted to grow from 16.3 billion yen in 2009, to 990 billion yen for automobiles and 507 billion yen for housing by fiscal year 2025. In 2018, fuel cell vehicles will compete with hybrid gasoline-electric (Japan Today, 2010).

2.3 History of the Institute for Fuel Cell Innovation (NRC-IFCI)

2.3.1 Foundation of NRC-IFCI

The Government of Canada established the National Research Council (NRC) in 1916. It now has 4,280 full-time employees, 1,200 guest workers, and twenty research institutes and national programs. One of these research initiatives is the Institute for Fuel Cell Innovation (NRC-IFCI). Established in 2002, NRC-IFCI employs 160 scientists and researchers in order to develop future alternative energy sources. They include polymer exchange membrane fuel cells (PEMFC) and solid oxide fuel cells (SOFC). The total NRC-IFCI annual budget is $12.2 million per year. As mandated, the NRC research institute, demonstration site, and industrial partnership facility, serves as the basis for the NRC Fuel Cell Program, and as a gateway to NRC capabilities.. NRC-IFCI developed key performance indicators for operations and strategic planning: financial customer and stakeholder satisfaction), value to Canada (alignment with federal priorities, contribution to economic development), internal business (IP asset of value, employee satisfaction), and innovation and learning. NRC-IFCI externally generated revenue for 2010-2011 is forecast to be $2.7 million, a 35% increase from the period covering 2009-2010 (NRC-IFCI Annual Report 2010-2011).

2.3.2 NRC-IFCI Structure

NRC-IFCI is a governmental institute, with a management team consisting of the General Director, and three additional directors for Business Development, Science and Technology, and Operation & Technology Demonstration. The key Department of Science and Technology consists of three main groups: high temperature fuel cells, low temperature fuel cells, and modeling.

The Low Temperature Fuel Cells Group (LTFCG)

LTFCG consists of three subgroups: catalysts, sensors and PEMFCs. LTFCG developed a new architecture for PEMFCs, fuel cell and air-battery catalysts and supports, and diagnostic sensors. The group has developed devices for the active flow field control in PEMFCs, which improves the cell-to-cell reactant distribution and performance stability. LTFCG is a main participant in the Contamination Consortium as established by NRC-IFCI, in addition to the Ballard and Hydrogenics FC companies. The consortium focuses on fundamental research into contamination problems and related mechanisms in PEMFCs. Specifically, the consortium analyzes performance degradation, making durability predictions through modeling.

The catalyst subgroup focuses on the development of fuel cells and battery catalysts and supports (both carbon and non-carbon). It has several patented technologies for the production of porous carbon spheres and non-carbon supports, and air-cathodes for air-metal batteries. The sensor group specializes in the development of gas and alcohol sensors for fuel cells and any gas related industries.

The High Temperature Fuel Cell Group (HTFCG)

The high temperature fuel cell department has developed the next generation of solid oxide fuel cells (SOFC), providing a means for the direct oxidation of hydrocarbon fuels containing sulphur and other impurities. The developed SOFCs have optimized resistance, thermal conductivity, and low operating temperatures. The key elements of SOFCs are cost efficiency, high performance, and reducing degradation <1% per 1000h. HTFCG develops the fabrication process for novel materials. The developed reactive spray deposition technology (RSDT) allows for easy scale-up, and for the production of a wide range of high performance materials with low cost precursors and low energy consumption. Clean fuel generation is one of the main directives of HTFCG. The hydrogen generator (Power on Demand H_2POD) can supply hydrogen for PEMFCs over a continuous period. HTFCG has a wide network that includes domestic and international partners (U.S., Europe, Japan, and India).

The Modeling and Numerical Simulation Group (MNSG)

The Modeling and Numerical Simulation Group (MNSG) provides the fundamental knowledge and technologies to design fuel cells and other clean energy applications. Through partnerships with universities and industrial partners (Ballard, AFCC, Hydrogenics, Nissan, and Tekion), MNSG has achieved a world-class reputation in the research of microstructure formation and mass transport phenomena in PEMFCs. Also, the group actively develops models for renewable energy industries (batteries and supercapacitors). The core competency of MNSG includes solid and fluid computational mechanics, and physical modeling of electrochemical phenomena, energy transfer, and failure modes. The Group uses process modeling to perform "what-if" analyses of fuel cells and battery test stations.

The Advanced Testing and Validation Centre (ATFC)

The ATFC creates a specialized and safe environment for the objective and standardized independent assessment and validation of fuel cells and other clean energy technologies. The ATVC provides a wide range of fee-for-service test equipment by highly professional engineering personnel. This testing range includes fuel cell and battery test stations, hydrogen environmental chambers, and vibration tables. Fuel cell stations with power of 0.5-5kW automatically provide the test data. The hydrogen environmental chamber (HEC) provides a characterization of full-sized electrical vehicles and other clean energy products in various simulated climatic conditions. Supported by the Canadian Hydrogen and Fuel Cell Association (CHFCA), Western Economic Diversification Canada, and governmental services, ATFC supports its industrial partners in the clean energy cluster and the commercialization of their innovative products.

2.3.3 NRC-IFCI's Business Model and Strategies

NRC-IFCI has the following key performance indicators for operative and strategic planning: financial, customer and stakeholder satisfaction, value to Canada (alignment with federal priorities, contribution to economic development), internal business (IP asset of value, employee satisfaction), innovation, and learning. The current distribution of available resources for its core competency development projects, value chain projects, and potential new collaborative projects is 40% for clean energy, 40% for fuel cells, and 10% for wear and corrosion (Table 2-1). NRC-IFCI uses a Project Evaluation model for the prioritizing and selecting above-mentioned R&D projects. This procedure was developed in the SFU Business School (Sharma, 2006).

The main risks of the current NRC-IFCI business plan include technological obsolescence and overestimation of the size of the fuel cell market. Current fuel cell market stagnation required a change in strategy in 2010-2011. Table 2-1 shows a real location of resources to clean energy development in NRC-IFCI (NRC-IFCI, 2010). The first strategic analysis for NRC-IFCI was carried out in the SFU School of Business in 2005 (Sparrow and Whittaker, 2005). The technology roadmap and resources allocation methodology and research portfolio mapping tools were developed in this work. It helped NRC-IFCI with limited resources to select an optimal strategy of FC development and to build core competencies and key capabilities in 2005. Since that time, the fuel cell market significantly extended and the initial commercialization of FC technology in FCVs and stationary applications has been achieved. However, NRC-ICFI significantly diversifies its business now according to the NRC reorganization and new market conditions. Therefore, this project presents a new strategic analysis for NRC-IFCI.

2.3.4 Partnerships and Networking

NRC-IFCI is a key partner of industry and academia with alliances with the BC Clean Energy Technology Cooperative, SOFC Canada, and the International Partnership for a Hydrogen Economy, the National Program on Fuel Cells & Hydrogen, the Fuel Cell

Table 2-1. Allocation of NRC-IFCI's Resources

Fuel cell technology development		**Clean energy technology development**				**Wear & Corrosion**
50%		40%				10%
Low Temperature Fuel Cell (PEMFC)	High Temperature Fuel Cell (SOFC)	Energy storage (metal air batteries, supercapacitors)	Smart grid	Clean fuels	Greening of conventional energy (wood, coal, oil sands)	-

Source: by author, adapted from NRC-IFCI Annual Report 2010-2011

Research Centre, and the Panel for Energy Research and Development (PERD). NRC-IFCI is an internationally recognized organization that has built international partnerships with leaders in the development of fuel cells in Europe, France, Asia, India, China, Taiwan, the United States of America (U.S. Department of Energy [U.S.DOE]), Los Alamos National Lab (LANL), and Concurrent Technology Co. NRC-IFCI was one of the leaders in the Fuel Cell and Hydrogen Technologies Cluster Initiative, which has grown to include eight BC companies over the past ten years. NRC-IFCI provides support for the Cluster Initiative for local small and medium enterprises (SMEs) with its world class R&D capacity, training of high qualified personnel (HQP), and joint research and commercialization coordination. Using the Cluster Initiative platform, NRC-IFCI partners and collaborates with BC-based technology SMEs to develop technologies, including fuel cells, to provide services that enable the clean energy industry to grow and successfully compete in global markets.

2.3.5 NRC-IFCI's Core Competencies and Technological Development

NRC-IFCI has the following core competencies: the ability to develop advanced materials and processing, novel architecture design, modeling and numerical simulation, sensors and diagnostics development, prototyping and systems testing. The main technological focus of NRC-IFCI is in the development of novel PEMFCs, direct alcohol fuel cells and SOFC, hydrogen and alternate fuels production and storage. The science and technology of NRC-IFCI is based on collaborations with industrial partners (fee-for-service, value chain, collaborative projects with industrial partners and other government national labs and universities in the USA and Asia), and participation in such national programs as the Technology Development Program (TDP) and other government department (OGD) projects. One of the key science and development (S&D) programs of the Canadian Government where NRC-IFCI is involved is the National Fuel Cell Program. This program supplies advanced catalysts on non-carbon supports for the next generation of high temperature PEMFCs, allowing for commercialization without technology challenges.

2.3.6 NRC-IFCI's Capabilities

NRC-IFCI's main capabilities include specialized equipment and HQP for the running of thirteen modern, specialized chemical labs, fuel cell test stations of up to 5 kW, a mechanical shop for the fabrication of hardware, and facilities for the fabrication of membrane electrode assemblies and catalysts. NRC-IFCI has technology demonstration and industrial incubation facilities and capabilities, such as a hydrogen environmental chamber (HEC), Pacific Spirit Filling Station, solar hydrogen generation photovoltaic panels, two stationary 5 kW building–integrated SOFC generators, and five Ford Focus fuel cell vehicles for testing. To date, NRC-IFCI has achieved PEMFC development in the following areas: the fabrication and characterization of membrane electrode assemble (MEA), and the ability to analyze such failure modes as contamination and microstructural changes, cells and stacks, in-situ/ex-situ measurements, diagnostics, modeling and simulation, sensor and catalyst development.

3: VALUE CREATION PROCESS IN THE FUEL CELL AND RECHARGEABLE BATTERY INDUSTRIES: EXTERNAL ANALYSIS.

3.1 NRC-IFCI Targeted Businesses

The position of NRC-IFCI in the market is easier to understand on the basis of an analysis of the key industries in the clean energy sector where NRC-IFCI operates. NRC-IFCI specializes in fuel cell technology development (50% PEMFCs and SOFCs), clean energy development (40% batteries, supercapacitors smart grid), and wear and corrosion (10%) (NRC-IFCI business plan 2010-11 [2010]).

The global fuel cell market, according to *Energy Business Reports,* will generate more than $18.6 billion in 2013 ($35 billion at the commercialization of PEMFCs in the auto industry), and 120,000 fuel cell vehicles (FCV) are expected to be launched by 2020 (Energy Business Reports, 2008). FCVs pertain mainly to buses and cars, where buses are likely the closer niche market with specific needs, price range, and production quality.

The first large scale fuel cell stack plant (10,000/year) will be built by Daimler-Benz in Burnaby (British Columbia, Canada) in 2012 (Green Autoblog, 2011). This investment confirms the key role of NRC and the BC cluster as world-class fuel cell research centres. NRC-IFCI's specialized facilities, qualified personnel, and achievements also affected Daimler AG's (parent company of Mercedes-Benz) decision. The fuel cell market has two end-user segments: electric transportation and stationary fuel cell applications (Table 3-1).

The NRC-IFCI's second target is the rechargeable batteries for electric vehicles and portable electronics industry. Boston Consulting Group predicts a $25 billion market for electric car batteries by 2020 (Batteries for Electric Cars, 2010). NRC-IFCI recently began developing components of rechargeable batteries and plans to extend its R&D to the development of rechargeable metal air-batteries. Cell manufacturers want to differentiate their technologies based on innovative R&D. Therefore, they are looking for new technologies and partners for innovative developments.

Table 3-1.PEMFC Applications

Stationary fuel cell applications		Fuel cell electrical transportation applications
Type	Goal	
Emergency power systems	Backup power supply when regular systems fail for residential homes, hospitals, etc.	Hybrid and fuel cell electrical vehicle (Honda CLX Clarity, GMC Sequel, Ford Edge)
Uninterrupted power supply (UPS)	Power supply in the absence of utility power, remote power / off grid power	Fuel cell forklifts or trucks used for lifting and transporting materials
Cogeneration	Using power and waste heat (Micro combined heat and power - (MCHP) can be beneficial in residential fuel cells)	Fuel cell buses

Source: by author, adapted from Frost and Sullivan, 2008

NRC-IFCI should use this trend to effectively collaborate with Canadian and international cell manufacturers (Batteries for Electric Cars, 2010). An analysis of two industries, fuel cells and rechargeable batteries, is discussed in the remainder of Chapter 3.

3.2 Structure of the Fuel Cell and Battery Industry

NRC-IFCI develops fuel cells and batteries, so an analysis of its possible value position in the chain of related industries helps to define its clients and partners. The value chain of electric-car fuel cells and batteries consists of eight steps: R&D, component production, cell production, module production, pack-assembly, vehicle integration, use, and reuse (Fig.3-1, 3-2).

Research organizations in the clean energy sector are seeking opportunities to occupy positions in the value chain for electric-vehicle fuel cells and batteries. It is very important for them, as they have limited capabilities for the scale-up and commercialization of their products. On the other hand, manufacturers of fuel cells and batteries are looking for innovative products and technologies to commercialize and differentiate their product portfolio. Therefore, the strategic vision of a scientific organization, in a value chain of product production, is one of the main reasons for the successful commercialization of their developments.

3.3 Overview of External Analysis

This analysis of the current situation, trends, and future of the targeted industries is a key element for the strategic planning of future R&D, and collaborations and strategic alliances for scientific organizations, such as NRC-IFCI. This analysis is based on the assessment of the seven competitive forces acting in industry (Porter, 1979). For the purposes of this analysis, two additional forces, the power of government and complementors,

Fig.3-1. Position of Organizations in the Value Chain for EV Rechargeable Batteries

Value Chain for EV Rechargeable Batteries →

1.Stages of the Value Chain							
R&D of Component Design, Hardware	**Compo-nent Produc-tion**	**Cell Pro-duction**	**Module Produc-tion**	**Pack As-sembly**	**Integra-tion of Batter-ies with Vehicle Inter-face**	**Use**	**Reuse & Recy-cling**
Battery compo-nents, de-sign, proto-type	Producers of electro-des, sepa-rator etc.	Production of single cells	Assembling of single cells into large mod-ules	Pack as-sembling	Integra-tion of batteries	Use	Recycling
2. Position of organizations in the Value Chain							
Research institutes (NRC-IFCI, etc)		**MNE battery manufacturers (Sony, Panasonic, Toshiba, Sam-sung, LG)**			**GM, Honda, Fiat, Volks-wagen, Ford, Nissan, Fiat**	**Consumers**	**Specialized companies**
Chemical companies (TKK, BASF, LG)							

Source: by author, adapted from Frost and Sullivan, 2007

Fig.3-2. Position of Organizations in the Value Chain for Fuel Cells

Value Chain for Fuel Cells							
1.Stages of the Value Chain							
R&D of FCs	**Production of basic components**	**Production of FC components**	**Production of unit cells**	**FC stack assembly**	**Fuel Cell Stack Integration**	**Use**	**Reuse & Recycling**
Development of FC design, hardware and prototypes	Basic materials (platinum, carbon etc.)	Basic components (catalysts, membranes, GDL, CCM)	Production of unit cells	PEMFC stack assembling	Integration of FCs with vehicle interface	Use	Reuse and recycling
2.Position of organizations in the Value Chain							
Research institutes (e.g. NRC-IFCI, U.S.DOE National Labs)	**Dow Chemical, 3M etc.**	**DuPont, Gore & Associated, 3M, BASF, ETEK, FUMA**	**Ballard, Nuvera, Hydrogenics, UTC, Nissan, Toshiba**	**Ballard, Nuvera, Hydrogenics,UTC, Nissan, Toshiba, Delphi.**	**Honda, Toyota, Daimler,GM, Ford, Renault-Nissan, Fiat**	**Consumers**	**Specialized companies**

Source: by author, adapted from Frost and Sullivan, 2008

were applied to the Porter analysis, as they are very important for the understanding of market trends (Weimer and Vining, 1999; Brandenburg and Nalebuff, 1996,).

NRC-IFCI is pursuing two types of businesses: fuel cell (PEMFC, SOFC) and clean energy technology (batteries, supercapacitors, and smart grid) development. The focus of NRC-IFCI in this area includes the development of PEMFC design, and components such as novel membrane electrode assemblies (MEA), durable catalysts, sensors, diagnostic methods and metal- air battery components.

3.4 The Fuel Cell Industry

3.4.1 Overview of the Fuel Cell Industry

The fuel cell industry has significant potential with the continuous growth of oil prices forecasted to double in the next 10-14 years (Frost and Sullivan, 1998)), and industry resource limitation. Expected world fuel cell market growth will be $8.5 billion with Canadian corporate cash revenues to be $133 million by 2015 (Science Metrix, 2008). Fuel cell vehicles (FCV) will decrease foreign oil dependency and increase national security for the majority of countries. The current focus on the reduction of green house gas emissions (GHG) by developed nations also serves to bolster the need for PHEVs. The main producers of fuel cell stacks are Ballard (55%), UTC (15%), Proton Systems 7%), Toyota (11%), Fuji Electric (4%), and Nuvera (4%) (Frost and Sullivan, 2008). However in 2012, one of the largest manufacturers of FC stacks will be Daimler-Benz when its large scale FC stack plant (10,000/year) in Burnaby (Canada) completed (Green Autoblog, 2011).

The most expensive element of fuel cells is the electrode, which comprises 50% of total fuel cell cost due to high platinum loading. The mass commercialization of fuel cell vehicles is possible when the platinum loading decreases four-to six-fold. The mass production of fuel cell vehicles is expected in 2018 (62,000/year) after the creation of the hydrogen infrastructure (Frost and Sullivan, 2008). In 2012, 70% of fuel cell cars will use PEMFCs using compressed hydrogen (82% of total fuel used in FC).

3.4.2 Significant Rivalry

By 2020, 120,000 fuel cell vehicles (FCV) are expected to be launched, and Honda, Daimler and Toyota might be earlier adopters in this market. The main developers of FCVs are arranged in the order of their advantage in FCV commercialization: Honda, Toyota, Daimler, General Motors (GM), Ford, Renault, Nissan, Fiat, and Volkswagen (Energy Business Reports, 2008). An expensive and complicated R&D process pushes the original equipment manufacturers (OEMs) to establish alliances for the joint R&D of FC stacks. For example, Ford, Daimler, and Ballard Power Systems established the Automotive Fuel Cell Cooperation (AFCC) for the development of PEMFCs for automotive applications. A majority of OEMs have their own R&D programs for the development of FCVs such as the Toyota Fuel Cell Program, General Motors Fuel Cell Activity, Daimler Fuel Cell Program, Hyundai Clean Energy Program, and Nissan Looking Ahead.

Toyota and Honda were the first companies to develop commercial hydrogen fuel-cell vehicles in 2002. Honda was the first original equipment manufacturer (OEM) to commercialize a FCV in 2010, along with a very economical hydrogen station for home use. One of the main constraints in the development of fuel cell cars is the limited hydrogen infrastructure. The creation of the hydrogen infrastructure with governmental support will increase the launch of FCVs by 20 million in 2020 (Energy Business Reports, 2008).

Honda first developed and commercialized the innovative Honda Solar Hydrogen Station. It is a solar-powered water electrolyser generating hydrogen and oxygen (the last released to the atmosphere), which fills the car tank in five minutes at 5000 psi. This offers a significant decrease from the current $1.6M cost of a single hydrogen station. More importantly, Honda developed the vertical 100kW V Flow stack that works with a Li-ion battery. The Li-ion battery saves kinetic energy with regenerative braking, and provides a buffer between the acceleration of the electric motor and the necessary time for the FC to support this acceleration. Toyota began development of FCVs in 1992. In 2010 Toyota, using Sun Hydro's solar hydrogen generators tested their ten FCV Highlanders. The company plans to launch a production of these FCVs in 2015 (Green Autoblog, August 30, 2010). Toyota plans to leverage its R&D by cooperating with Daimler and Tesla.

Daimler has developed a FCV in 1994 and has already spent $1.23 billion on fuel cell technology to develop affordable hydrogen-powered vehicles. GM and The Gas Company have built 20-25 hydrogen filling stations on Oahu in Hawaii (Green Autoblog, 2010). Ford and Bayerische Motoren Werke AG **(**BMW) have both pursued hydrogen ICEs using traditional piston engines. BMW actually uses liquid hydrogen as a fuel while virtually every other automaker prefers compressed gaseous hydrogen. BMW has also built a run of one hundred seventh-series sedans that is actually dual fuelled, with the ability to run on either hydrogen or gasoline. Mazda has followed a different path, choosing to use its Winkle rotary engines as the basis for its hydrogen ICE work.

3.4.3 The Significant FC Substitute Threat

FCs in electrical vehicles face a significant threat from rechargeable NiCd and Li-ion batteries, or metal-air batteries such as zinc-air rechargeable batteries (example with ReVolt rechargeable batteries, Fig. 3.3) in hybrid vehicles and plug in hybrids (HEV/PHEV) (i.e. Toyota Prius, Honda Civic, and Chevrolet Volt) (ReVolt, 2010). The main advantages of zinc metal-air batteries in comparison with PEMFC and Li-ion batteries are outlined in Table 3-2. Batteries already dominate the HEV/PHEV/EV marketplace, an existing technology that presents a significant challenge to PEMFC adoption by automakers. However, an analysis of the comparative weights of a Li-ion battery (830 kg) versus a FC (125kg) as energy storage for EVs running 300 km shows the necessity for multiple solutions, or a combination of solutions for different applications (Abuelsamid, 2009).

3.4.4 Moderate Bargaining Power for Suppliers

Suppliers of materials for the manufacture of FCs are divided into four main groups: suppliers of basic materials, basic FC components, assemblies and systems, and fuel cell stacks. Fig. 3-3 shows the supply chain of the main producers of components for FCs for FCVs. For example, UTC Fuel Cells has a unique position, as it produces all of the main FC components and systems. Toyota, Mitsubishi, and GM combine the fuel stacks, fuel processors, and overall system integration. The suppliers of fuel stacks have a more powerful position as they integrate all of the main FC components. These components are catalysts, membranes, gas diffusion layers, catalyst-coated membranes (CCM), membrane electrode assemblies (MEA), and control equipment (temperature, current/voltage, humidity). The cost structure of fuel cells shows that more than 60% of the total cost relates to catalysts (e.g., the expense of platinum) and membranes.

The main type of membranes used in PEMFCs is Nafion, which was developed and patented by the largest chemical corporation, DuPont. Platinum price depends on a lot of factors in the market. In additional to DuPont's control of the membrane supply, De Beers Consolidated Mines (S. Africa) and Norilsk Nickel (Russia) have the largest share of the Pt market. Widespread commercialization of fuel cells is slow to take off due to the high costs of Pt-based catalysts and membranes (Nafion ®).

There is, however, hope of reducing the cost of the catalysts through new technical approaches. Large investments in the development of a cost effective catalyst by the U.S.

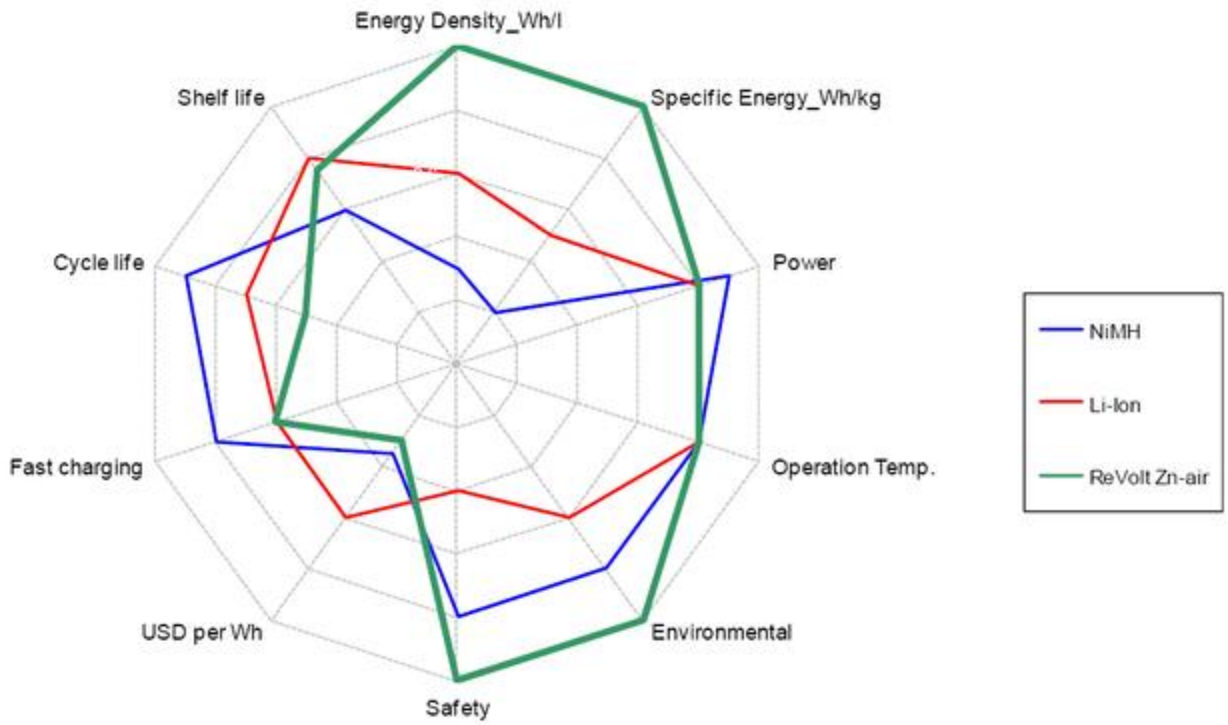
Table 3-2: Advantages of Zinc-Air Batteries (ZAB) Over PEMFCs and Li-ion Batteries

Li-ion batteries	**PEMFC**	**ZAB**
Plentiful resource	Fossil fuel sourced	No fossil fuel sources
High energy density 1353 Wh/kg (theoretical) vs. 160Wh/kg (theoretical) for Li-ion	Inexpensive to produce	Inexpensive to produce
No explosion	Purchased from special outlet	Purchased at retail outlets
-	Fire/Explosive hazard	No explosive hazard
-	Compressed gas	Metal slurry
-	Can be produced from Electrolyser	Recycle through electrolysis
-	No indoor application	Indoor application
-	Immature metal hydride storage technology	Storage in plastic container

Department of Energy has led to a new generation of durable and cost effective catalysts with a hierarchical structure demonstrating the highest oxygen reduction reaction (ORR) mass activity (1170 mA/mg_{Pt}, LANL). In addition, a catalyst with a Pt shell in combination with palladium on carbon (Pd/C) also showed a promising mass activity of 350mA/mg_{Pt} (Brookhaven DOE National Lab) (U.S. DOE [2010]). These labs work closely with leading catalyst manufacturers to increase their commercial potential (U.S. DOE, 2011).

Another expensive component of FCs is the polymer membrane at \$600-800/m^2

Fig.3-3: Comparison of NiMH, Li-Ion and Revolt's Rechargeable Zinc-Air Batteries



Source: Revolt, 2010

(Nafion®), the main manufacturer of which is DuPont. DuPont's Nafion® membrane has been the most widely used membrane during last ten years in spite on its high cost. Now other producers of polymer membranes are trying to develop cheaper membranes to replace Nafion®.

3.4.5 Limited Effect of Buyers

Although there have been demonstration fleets of fuel cell buses and fuel cell cars, the first FCV on the consumer market, the Honda FCX, only launched in 2010. Therefore, consumer awareness of FCVs is limited. Furthermore, FCV demand is constrained due to the overall high price of FCVs, and the cost of hydrogen gas station construction. Consumers wait for the appearance of a developed hydrogen infrastructure. Some automakers such as Volkswagen, Daimler and Toyota use direct methanol fuel cells, thus increasing the attractiveness of FCVs in the absence of a hydrogen gas station infrastructure. The development of the Honda Solar Hydrogen Station for home use significantly increases the potential demand for FCVs. The solar batteries of these stations charge during daylight hours and provide electrical energy for the electrolysis of water into its elemental components of hydrogen and oxygen. Hydrogen is then accumulated in special tanks.

In summary, consumer buying power in the short term is low, but is projected to experience moderate growth with the mass production of FCVs set for 2018 (Energy Business Reports, 2008).

3.4.6 Threat of New Entrants

The development and manufacture of PEMFCs requires significant investments in R&D and in highly qualified personnel. The history of Canadian-developed Ballard Power Systems during the last eighteen years has showed that in spite of significant investments from the Government and private sectors, the company could not develop economical FCs for the auto industry. In 2007, the company completely shifted its focus from FCVs to the development FCs for forklifts and stationary electrical generators. The main automakers also started their own expensive FCV development programs. However, the mass production of fuel cell electric-cars by a majority of automakers is not expected until at least 2018 (Frost and Sullivan, 2008). Thus, all these factors mean the threat of new entrants is weak in the short term and medium over the long term.

3.4.7 Significant Governmental Regulation

In the FCV market, government support plays an important role as the private sector does not have the financial resources for the development of new products and the commercialization of a hydrogen infrastructure. Main governmental regulation of the hydrogen infrastructure includes the standardization of safety protocols, and financial support for OEM R&D toward the development of new generation, low cost FCVs and their components. Governments of different countries have established special programs and consortia for the cooperation of automakers and FC component developers and associations (renewable energy, fuel cells, and fuel cell infrastructure).

The Canadian Hydrogen and Fuel Cells Association, Canadian Transportation Fuel Cell Alliance (CTFCA), and Hydrogen Early Adopters are the main programs established by Canadian Government for the development of a hydrogen infrastructure (e.g., the Pacific Hydrogen Highway) and the commercialization of FCVs in Canada.

The Clean Energy Partnership (CEP) has been established in Europe to encourage European auto manufacturers and oil companies to work toward FCV commercialization. Clean Urban Transport for Europe (CUTE 2001-2006) and the HyFLEET: CUTE project financed the launch of 200 hydrogen powered vehicles. The U.S. Department of Energy established the Freedom Car program to encourage cooperation between automakers and federal agencies (i.e., national research labs, etc.) for the commercialization of FCVs by 2012-2014. The Freedom Car goal is to lower the FC stack cost to $30/kWh.

Japan Hydrogen and Fuel Cell Demonstration Projects (JHFC) is one of the more successful governmental programs for the support of FCV commercialization. Honda and Toyota demonstrated the first FCVs in 2002. Nissan launched Nissan's FCV X-Trail in 2007. In 2010, Honda launched the first certified FCV on the consumer market.

3.4.8 The Significant Role of Complementors

Electric transportation is the main segment of fuel cells (PEMFCs). However, the development of this segment significantly depends on the development of a hydrogen refuelling station infrastructure. As previously noted, the number of companies providing these stations (complementors) is limited due to the necessity of significant investment. Hydrogen gas stations should be placed every two kilometres in a city, and every ten kilometres along a highway. With a hydrogen infrastructure that requires significant investment of over a million dollars per station, complementors strongly affect the competitive structure of this industry (Frost and Sullivan, 2008). The absence of the developed infrastructure of hydrogen refuelling stations is one of the main barriers of FCV market expansion.

3.4.9 Summary of the Fuel Cell Industry Analysis

Analysis of the fuel cell industry shows a competitive environment, which increases due to the development of fuel cell electric vehicles by almost every automaker (Table 3-3). Several companies such as Honda, Toyota, Mercedes, GM, and Ford launched their first FCVs during the last few years. Mercedes announced its plan to build the first large scale plant to produce fuel cell stacks in Burnaby, British Columbia, Canada, in 2012 (Green Autoblog, 2011). The mass production of fuel cell electric-cars by a majority of automakers is projected to start after 2018 (Frost and Sullivan, 2008). The threat of rechargeable batteries as a fuel cell substitution is high as current hybrid and electric vehicles already use rechargeable NiCd and Li-ion battery technology. The bargaining power of suppliers is moderate due to the limited production of fuel cells. This power is higher for specialized, medium-sized companies than for multinational corporations due to different volumes of purchased raw materials. The necessity of significant investment and technological capabilities in the commercialization of fuel cells determines the low threat of new entrants in the short term and moderate in the long term. Governmental regulation is powerful due to the tax rebate structure to encourage the purchase of new FCVs. These rebates have already significantly increased sales. The power of companies (complementors) supplying the hydrogen refuelling stations is high as the successful commercialization of fuel cell electric cars is not possible without a hydrogen refuelling station infrastructure.

3.5 Battery Industry Overview

This section outlines the results of the battery industry analysis with the addition of two forces: the power of government and that of complementors. The additional last two forces are very important for understanding market trends. For example, there are different growth rates of HEV and EV segments in the U.S. and Europe due to varying governmental support of HEV and EV sales.

3.5.1 Segmentation of the Rechargeable Battery Market

3.5.1.1 Segmentation of the Rechargeable Battery Market by Chemical Composition

The rechargeable battery market currently comprises four chemistries: lead-acid, nickel-cadmium (NiCd), nickel-metal hydride (NiMH), and lithium-ion (Li-ion).

Li-ion Batteries

The rechargeable battery market experienced a compound annual growth rate (CAGR) of 13% from 2004 to 2008, with a CAGR of 10% for lead-acid, and 20% for NiCd, NiMH,

Table 3-3: Effect of the Competitive Forces on Fuel Cell Industry

Competitive Force	Short Term	Long Term
Bargaining power of suppliers	Low	Medium
Threat of substitutes	High	Medium
Threat of new entrants	Low	Medium
Power of Government	High	Medium
Power of complementors	High	Medium

Source: by author

and Li-ion batteries in 2007-2008 (SBI Energy, 2009). World distribution between the different types of rechargeable battery chemistries is as follows: 61% for lead-acid (mainly for the auto industry), 37% for portable electronics (of which 75% Li-ion, 12% Ni-Cd, 13% Ni-MH comprises this segment), 2% for hybrid vehicles (Ni-MH), and 1% for large-scale batteries (SBI Energy, 2009) In spite of the long-dominant position of lead-acid rechargeable batteries, the focus in this analysis is on NiCd, NiMH, and Li-ion batteries. These batteries are of interest due to positive market growth and some of them, such as NiMH and Li-ion batteries, are already replacing lead-acid batteries in the automobile industry. Moreover, lead-acid batteries are environmentally “unfriendly” due to the high amounts of toxic lead. By comparison, the amount of cadmium in easily recycled NiCd batteries is considerably lower.

Lead-Acid Batteries

Market-dominant lead-acid rechargeable batteries were the first widely available commercial batteries with a market share reaching 60% (SBI Energy, 2009). Lead-acid batteries have a valve-regulated design (VRLA) in which the lead electrodes turn into lead sulphate during discharge. They are not applicable for HEVs due to their low specific energy. Rechargeable batteries for HEVs/EVs need to have high specific energy (energy per battery unit volume), which determines the operating duration of the device where used. The operating duration of lead-acid batteries is 100 times less (12 kWh/kg) as compared to the best batteries. The specific power of a battery is responsible for the acceleration of an electrical engine. A gasoline engine, by comparison, is only 150-400Wh/kg. Table 3-4 presents the main technical characteristics of lead-acid batteries. The advantages of lead-acid batteries include: reliability and simplicity of design, durability, low self-discharge, low maintenance, and have a high discharge potential. But these batteries have many disadvantages as well: uncontrolled discharge, a poor weight-to-energy density ratio limits usage to stationary applications, a limited number of full discharge cycles, environmentally hazardous, transportation restrictions due to the potential for electrolyte-sulphuric acid spillage, thermal runaway, and reduced performance at low temperature.

NiCd Batteries

Alkaline nickel-cadmium (NiCd) batteries, invented in 1899 by W. Jungner, consist of two types: sealed and vented. These batteries use cadmium as the negative electrode and nickel oxyhydroxide (NiOOH) as the positive electrode. Table 3-4 presents the technical characteristics of NiCd batteries.

There are many advantages to NiCd batteries: a fast and simple discharge despite prolonged storage, a high number of charge/discharge cycles (up to 1,000 cycles), stability at low temperatures, simple to transport and store, are the most rugged rechargeable battery, have the lowest cost per cycle, and are available in a wide range of sizes and performance options. However, NiCd batteries have a number of disadvantages: low capacity (up to 50% less that NiMH, and one-fourth of that of Li-ion batteries), low energy density, charging memory, environmentally hazardous due to the cadmium content. Furthermore, the production of NiCd batteries is declining as a result of stringent regulations restricting the use of cadmium in many countries. The Environment Directorate of the European Commission, along with certain Nordic countries, has limited the use of NiCd batteries. These batteries are popular in portable electronics, emergency medical equipment, professional video cameras, and power tools. However, the NiCd battery market is shrinking due to its poor price-performance ratio as compared to other battery chemistries. In 2009, the sales of NiCd rechargeable batteries decreased by 43% in the portable electronics segment (SBI Energy, 2009).

Nickel Metal Hydride (NiMH) Rechargeable Batteries

When the first commercial NiMH batteries appeared on the market in 1989, the Japanese company G.S. Yuasa developed the first high-energy paste electrode technology for these batteries that determined their commercial success. These batteries dominate the HEV/EV market with a 97% market share. NiMH technology uses a hydrogen-absorbing alloy for the negative electrode

Table 3-4: Technical Characteristics of Lead–Acid, NiCd, NiMH, and Li-ion Batteries

Characteristic	Battery			
	Lead-acid	NiCd	NiMH	Li-ion
Specific energy, Wh/kg	30-40	40-60	30-80	100-250
Energy density, Wh/L	60-75	50-150	140-300	250-360
Specific power, W/kg	180	150	250-1000	250-340
Charge/discharge efficiency,%	50-92	70-90	66	80-90
Self-discharge rate, % /month at T=20^{o}C	3-20	10	10	8% (at10^{o}C)
Energy/consumer price, Wh/ US$	3-20	-	2.75	1.5
Cycle durability, cycles	500-800	2000	500-1000	1200
Nominal cell voltage, V	2.1	1.2	1.2	3.5-3.6

Source: Gates Energy products, 1997; Cowlishaw, 1997; Power Stream, 2009

and nickel oxyhydroxide (NiOOH) for the positive electrode.

There are many advantages to NiMH batteries than NiCd batteries: 40% higher capacity than Ni-Cd batteries, less prone to memory development, two to three times the capacity of an equivalent, and absence of any poisonous components However, compared to Li-ion batteries, the energy density of NiMH is lower and the self-discharge rate is higher. Table 3-4 shows the main technical characteristics of the NiMH batteries. Conversely, there are disadvantages. For example, NiMH battery performance decreases after 200 cycles at high load currents, and the self-discharge of NiMH batteries is one-and-a-half to two times greater as compared to NiCd batteries. The hydride improves hydrogen bonding and reduces the corrosion of the alloy. New chemical additives improve self-discharge. NiMH batteries are complex and require carefully controlled, prolonged trickle charging. Finally, NiMH batteries are difficult to maintain. They require full discharge to prevent the formation of crystals.

Li-ion Batteries

Lithium-ion (Li-ion) batteries, developed by M.S. Whittingham at Binghamton University in the 1970s, operate on the basis of lithium ions moving from the negative electrode to the positive electrode during discharge, and in the opposite direction when charging (Gates Energy Products, 1997). Table 3-4 shows the main technical characteristics of Li-ion batteries. The advantages of Li-ion battery technology include: a wide variety of shapes and sizes, much lighter than other rechargeable batteries, and have high open circuit voltage in comparison to aqueous lead-acid, NiMH, and NiCd batteries. Open circuit voltage increases the power that can be delivered at a lower rate of current. Additional Li-ion battery advantages include no memory effect, and have a low self-discharge rate of 5-10% per month compared to a rate of over 30% per month for NiMH batteries. There are some disadvantages to Li-ion batteries including: high price, thermal runaway and cell rupture in older batteries during charging cycles, and less durability than NiMH and NiCd batteries. About 1% of Li-ion batteries are recalled due to safety concerns.

3.5.1.2 Market Segmentation of Rechargeable Batteries by End User

The rechargeable battery market by end user as of 2008 was as follows (Pillot, 2009): HEV/EV - 7%, cellular phones – 34%, portable PCs- 24%, power tools – 13%, other -22% (military, aerospace, medicine). These segments are each discussed below:

HEV/EV Segment

The world HEV/EV market is growing as a result of high oil prices, government tax incentives to encourage HEV/EV purchases, and the promotion of greener energy sources and restrictions on automotive emissions. In 2008, 515,000 HEVs were produced, which represents less than 1% of vehicles sold worldwide (Pillot 2009). Further analysis of HEV sales by region shows that 60% of purchases occurred in the U.S., 15% in Europe, 18% in Japan, and 7% in others (Table 3-5). Clearly, the regional sale of HEVs reveals that they are more popular in the U.S. than in other regions. This explains the expansion of the main manufacturers of rechargeable batteries and HEVs into the U.S. market. A lack of stimulation of HEV sales in Europe can be attributed to the widespread use of diesel cars, whereas diesel has never enjoyed the same popularity in the U.S. This is the main reason why the sale of HEVs has not taken off in Europe. Despite the largest crisis in auto industry history in 2008-2009, several automakers announced their plans to start manufacturing PHEVs and EVs by 2009 (General Motors, Nissan, Mitsushita, and Tesla). In 2009, 61% of secondary batteries produced in the world were lead-acid, which continue to be widely used in the auto industry for conventional gasoline powered vehicles. Rechargeable NiMH batteries are now the main battery of choice for use in HEV/EVs (SBI Energy 2009). Although NiMH battery is mainly secondary battery for HEVs (2% of world production of rechargeable batteries for HEVs), several automakers were willing to start using Li-ion batteries for PHEV/EVs as of 2010.

Portable Electronics

The market share of rechargeable batteries in the portable electronics as of 2008 was 37%, (75% - Li-ion, 12% NiCd, and 13%-NiMH batteries) (SBI Energy, 2009). The segment of alkaline rechargeable NiCd and NiMH batteries for consumer electronics consists of three parts such as frequent replacement: 67.8% (remote control, games, etc.), infrequent replacement: 23% (digital cameras, laptops, PDF, cellular), and other applications 9.2% (military and defense equipment).

3.5.1.3 Regional Segmentation of the Secondary Battery Market

The distribution of sales of rechargeable batteries in 2008 by region is shown in Table 3-6 Japan excels in the production of rechargeable batteries, with China in second place (Pillot, 2009).

NiCd Batteries

The main market share in the NiCd batteries segment (world sales of $800 million) belongs to Sanyo (Japan) and BYD (China). This segment has to withstand strong competition from NiMH and Li-ion batteries. The manufacturers of power tools, such as Makita, Bosch, and DeWalt, which used to be the main consumers of NiCd batteries have now replaced them with more technically advanced Li-ion batteries. This resulted in a 16% decline of NiCd battery sales in 2008 (Pillot, 2009) (Table 3-7).

NiMH Batteries

Japanese companies such as Panasonic EV, Sanyo, Yuasa, and MBI are world leaders in the manufacture of NiMH rechargeable batteries with a total market share of 71% in

2008. The market of NiMH rechargeable batteries was stagnant in 2008 in spite of growth in the HEV/EV segments. The total sales volume was $1.2 billion (Table 3-8).

Table 3-5: World Market Share by HEV Manufacturers

Company	Market share, %
Toyota	82.2
Honda	9.7
Ford	3.8
GM	2.6
Nissan	1.7
Chrysler	0.02

Source: Pillot, 2009

Li-ion Batteries

In contrast to the NiMH and NiCd battery sectors, Li-ion rechargeable batteries showed a positive market growth of 20% in 2008, with total sales of $7.2 billion and a higher rate of competition due to a greater concentration of manufacturers (Table 3-9). In 2008, the demand for Li-ion batteries was geographically distributed as follows: Asia Pacific (48%), North America (26.35%), Europe (22.9%), and Rest of the world (2.85%) (Frost and Sullivan 2007). Therefore, the manufacture of NiCd, NiMH and Li-ion batteries

Table: 3-6: Worldwide Sales of Rechargeable Batteries in 2008

Region	Sales, billion $	Growth, %
China	2.3	+10
Japan	5.1	+13
South Korea	1.8	+13
Rest of the world	<0.1	-

Source: Pillot, 2009

Table: 3-7. World Market Share of NiCd Rechargeable Batteries in 2008

Company	Market share, %
Sanyo (Japan)	53
BYD	24
SAFT	8
MBI (Japan)	8
Others	7

Source: Pillot, 2009

was concentrated in Japan, South Korea, and China. The U.S. market for rechargeable batteries is one of the biggest in the world with only lead-acid batteries sales of $6.4 billion, which is roughly comparable to world Li-ion battery output in 2008 of $7.2 billion (33% growth). Although the greatest demand for Li-ion, NiCd and NiMH batteries is in the U.S., the U.S. battery imports account for $1.17 billion of batteries in 2008 from China, Japan, Mexico and South Korea (U.S. DOE, 2009) (Fig. 3-9).

Table: 3-8: World Market Share of NiMH Batteries in 2008

Company	Market share, %
Sanyo (Japan)	23
Panasonic EV (Japan)	29
Yuasa	10
GP	14
MBI	9
Others	15

Source: Pillot, 2009

3.5.2 Market Trends

The main market drivers of the rechargeable battery industry are attributed to dropping prices, strong demand for energy resources, and the growth of the portable electronics and HEV/EV markets. Technical advances also contribute to marketability: the development of new batteries with high energy and power density, reliability, quality, low self-discharge, stability in a wide range of temperatures, and long shelf life. New regulations have mandated replacement of toxic metals in batteries. This means they are longer-lived and are more easily recycled. NiMH batteries are ideal for power tools, HEV/EVs, toys, and remote controls, while Li-ion batteries are suited more for PHEV/EV, portable electronics, and security systems.

NiCd Batteries

The market for NiCd rechargeable batteries experienced lower sales due to strong competition from NiMH and Li-ion batteries in major market sectors of power tools,

Table: 3-9: World Market Shares of Li-ion Rechargeable Batteries in 2008

Company	Market share, %
Sanyo (Japan)	25
Sony (Japan)	16
SDI (S. Korea)	17
LG Chemical (S. Korea)	8
BYD (China)	6
Maxell (Japan)	5
Lishen	4
MBI (Japan)	6

Source: Pillot, 2009

household electronic devices, cordless phones, and toys. There is active penetration into the markets of developing countries. This shift is a result of the European Union restriction of the use of NiCd batteries. These batteries are still popular in day-to-day portable electronics such as alarm clocks, remote controls, and radios.

3.5.2.1 Market Drivers in Segments of Secondary Batteries

NiMH Batteries

NiMH batteries have experienced a high rate of growth in the HEV/EV sector and they will be the main secondary batteries for HEVs/EVs by 2013 (U.S. DOE, 2009). These batteries provide a wide range of sizes for different applications. They are safer in contrast to NiCd batteries.

Li-ion Batteries

The Li-ion rechargeable battery market can best be defined by lower prices and the emergence of new portable electronic devices with high power consumption (MP3 players, Bluetooth products, iPods, and iPhones). Li-ion battery demand will increase in consumer (digital cameras, power tools, camcorders, games, cellar phones) and industrial (military, aerospace, medical equipment) segments at 6.8% and 19.9% respectively from 2006 to 2013 (Frost and Sullivan, 2009).

An analysis of rechargeable battery market trends suggests a decline in the market share of NiCd and NiMH batteries in portable electronics, and NiMH batteries in HEV. Li-ion secondary batteries will be the main substitutes for NiCd and NiMH secondary batteries in the short term. However, these market trends have limits that will likely affect the forecasted parameters of this market due to safety issues for Li-ion batteries (<1% recall), a price increase of raw materials such as nickel for NiMH, and cobalt (Co) and lithium (Li) for Li-ion batteries. Further limitations are caused by limited lithium resources, a lifespan of less than five years, and dropping prices and re-sultant decreases in corporate profitability

3.5.2.2 Proactive Strategic Research and Development of Rechargeable Batteries

A competitive advantage in the oligopolistic market of rechargeable batteries is only possible with excellent R&D. The high profitability of this market stimulates price competition, which requires continuously improved product portfolios. The diversified intellectual property (IP) portfolio is one important tool for successful competition in this market. Thus, an effective research policy and collaboration with universities are key factors in market share expansion. Some examples of innovative activities in different countries are shown below.

U.S. Market

The U.S. has lost its leadership in the secondary battery market, and U.S. venture capital increased its investment in the development of rechargeable batteries from $4.3 million in 2002 to $200 million in 2008 (Dow Jones Venture Source, 2010). The U.S. Federal Government, through its American Recovery and Reinvestment Act of 2009 (ARRA), granted $2 billion for the production of advanced batteries, and $7 billion for the development of sustainable energy technologies (U.S. DOE, 2009). The main market for rechargeable batteries is the U.S. Department of Energy (DOE) with two main offices: the Office of Energy Efficiency and Renewable energy (EERE), and the Office of Electricity Delivery and Energy Reliability (OE).

The U.S. government has demonstrated a preference for the lithium-ion battery sector. In 2008, it invested in Li-ion battery technology ten times more than in other battery chemistries. The DOE Energy Storage and Power Electronics (ESPE) program invested $3.8 million into the development of high temperature sodium, lead-acid, and flow battery technologies in 2008. Other crucial players in the U.S. rechargeable battery market are the U.S. Advance Batteries Consortium (USABC) and the Freedom Car Technologies Energy Storage Program (FCVT-ES) for a total of $48.2 million allocated to Li-ion battery development (U.S. DOE, 2011). The USABC has achieved the targeted parameters for HEV and plug-in hybrid vehicles (PHEV) through the development of a HEV battery with 300Wh, and discharge power of 2kW/s and energy cost of $20/kW, and a PHEV battery with 11.6 kWh and discharge power of 3.8kW/s (USABC, 2010).

The European Union

Europe is dominating the field of battery research by concentrating mostly on lithium-ion batteries. The Association of European Storage Battery Manufacturers (EURABAT) has ten R&D centres and collaborates with twenty universities. German battery manufacturers established the European Lithium-Ion Battery consortium in 2015, with planned investment of $560 million (SBI Energy, 2009).

China

The People's Republic of China (PRC) has 400 organizations that work with rechargeable batteries, but the PRC is interested only new commercial products.

Japan

SANYO, Sony, and Panasonic spend over $200 million on battery technology research in comparison with $10 billion of governmental investments

3.5.3 Industry Rivalry

The rechargeable battery market is oligopolistic consisting of two strategic groups of manufacturers. The first group consists of the eleven multinational manufacturers (Sanyo, Panasonic EV, Matsushita Battery Industrial Co.(Matsushita Industrial Co. Ltd [MBI]), Lucky GoldStar (LG), Samsung SDI, SAFT, Build Your Dream Co. Ltd. (BYD), Yuasa, Giant Battery Co. Ltd. (GB), Lishen, and Hitachi Maxell). The second group consists of the twenty specialized battery manufacturers that focus on regional markets (Shanzben B&K Electronics Co. Ltd. (B&K), Duracell; Energizer; VARTA Microbattery GmbH, Yardney Technical Products, GB, Eagle Picher Technologies, etc.). Each battery segment has a different level of competition, customer loyalty, and price elasticity (Table 3-10).

The price of NiCd batteries will reduce due to a decline in demand. The price of Li-ion

Table 3-10: Short (2010-2013) and Long Term (2013-2020) Characteristics of Competition Across the Rechargeable Battery Segments

Battery Segment	Level of competition		Level of price sensitivity		Level of product changes	
NiMH	High	Medium	Medium	High	Medium	High
Li-ion	High	Medium	High	Medium	Medium	High

Source: Frost and Sullivan (2007), World Secondary Lithium-ion Battery

batteries ($/kWh) is thirty percent higher than the price of NiMH batteries as of 2010, but are predicted to equilibrate in 2015. The level of competition in the NiMH segment is high as all launched HEVs, and a further seventy percent of HEVs by 2015 will be equipped with NiMH batteries. NiMH manufacturing profitability is higher than that of Li-ion batteries for cellar phones. The use of Li-ion batteries will increase and they will be the main batteries for PHEV/EVs in the short term. Li-ion batteries will replace more than 30% of NiMH batteries in HEVs after 2015. Thus, the rate of modification of NiMH batteries should be high over the long term to maintain a competitive advantage. The sale of HEVs in the U.S is lower than in Europe. However, the U.S. has the largest HEV market share with 60% of worldwide sales, so the majority of automakers have their own programs for the launch of PHEV/HEVs for this market. NiMH battery manufacturers face strong competition to supply batteries to Ford (Sanyo), Chrysler (Panasonic EV), GM (MBI, Cobasys), Toyota (Panasonic EV), and Honda (Sanyo and MBI) (FourPxArticles (2011). Currently, the demand for Li-ion batteries is determined by the demand for portable electronics.

The main producers of Li-ion batteries from Japan and South Korea (with an 80% world market share) also produce portable electronics (LG, Sony, Panasonic, and Sanyo). From 1992-

1995 the main Li-ion manufactures were the Sony Corp, AAT Battery Co., Mitsui & Co. (with a 43% stake and $31 million investment), Sanyo Electric Industrial Co., Nippon Moli Energy Corp., NEC (with a 50.5% stake and investment of $36.5 million), and MBI (Farber, 1995). NEC's subsidiary was the first company to manufacture Li-ion batteries in North America. In 1994, Sony Corp. produced 15 million Li-ion batteries per year, and A&T Battery Co. produced 4.8 million batteries per year. In 1995, Sanyo and Matsushita started their production of Li-ion batteries at 12 million cells per year. Interestingly, one of the first manufacturers of Li-ion batteries was a small Canadian company, Moli Energy in Vancouver. It started the fabrication of Li-ion batteries one year earlier than Sony Corp in 1990. However, this early start did not allow this company to achieve good quality and equipment. As a result, Moli's batteries had several overheating accidents. The legal action against this company led it to bankruptcy and sale to NEC (Japan) in 1993.

The number of competitors increased two-fold at the next stage of technological cycle (Brodd, 2005). The new players from South Korea (LG) and China (BYD) appeared in 2002. Strong competition in the market of Li-ion batteries was one of the reasons for the purchase of the market leader Sanyo (world market share 29% in 2008) by Panasonic. This mega-corporation, with revenue of $110 billion in 2010, will be the market leader in the long run (Lux Research, 2010).

3.5.4 New Entrant Threat

The significant growth of the demand for rechargeable NiMH and Li-ion batteries in HEV/EVs and the portable electronics segment determines their attractiveness for new entrants. The number of competitors will increase two-fold at the next stage of the technological cycle of rechargeable batteries (Brodd, 2005).The market for lead-acid and NiCd batteries is not practical for new entrants due to sales saturation and product demand reduction. For example, the NiCd battery sector showed negative growth in 2008 (Pillot, 2009)**.** Lead-acid batteries will remain main rechargeable batteries at least until 2015, but is facing a gradual reduction in sales (SBI Energy White Paper). In contrast to NiCd and lead-acid, the NiMH battery segment is very attractive to new entrants due to the strong demand for HEV/EVs, which will remain the ideal battery for this segment for at least the next five years. The Li-ion battery segment is currently one of the most attractive ones for new entrants since it has the highest interest due to the portable electronics and PHEV/EV segments.

The new entrants from China and South Korea in the Li-ion battery market could decrease the world market share of Japanese competitors as seen from 82% in 2001, to 56% in 2008 (Pillot, 2009). The first new entrants in the Li-ion battery market were South Korean manufacturers LG, Samsung SDI, and SKS. They have advantages in sales of consumer and mobile electronics, which require light, portable, and effective Li-ion batteries. Together with Chinese competitors they have managed to shrink the Japanese market share from 75% in 2001 to 56% in 2008. Now South Korean sales are $1.8 billion (13% growth in 2008). Following South Korea, China began mass production of Li-ion batteries in 1997, had 20% of the worldwide market share by 2002 , sales of $2.3 billion, and an annual growth of 10% as of 2008 (FourPxArticles (2011). Although the market is currently stable, the boom in the HEV/EV markets promises to change the landscape of this rivalry in the next two years. The success of new entrants also depends on governmental support. The success of South Korean companies with an 80% level of imported components depends on the support of the South Korean government. South Korea spent 465 million won from 1997 to 2002 for the support of the R&D of local Li-ion battery manufacturers

(FourPxArticles, 2011). However, this rechargeable battery market has some barriers for new entrants.

Strong intellectual property (IP) protection on the part of current corporations and the threat of legal challenges associated with the deployment of new technologies pose significant barriers. Japanese manufacturers were the first in the market of Li-ion rechargeable batteries. Although Japan now yields its position to South Korean and Chinese competitors in sales, it has retained a key position in technological innovation. A significant investment in the building of new battery plants and quality control is another obstacle. Panasonic spent ¥100 billion to build a plant in Osaka in 2010 with a capacity of 600,000 million Li-ion cells (Japan's Corporate News, 2008). Customer trust is a necessary element for new orders. SANYO, Sony, and Matsushita have had significant Li-ion battery recalls of 46, 1.3 and 75 million cells respectively in 2007-2008. This has the potential to decrease future sales.

One of the most important barriers for new entrants to the market is strong IP protection of key components for the manufacture of batteries. This is a significant advantage of Japanese battery producers over that of their Chinese and Korean competitors, in spite of the decrease of the Japanese share of the Li-ion battery market from 75% to 56% in the period 2002-2008. LG and Samsung can independently produce only 50% of the main components of their Li-ion batteries, and this has strongly affected their market share. Japanese companies control 70-100% of the manufacture of key components for Li-ion batteries (separators, electrodes, and purified electrolyte) (FourPxArticles, 2011). The first Japanese producer of Li-ion batteries, Sony Corp., holds the largest number of patents (218) and the “right holder's best score," which indicates the average quality of patents as 32.2. In contrast, Panasonic holds 189 patents with 31.3 as its right holder's best score, while Sanyo Electric Co. Ltd. has 152 patents (Tech & Industry Analysis from Asia, 2010).

3.5.5 The High Bargaining Power of Buyers

The buyers of rechargeable batteries can be divided by application in two groups: consumer and industrial (Consumer Electronics Association, 2005) (Table 3-11). Because the bargaining power of consumer electronics buyers is high it reduces price (Frost and Sullivan, 2007). It is one of the main trends in the rechargeable battery market. In 2008, the sales of rechargeable batteries by chemistries were: 61% for lead-acid and 39% for NiCd, NiMH, and Li-ion batteries. (SBI Energy White Paper, 2009).

The bargaining power of industrial buyers is very high as they have well-organized supply chains, several suppliers, and demand for millions of dollars of product. This allows them to

Table: 3-11: Worldwide Sales (%) of Rechargeable Batteries in the Segments of Consumer and Industrial Applications in 2008

Worldwide sales of rechargeable batteries, %				
Consumer applications				Industrial applications
24 (portable electronics)	34 (mobile electronics: cellular and smart phones)	13 (power tools)	7 (hybrid vehicles)	13 (military, telecommunications, medical, industrial power tools, aerospace, and HEV/EV)

Source: Pillot, 2009

dictate the conditions of deals. Their main requirement is the timely supply of high quality products. In the HEV/EV segment, the majority of battery suppliers try to get contracts with automakers for industrial NiMH and Li-ion batteries. The automakers use their bargaining power to negotiate significant discounts with battery manufacturers. Some of them have two battery suppliers that additionally increase buyer bargaining power. For example, Honda uses Sanyo and

MBI's NiMH batteries, and GM uses LG, MBI, and Cobasys batteries. Toyota, Lexus, Nissan and Chrysler use Panasonic EV NiMH batteries. Automakers also have joint ventures with battery producers, for example Toyota with Panasonic and Nissan with NEC. Panasonic EV as a supplier of NiMH batteries for the four automakers has the strongest competitive advantage (the Panasonic EV market share is 85.5% in the NiMH segment for HEV use) (Pillot, 2009). Automakers select suppliers with reliable production and strong core competencies. GM, for instance, has selected LG as supplier of Li-ion rechargeable batteries from five possible candidates for its HPEV Chevrolet Volt based on a unique, safer cathode chemistry, laminated battery package, and safety-reinforced separator with ceramic coating for dual protection against thermal runaways. Using their bargaining power, the buyers in this segment require new technologies such as the Li-ion polymer batteries with gravimetric power density 700W/L, a life cycle greater than 4000 cycles, a fifteen minute recharging time, and thin film (five microns) of Li-ion polymer.

3.5.6 The Bargaining Power of Suppliers (Low for Hardware and Medium for Active Components)

The main suppliers of rechargeable batteries are defined as companies that focus on hardware and active components (cathodes, anodes, separators, and electrolytes), and those with a focus on batteries. The concentration of hardware suppliers (or those companies with lower bargaining power) on the market is higher in comparison with suppliers of active components, and their competition against each other decreases overall bargaining power. The majority of battery manufacturers have at least two suppliers with ISO 9000 Quality certification. They have the low bargaining power. The bargaining power of active component suppliers (Table 3-12) with a focus on cathodes and separators is medium, with as few as five to ten alternative suppliers with high quality products at present on the market). Several separator suppliers (total demand is 265 million tons [Pillot, 2009]), such as Enten, Gelgard, Tonen, UBE, Asahi (hydrophilic polyolefin nonwovens), Japan Vilene, Kanai Juyo Kogyo, Nippon Kodoshi, and Nitto Denko have medium bargaining power.

The bargaining power of lithium electrolyte suppliers is high (total demand for lithium is 12,500 tons as few companies are able to provide the necessary purity of 99.5% [Pillot, 2009]). Li-ion battery manufacturers depend on only a few suppliers from Japan, which determines strong bargaining power of suppliers. For example, the required lithium carbonate for Li-ion batteries has to be purified to 99.5%, and only a few Japanese firms can provide sufficient quality of this purified element (Kempf, 2008). South Korean companies have only 30% of their own main technologies for lithium-ion batteries in comparison to their Japanese rivals. South Korea spent 12

Table 3-12: Suppliers of Active Components for Rechargeable Batteries

Cathode suppliers (bargaining power is medium)				
Zhuhai Kesai Import & Export Co., Ltd.	Shenzhen Southtop Technology Co., Ltd.	Linyi Gelon New Battery Materials Co. Ltd.	General Electronics Battery Co.	Ex Co., Ltd.
Lithium electrolyte suppliers (bargaining power is high)				
Mitsubishi	Chiel	UBE	Tomiyama	Mitsubishi
Separator suppliers (bargaining power is medium)				
Enten	Gelgard	Tonen	UBE	Asahi

Source: Pillot, 2009

billion won for acquisitions in the raw materials business in 2010 (Christian, Soble, and Hille, 2010).

Limited world lithium resources and possible future supply problems are two potential limitations of the Li-ion battery market. Argentina, Chile, and Bolivia have about 70% of the global lithium resources. The market for lithium consists of only four main suppliers (Prettier, 2009), such as Chemetal (Germany) -28%, China - 27%, SQM - 29%, FMC (Argentina) -17%. The current demand for lithium chemicals is 3-5%, and will increase by 20% by 2020 for all types of electric vehicles PHEV/HEV/EV. Annual demand in 2020 for lithium carbonate will be 55-65 kilotons, but currently required lithium resources are about 25 kilotons per year (Financial Times, 2010). These lithium reserves will be sufficient only for eight million GM Volt plug-in hybrids in a market consisting of 60 million gasoline powered cars as of 2008. The strong demand for Li-ion batteries in the PHEV/EV segment is one of the main reason for the increase of the price of lithium from $350/ton in 2003 to $3,000/ton in 2008 (Linden, 2003). Thus, the bargaining power of lithium compound suppliers will only increase in the next decade.

3.5.7 The Threat of Substitutes

The threat of substitutes for rechargeable batteries is low at the moment. The main substitutes are rechargeable metal-air (Li, Zn, Mg, Fe) batteries, which have higher technical characteristics in comparison with conventional rechargeable NiMH and Li-ion batteries. Lithium air batteries have a higher energy density than lithium ion batteries because of a lighter cathode, and the fact that oxygen is freely available in the environment and does not need to be stored in the battery. Theoretically, with oxygen as an unlimited cathode reactant, the capacity of the battery is limited only by the Li anode. Lithium-air batteries are currently in development and are not yet commercially available. They combine the advantages of lithium-ion and metal-air batteries. One of the active developers of these batteries is IREQ (Canada), which has received a significant support from the U.S. Department of Energy for the improvement of this technology (IREQ, 2010). Lithium-air batteries have a higher energy density than lithium ion batteries due to the lighter cathode and freely available oxygen. The capacity of this battery is limited by the Li anode. Lithium-air batteries are now under active development.

The other substitute is a rechargeable zinc-air battery (ZAB). These batteries have a higher energy density of 1530 kW/kg than NiMH (278 kW/kg) and Li-MnO_2 (1001 kW/kg) batteries, as well as such promising advantages as low cost, cheaper Zn fuel ($2/kg versus $17/kg for Ni), and non-toxic alkaline electrolyte. After several years of development, a Swiss company, ReVolt, has achieved the commercialization stage of its rechargeable ZAB. ReVolt received a $5 million U.S. government grant to build a plant for the manufacture of large zinc-air flow ZAB for plug-in vehicles in Portland (USA) in 2010. ReVolt developed zinc-air batteries for the replacement of Li-ion batteries (ReVolt, 2010)

The last potential substitutes are supercapacitors. Supercapacitors are the storage devices in the electric field between pair capacitors. They charge faster than rechargeable batteries during regenerative breaking and easily release energy during its charging mode. Toyota Motor Corp. commercialized them for use in their HEV Toyota Supra. But today, other Toyota competitors have announced plans to use these ultra capacitors for HEV/EVs.

3.5.8 The Power of Government

The effect of governments on the market of rechargeable batteries can stimulate HEV/EV sales and industry collaboration, can support R&D programs focusing on new energy storage technologies (supercapacitors, metal-air batteries), and help protect the environment through mandated restrictions on the use of toxic metals and programs to encourage the utilization of rechargeable batteries. The United Kingdom, the United States, Canada, Japan, and China have developed national programs for the stimulation of HEV/EV sales. In the UK, anyone who buys an HEV/EV will be able to take advantage of a subsidy of up to £5,000 (CDN $7,684) under plans to be set out by the government (Pickard, 2010), purchasers of the GMC PHEV Volt will be eligible for a US$7,500 federal tax credit (Green car congress, 2007), as will be a CAN$10,000 U.S. subsidy for consumers in Canada (CBC News, 2009). The European Union (EU) limited the production of batteries containing cadmium and mercury (minimum of 2%) in 2008. Japan required all manufacturers and importers of rechargeable batteries to establish collection and recycling systems in 2002.

The governments of the U.S., Japan, and South Korea made significant investments in the development of new technologies of rechargeable batteries and new energy storage devices, such as supercapacitors and metal-air batteries. The U.S. invested $2 billion in grants as part of the American Recovery and Reinvestment Act of 2009 (ARRA) for the manufacturing of advanced batteries (Li-ion batteries are specifically mentioned), and $7 billion in grants for the R&D of renewable and efficient energy technologies and the modernization of the electric grid. The European Storage Battery Manufacturers (Eurobat) has ten different industrial research centres and 20 different universities which focus on Li-ion battery development (Lithium Ionen Batterie LIB 2015 [Germany]). There are 400 organizations in China that focus on the development of new batteries. The South Korean Government spent 465 million won for the development of Li-ion batteries from 1997 to 2002. South Korea and China strongly support their national Li-ion manufacturers by providing low rate interest loans and tax rebates. The Japanese government encourages competing companies to share information and cooperate during the introduction of new products/technologies (Brodd, 2005).

Total investments in the development batteries and electric cars in 2010 were about $18.2 billion worldwide (Simon, 2009). Governments also have an affect on the demand for Li-ion batteries by regulating their transportation through the TSA, IATA, and UNA standards. This regulation strongly effects customer mobility (Brodd, 2005).

3.5.9 The Low Bargaining Power of Complementors

The growth of the PHEV/EV market requires a developed infrastructure consisting of charging stations, which are complementors for vehicles with rechargeable batteries. The power of such complementors is low over the short term as the total amount of PHEVs requiring on-the-road charging will be limited. However, the mass production PHEVs/EVs will increase the power of these complementors to the medium level.

3.5.10 Summary of the Battery Industry Analysis

The analysis of the rechargeable battery industry demonstrates a competitive environment (Table 3-13). The competition increases because of a decrease of concentration in this industry. An increase of this concentration leads to an increase of power buyers and suppliers, and a threat to new entrants. Competitive forces are differently distributed in two main strategic groups. The power of suppliers is higher for specialized battery companies than for multinational corporations due to different volumes of purchased raw materials.

3.6 Summary of the External Analysis

Analysis of two NRC-IFCI targeted industries, fuel cells and batteries, shows different competitive environments and trends. The FC industry has less competition than the battery industry due to the power of suppliers and the threat of new entrants. The mass commercialization of FCs is expected only after 2018, and only after significant investment in R&D and commercialization (Frost and Sullivan, 2008). Moreover, the absence of a developed hydrogen infrastructure (hydrogen refuelling stations) and strong government support are two of the main challenges to the FC industry. The threat of rechargeable batteries as a fuel cell substitute is high as current hybrid and electric vehicles use NiMH and Li-ion batteries.

The success of mass HEV commercialization will determine significant growth of rechargeable battery demand. The battery industry requires less investment in R&D than the fuel cell industry. However, the technical (energy density) and resource limitations (world Li resources) of commercialized rechargeable NiMH, NiCd, and Li-ion batteries provide good opportunities for rechargeable metal-air batteries to overtake this market. Some MABs, for example ZAB, are significantly cheaper and more effective than NiMH, NiCd, and Li-ion batteries. This gives the NRC-IFCI the opportunity to diversify its business and develop rechargeable MABs using its FC core competency, and capacity for MAB development and prototype manufacture. MAB development will increase NRC-IFCI's business sustainability and competitiveness in the Clean Energy Sector. The next chapter discusses the internal analysis of NRC-IFCI resources and capabilities, with particular focus on the value creation process for fuel cells and rechargeable MABs. The external analysis will properly determine the NRC-IFCI's position in these value creation chains in reference to available resources and capabilities.

Table 3-13: Summary of the Battery Industry Analysis

*-Group 1 – multinational corporation with battery divisions, **-Group 2 – specialized corporations with focus on regional markets

Force	Strategic Group	Short term	Long term
Rivalry	1*	Medium	High
Threat of new entrants	1	Medium	Medium
Bargaining power of buyers	1	Low	Medium
	2**	High	High
Bargaining power of suppliers	1	Low	Low
	2	Medium	Medium
Threat of substitutes	1,2	Low	Medium
Power of government	1,2	Medium	Low
Power of complementors	1,2	Low	Medium

Source: by author

4: INTERNAL ANALYSIS OF NRC-IFCI

The performance of a non-profit scientific organization is determined by its external environment, internal core capabilities and resources, and strategy. Chapter 4 provides an internal analysis of NRC-IFCI primary and support activities in the value creation process of fuel cells and batteries. The mapping of NRC-IFCI's weaknesses and strengths onto a value creation process determines the NRC-IFCI's competitive advantage.

4.1 Resources and Capabilities

NRC-IFCI has several key resources for the development of innovative products and technologies in the Clean Energy Sector. These include financial (cash, capital), physical (equipment, land, buildings), human (labour, effective management), technological (patents and licenses), and intangible (corporate culture and brand, reputation on the market). The analysis of the value and capabilities of these resources will be discussed below.

4.1.1 Financial Resources

The NRC-IFCI has two main types of funding: A- and B-base. A-base funding is the NRC's corporate financing, and B-base funding is the financing from BC, the clean energy cluster, fee-for-services contracts, grants, and license royalties. The NRC-IFCI has a target identified in its Business Plan (NCR-IFCI business plan 2010-2011). NRC-IFCI plans to increase income by 35% for financial sustainability by acquiring direct investment from the province of BC, the renewal of the cluster in clean energy, and an extension of its stakeholder base (Table 4-1). During the crisis in the fuel cell market, NRC-IFCI established a challenging target to decrease their A-base funding in 2010-2011. This was in order to mitigate the risk of insufficient funding for key projects and to support its core competency on the basis of sustainable cooperation with other governmental departments (OGD), particularly the Ministry of National Resources Canada, NRC Institutes (ICPET, NINT, IAR), and the Provincial Governments of BC and Alberta. In 2009-2010, the target focused on NRC and National Programs. In terms of revenue forecasts by program, the main revenue growth of NRC-IFCI in 2010-2011 will come from the Clean Energy Sector (Table 4-2). In 2010-2011, the NRC-IFCI actual income was $13 million (Table 4-3). According to NRC's new strategy, the A-base financing will decrease permanently every year (18% in 2011-2012), but NRC institutes will be able to participate in new strategic Flagship and NRC programs to compensate for the loss of the A-base funding.

NRC-IFCI has four types of main projects to support its core competency (20% of total) and generate revenue (80% of total). They work collaboratively with industry, international and national programs, and internal projects (Table 4-2) (NRC-IFCI Annual Report 2010-2011). The focus of these projects is to support Canadian industry. NRC-IFCI also leverages its core competency by developing internal projects that increase the competitive level of NRC-IFCI developments. NRC-IFCI's proposed total budget (Table 4-1) is 20% revenue generated by fee-for-service contracts and about 50% centralized financing from NRC (A-base). In December 2010, the current total cash income was $2 million (targeted $2.8 million) and the project portfolio cash leverage achieved $0.15 million (targeted $0.7 million). For fiscal year 2011-2012, the NRC-IFCI set a higher leverage level of project cash -$0.8 million (NRC-IFCI Annual Report 2010-2011). The high percentage of A-base financing in total NRC-IFCI budgets is the reason for its flexibility

Table 4-1.Estimated Budget in 2010-2011

Budget		**Expenses**	
Budget	**Total budget,K$**	**Expenses**	**Forecasted expenses, (K$)**
A-Base	6.171	Salary	9.026
B-base	3.434	Operations	5.083
NRC-sunset	600	Capital	427
Additional Appropriations (International, National programs, etc.)	1,451	-	-
External Revenue	2,850	-	-

Source: by author, adapted from NRC-IFCI Annual Report 2010-2011

Table 4-2. Revenue of NRC IFCI by source and program

Parameter	**2008/09, M$ (actual)**	**2009/10, M$**	**2010/11, M$ (forecast)**
1.Source	**Revenue forecast by source**		
JRP,FFS, and OGD	1.9	2.0	2.7
2.Program	**Revenue forecast by program**		
Clean energy program	0.7	1.1	1.7
Fuel cell technology	1.9	2.4	2.1
Wear &corrosion	0.5	0.5	0.5

Source: by author, adapted from NRC-IFCI Annual Report 2010-2011

Table 4-3: NRC-IFCI's Annual Operating 2011/12 and Budget 2011/12

Budget	**Actual 2010/11 /$, million**	**Budget 2011/2012 / $, million**
A-base	6.1	5,1
B- base	3.5	3.5
Central (NRC, TDP programs)	0.4	0.65
Total	13.0	12.75

Source: by author, adapted from NRC-IFCI Annual Report 2010-2011

to meet the new NRC strategic requirements for the cross-NRC programs announced in March 2011. This includes national priority of strategic Flagship programs. NRC-IFCI has developed several national and international consortia to increase the revenue generation and to protect its core competency.

4.1.2 Tangible Assets

NRC-IFCI has modern tangible assets such as a new building, two labs for the testing of fuel cells and batteries equipped by fifteen fuel cell stations, a new spectroscopic lab with modern equipment for investigating complex physical, chemical and electrochemical properties of new material, and fuel cell components. The mechanical shop supplies the fabrication of fuel cells and components for the tests. NRC-IFCI actively uses the equipment and capabilities of other NRC institutes to increase its competitiveness. This supplies synergy in the development of new technologies and materials. However, some necessary equipment such as transmission electron microscopy (TEM), X-ray photoelectron spectroscopy (XPS), and Auger electron spectroscopy

(AES) spectrometers for material characterization, atomic layer deposition, and catalyst deposition are required. Moreover, additional facilities for the scaling up of catalysts, MEA/CCM and other key components of fuel cells are necessary to improve customer satisfaction.

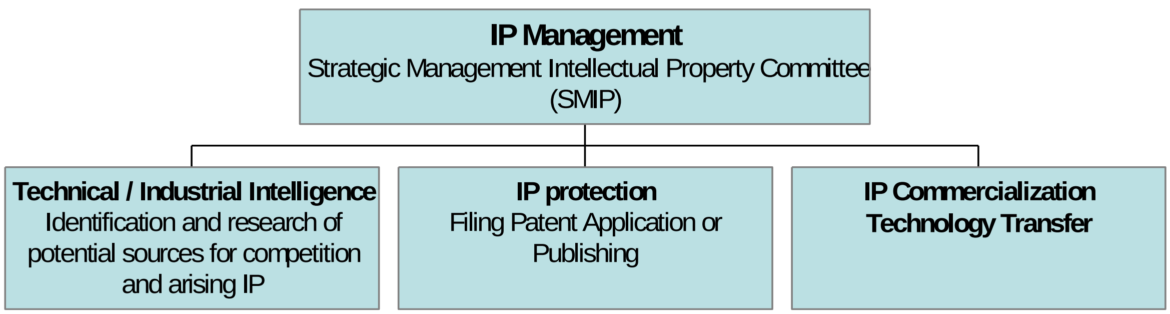
4.1.3 Human Resources

NRC-IFCI has a highly educated personal of 160 scientists, engineers and support staff. The necessary supplemental work is carried out by our temporary staff. Permanent training sessions, and participation in international conferences and workshops increases the knowledge and competitiveness of key personnel. NRC-IFCI's top management has work experience in industry and leading scientific organizations, and participates in large international collaborative programs. The business development office personnel have wide experience in the commercialization of technologies, venture funding, and marketing. NRC-IFCI invites and encourages workers from foreign universities and national labs to visit for short terms to share their knowledge and experience with NRC-IFCI researchers and to increase NRC-IFCI's competitiveness. However, NRC-IFCI has some human-resource related weaknesses, such as a long hiring process of new employees for short-term projects and the absence of sufficient experience of key personnel in cross-NRC programs, which will be the main form of collaboration from 2011 onwards.

4.1.4 Intangible Assets

One of the main assets of a non-profit scientific organization is its intellectual property (IP). NRC-IFCI has very diversified IP portfolio (thirty two inventions and one sold license) and effective IP management (Table 4.1). IP increases the NRC-IFCI attractiveness in international collaboration with leading scientific organizations and industrial partners. Fig.4-1 shows the structure of IP management. The strategic management intellectual property committee selects the technologies for IP protection following a review of detailed technical and industrial intelligence by professional consulting companies. The business development office supplies all the necessary support for the inventors from the first to the final stages.

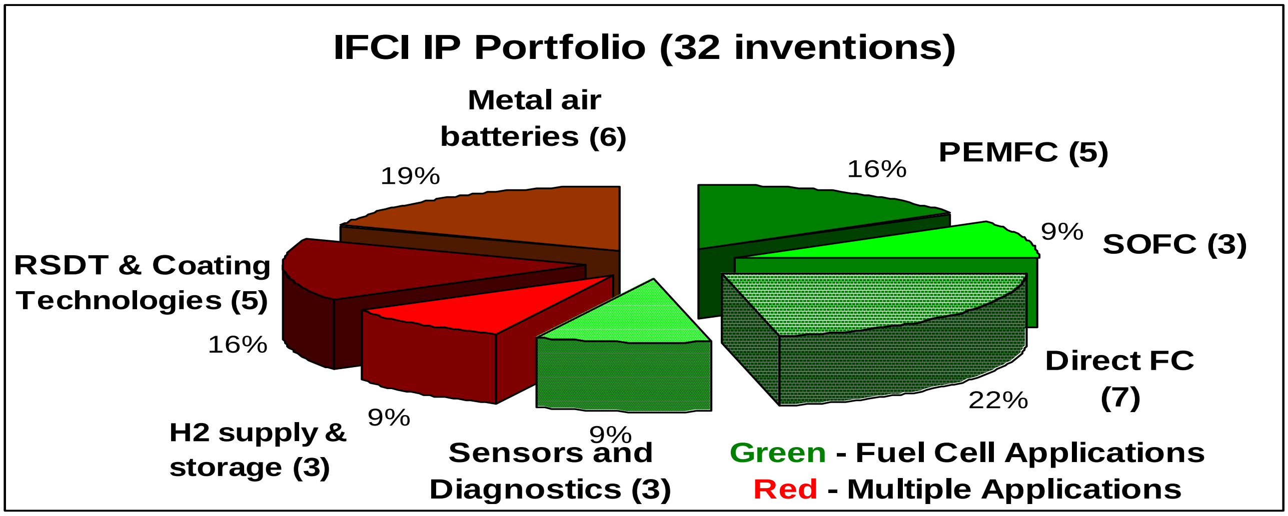
Fig. 4.1: Structure of NRC-IFCI's IP Management



Source: Neburchilova, 2010

NRC-IFCI's IP portfolio covers the following: fuel cells PEMFC (five patents, SOFC (three patents), direct fuel cells (seven patents); batteries (three patents), hydrogen supply and storage (three patents), RSDT and coating technologies (five patents), and sensors and diagnostics (three patents. Forty-four percent of the patent portfolio relates to multiple applications, which significantly increase its value and potential for the diversification and commercialization of IFCI inventions. The IP portfolio increased several times during the last four years, which demonstrates the growing NRC-IFCI innovative potential. One of the indicators of the efficiency of NRC-IFCI's IP management is the percentage of the transformation of formal patent applications to actual, effective U.S. provisional patent applications. It demonstrates growth during last nine years (Fig. 4.3).

Fig. 4.2: Structure of NRC-IFCI Portfolio



Source: Neburchilova, 2011

Table 4.4: NRC-IFCI Projects Portfolio

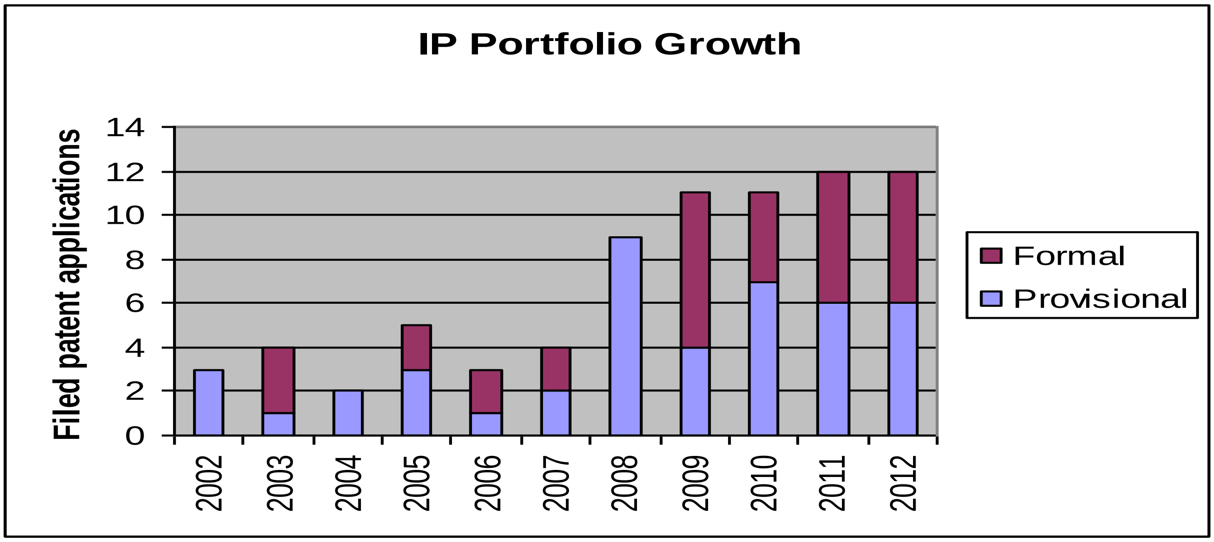
#	Project type	Goals
1	Research Collaborations	Generating new fundamental knowledge
2	Collaborations and Fee-for-service	Testing and evaluation using own tools
3	Research Collaborations / the research is conducted separately; only data exchange	Generating new IP
4	Joint Research Collaborations	Generating new IP
5	Internal Projects	Generating fundamental knowledge and IP

Source: Neburchilova, 2010

4.2. NRC-IFCI's Position in Value Creation Process for Fuel Cells

In this section, the NRC-IFCI value chain for the development of fuel cells is shown. The

Fig.4.3: NRC-IFCI's IP Portfolio Growth



Source: Neburchilova, 2010

value chain of activities transforming inputs to outputs is more applicable for commercial companies (Porter, 1985). Nevertheless, the prototypical value chain was applied to NRC-IFCI as a non-profit scientific organisation to determine the value-adding activities in the commercialization of NRC-IFCI's fuel cells. The additional analysis of NRC-IFCI's weaknesses and strengths in relation to its support and primary activities in generating fuel cells will determine its competitive advantage. Fig. 4.4 demonstrates the prototyping value chain for the development of NRC-IFCI's fuel cells. The analysis of its primary activities directly creating values and support activities will be demonstrated in the following chapters.

4.2.1 Primary Activities in Fuel Cell Development

The five primary activities including the development of fuel cells, components, FC components, lab scale up/validation, unit-cell production/validation, stack assembly/validation, and pilot plant-scale/commercialization, mainly determine the value of R&D in the value chain of fuel cell

Fig.4.4 Value Creation Process for Fuel Cell Companies

Primary activities	1.Development of fuel cells (FC) and their components	2.FC components production and validation	3.Unit-cell production and validation	4.Stack assembly and validation	5.Pilot plant-scale-up/ Commercialization	Margin
	1.1.Modeling and numerical simulation	2.1.Production of FC components	3.1. Unit-cell production	4.1. Stack assembly	5.1. Production	
	1.2.FC design	2.2.Production of FC hardware	3.2. Quality control and validation	4.2. Quality control and validation	5.2. Marketing/ distribution	
	1.3.FC hardware, MEA, and catalysts	2.3.Ex-situ test of FC components	-	-	5.3. Warranty service	
	1.4. FC diagnostics	-	-	-	-	
	>>> Research and Development >>>					
Support activities	1.Company infrastructure	General management	Financial management	Business development	IP management	
	2.Human resources management	Hiring	Training	Team management	Administration	
	3.Technology development	Device design development	Modeling and numerical simulation of main processes, components and their integration	Hardware, components and diagnostics development	Platform technology development (from unit cell to stack)	
	4.Procurement	Selection of materials and suppliers	Coordination with customers and suppliers	Control of supply chain	Handling and order placement	

Source: by author, adapted from Porter, 1985.

commercialization. Some of these activities NRC-IFCI performs itself and others using outsourced firms.

4.2.1.1 Development of Fuel Cell (FC) Design, Components, and Hardware

Computational simulation is the preliminary development stage of FC components. It helps to find the optimized properties and composition of some FC components. NRC-IFCI has solid expertise in modeling and computational simulations. The catalyst group develops the catalysts and supports depending on working conditions. The non-carbon supported catalysts for high temperature PEMFCs (160-190^{o}C) without support oxidation during an operation is a good example. The membranes electrode assembly (MEA) group integrates the NRC-IFCI's developed catalysts into CCM using conventional deposition methods. The advanced catalyst layer develops through modeling and validation: structure-based modeling, formation, stability and life time, electro catalyst properties, and proton/water transport.

4.2.1.2 Lab Scale up of FC Components /Validation

The lab scale up of FC components provides the FC hardware, sensors, flow field plates, current collectors, catalysts, MEAs, and other necessary equipment for the assembly of PEMFCs. The produced FC components are tested using the NRC-IFCI's and industry protocols in simulated conditions. For example, catalysts and their supports test in half-cells in electrolyte simulating the operational FC conditions. The internal validation will allow selection of the best FC components before they are assembled.

4.2.1.3 Unit-cell Production/Validation

The unit cell production is one of the key stages of FC manufacturing. The first stage of unit production is the production of hardware and other necessary equipment in NRC-IFCI's mechanical shop. The internal in-situ test of every produced cell is carried out before any external validation by a strategic fuel cell developer.

4.2.1.4 Stack Assembly and Validation

The unit cells produced in the previous stage are assembled into the fuel stack, partially at NRC-IFCI or at the facilities of an outsourced fuel cell developer. Their validation requires powerful fuel cell test stations, so, depending on client need, validation can be conducted at their industrial facility.

4.2.1.5 Manufacture and Commercialization

The pilot plant scale up and commercialization is not part of NRC-IFCI's business. The NRC-IFCI does not have the expertise in marketing, distribution, sales and warranty service of their developed products. Thus, before this stage, NRC-IFCI looks for a strategic partner for outsourcing licensing of the developed fuel cells. The success of this stage completely depends on the quality and technical parameters, and the efficiency of the developed FC prototypes and IP protection. This primary activity is not NRC-IFCI's focus, so it is not assessed in this section.

4.2.2 Support Activities in the Fuel Cell Development

Support activities in contrast to primary activities are not directly involved in the creation value chain (Porter, 1995) (Fig.4-4). However, without these activities and their effective interconnection, no business is possible. Therefore, this analysis (firm infrastructure, technology development, human resources, and procurement) is presented in this section.

4.2.2.1 Firm Infrastructure

The firm infrastructure (general, financial, IP management and business development) is one of the important support activities, and determines the efficiency of the value creation process. General management supplies the effective utilization of all internal resources and supports the external relations with partners, governmental agencies, the NRC head office and institutes. Financial management is responsible for providing and managing the financial resources to achieve the organization's goals and to supply the necessary level of this support during the entire value creation process. IP management is responsible for the creation and management of the competitive patent portfolio, which determines the attractiveness of NRC-IFCI as a partner in international collaborations with leading scientific organizations and industrial partners. The presence of developed fuel cells IP protection, or their components, is the key factor for the out-licensing of NRC-IFCI technologies and any successful commercialization. The search for potential licensees, commercialization methods, negotiations and support of effective relations with industrial partners is the main function of business development activity.

4.2.2.2 Technology Development

Technology development is one of the key supportive activities of NRC-IFCI FC development. This activity is based on the development of FC design (hardware, sensors) and diagnostic methods, MEA, catalysts, modeling, and numerical simulation. The development of FC's design and hardware allows NRC-IFCI to produce FC prototypes and to optimize their parameters depending on each client need. The development of MEA and catalysts, which are the main FC cost drivers, allow NRC-IFCI to satisfy the market requirements for FCs. Modeling and numerical simulation allow NRC-IFCI to optimize the design and composition of FC components.

4.2.2.3 Human Resources

NRC-IFCI has a large multinational and multidisciplinary team, so human resources management is a crucial factor in successful team building and in the achievement of technical and organizational goals. This support activity supplies the hiring and training of professional staff and the proper distribution of human resources between different projects. This allows maximum utilization of all internal capabilities.

4.2.2.4 Procurement

Procurement support satisfies the organization's need to get the necessary resources (materials, finance, and management of relations with industrial partners) on time for the value creation process.

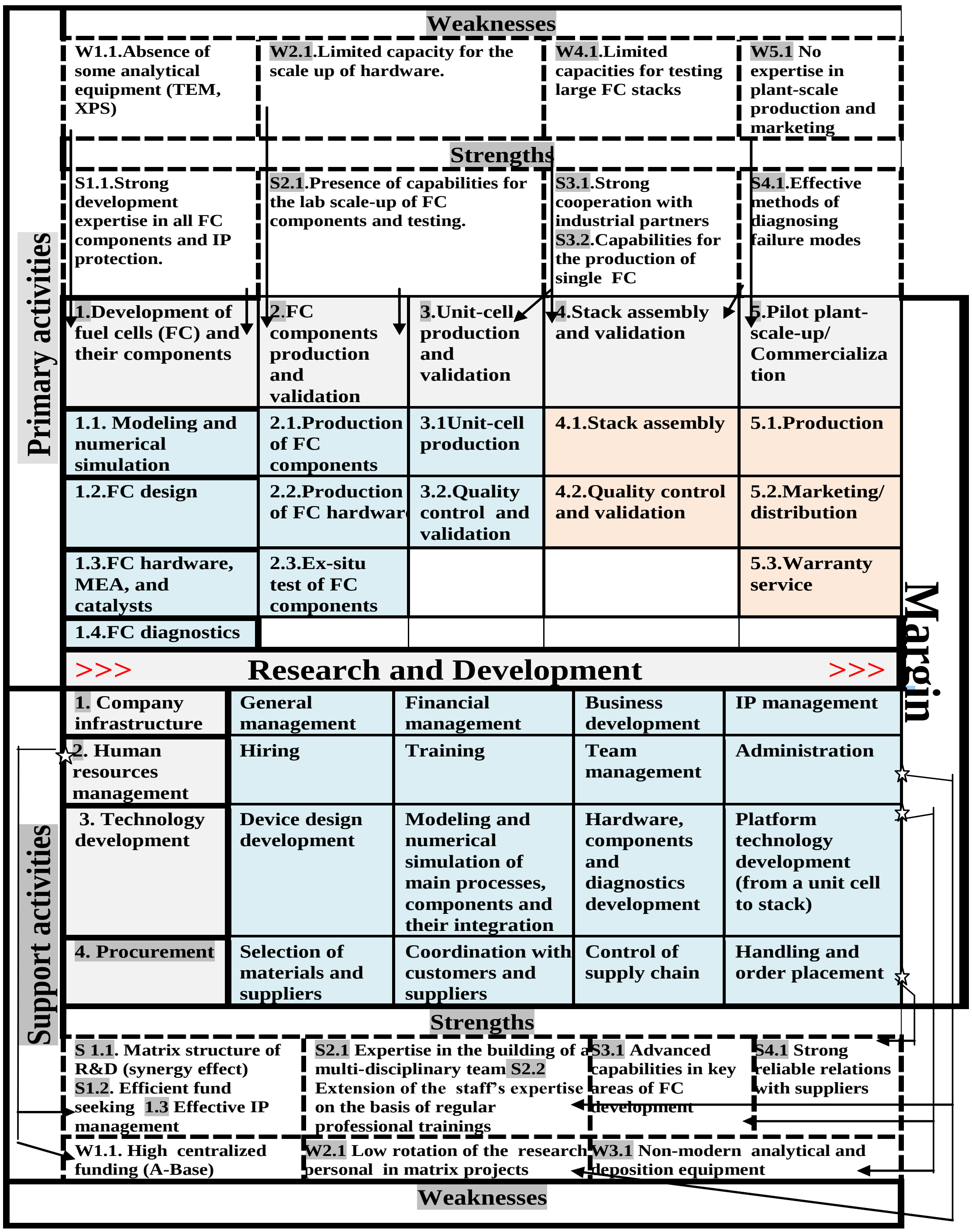
4.2.3 NRC-IFCI's Position in the Value Creation Process for Fuel Cells

Identification of the key NRC-IFCI competitive advantages is based on the overlapping of NRC-IFCI's strengths and weaknesses as described in section 4.2 of the value creation process (Duncan, 1998) (Fig.4.5). The determined strengths indicate the areas where NRC-IFCI can gain competitive advantages. All activities of the value chain were divided into two groups: performed by NRC-IFCI (depicted in blue) and NRC-IFCI partnerships and outsourced organizations (yellow). The NRC-IFCI's inputs such as knowledge, materials, technologies, and IP in the value creation pathway increases the significance of these inputs for potential out-licensing. This out-licensing enhances the value of IP in the value creation process. An alternative commercialization of developed FCs is the establishment of a joint venture with a fuel cells developer. NRC-IFCI's revenue generation is based on fee-for-service contracts, joint research collaborations, and out-licensing.

4.2.4 NRC-IFCI's Strengths and Weaknesses in the Value Creation Process for Fuel Cells

The effect analysis of NRC-IFCI's strengths and weaknesses on its position in the value creation process (Fig.4.5) allows for proper positioning choice and determines the competitive

Fig.4.5 NRC-IFCI's Strengths and Weaknesses in the Value Creation Process for Fuel Cell Companies



Source: by author, adapted from Porter, 1995, and Duncan, 1998 advantage of the institute. The main strength of NRC-IFCI is its unique multidisciplinary team with diversified knowledge of fuel cells, batteries, and other areas of the Clean Energy Sector. NRC-IFCI has sustainable and long-term relations with the main Canadian FC developers, such as Ballard and AFCC. Both are ready to commercialize NRC-IFCI's competitive and innovative products. Participation in the Fuel Cell Cluster allows NRC-IFCI to determine client needs and change its focus on time, depending on current market trends. Not only professional staff and effective collaboration with industry determine a competitive position in the value creation chain of fuel cells, but also modern capabilities in the production of prototypes, their characterization, and tests. Finally, when professionals in specific areas participate in different cross-NRC-IFCI projects and the NRC-IFCI's matrix projects, synergy is achieved. This combination of NRC-IFCI's strengths creates the unique value of fuel cell R&D that is difficultly to copy.

However, several NRC-IFCI weaknesses, such as a strong dependence on the centralized NRC A-base funding and limited capacities for lab scale up of FC components, are real threats to the sustainability of the organization. This financial weakness needs to be addressed urgently, as the new NRC strategy has been implemented and will permanently decrease A-base funding over the next five years. Substitute funding can be accessed through the cross-NRC and strategic Flagship programs: printable electronics, wheat, bio-composites (a developing value chain that replaces imported products), and algae (reduced GHG), but this requires some repositioning.

In summary, NRC-IFCI understands its own weaknesses and is in the process of decreasing its dependence on A-base funding by participating in several flagship programs and extending its lab scale up facilities. All these activities will increase NRC-IFCI's competitiveness for a positive effect on the commercialization of its developments.

4.3 NRC-IFCI's Position in the Value Creation Process for Rechargeable Metal-Air Batteries

NRC-IFCI started preliminary development of metal-air battery (MAB) components only two years ago, and full development of MAB design and prototype manufacture should be the next logic step in the process. This is one of the main alternatives for NRC-IFCI strategic development as outlined further in Section 5. An evaluation of the main stages of the value creation process for rechargeable MABs is shown in this section. NRC-IFCI is not a producer of MABs, so the prototypical value chain analysis has been adapted to the main stages of MAB commercialization (Porter, 1985) (Fig.4-6). The list of primary and support activities for the achievement of this goal is shown in the following sub-sections. Note, the support activities for battery development are similar to those used for FC development (see Section 4.2.2). The overlapping of NRC-IFCI's weaknesses and strengths in battery development onto the value creation process illustrates NRC-IFCI's competitive advantage (Duncan, Ginter, and Swayne, 1998).

4.3.1 Primary Activities in Battery Development

The five primary activities include development and design of battery components, battery component production and validation, battery unit cell production and validation, battery assembly and validation, production and commercialization. The R&D in the value creation process for rechargeable metal air batteries (MAB) is the first stage. Some of these activities NRC-IFCI per-

Fig.4.6 Value Creation Process for Producers of Rechargeable Metal Air Battery Companies

Primary activities	**1.Development and design of battery components**	**2. Battery component production and validation**	**3. Battery unit cell production and validation**	**4.Battery assembly and validation**	**5.Production / Commercializa - tion**	Margin
	1.1. Modeling of batteries and their components	2.1. Production of battery components	3.1. Battery unit cell production	4.1. Battery assembly	5.1.Production of batteries / battery stacks	
	1.2. Battery design	2.2. Internal quality control and validation	3.2. Internal quality control and validation	4.2 Battery test	5.2.Marketing / distribution	
	1.3. Battery hardware (current collectors, separators, sensors)	-	-	-	5.3.Warranty service	
	1.4. Catalysts, electrodes and gas diffusion layers	-	-	-	-	
	1.5. Battery diagnostics	-	-	-	-	
	>>> **Research and Development** >>>					
Support activities	1. IFCI infrastructure	General management	Financial management	Business development	IP management	
	2. Human resources	Hiring	Training	HR management	Administration	
	3. Technology development	Fuel cells/ primary batteries /sensors	MEA development	Catalyst and GDL development	Modeling of catalysts, MEAs, FC and water management systems	
	4. Procurement	Selection of materials and suppliers	Coordination with customers and suppliers	Control of supply chain	Handling and order placement	

Source: by author, adapted from Porter, 1995 forms itself and others using outsourced firms, out-licensing, or purchase of commercial products. NRC-IFCI selects the best option at the every stage in the dependence on available recourses and capabilities.

4.3.1.1 Development of Battery Design, Components, and Hardware

NRC-IFCI's unique expertise in the development of FC hardware and components is applicable to battery development as well. The main component of rechargeable MABs is the bi-functional electrode, which includes oxygen reduction reaction (ORR) catalysts on carbon/hybrid (carbon-metal oxide) supports and gas diffusion layers. NRC-IFCI has solid expertise in this field and can easily modify these ORR catalysts for their deployment in MABs. NRC-IFCI's expertise in modeling FC hardware is fully applicable to the battery design process as well.

4.3.1.2 Battery Component Production and Validation

NRC-IFCI can use its current facilities for the scale-up of such FC components as catalysts, and GDLs for battery development. The internal validation of produced battery components will satisfy the required industry quality.

4.3.1.3 Battery Unit Cell Production and Validation

The production of unit-cells of rechargeable MABs will be organized in with quality control at the every stage of the technological process. Produced unit-cells will be performance tested in the NRC-IFCI specialized test lab.

4.3.1.4 Battery Assembly and Validation

The output at this stage is the assembly of unit-cells at the facilities of battery manufacturers under NRC-IFCI technological control. NRC-IFCI does not have the scale up facility for assembling MABs. An optimal solution would include ICFI licensure to a battery producer, or through a strategic cooperation agreement with a battery producer.

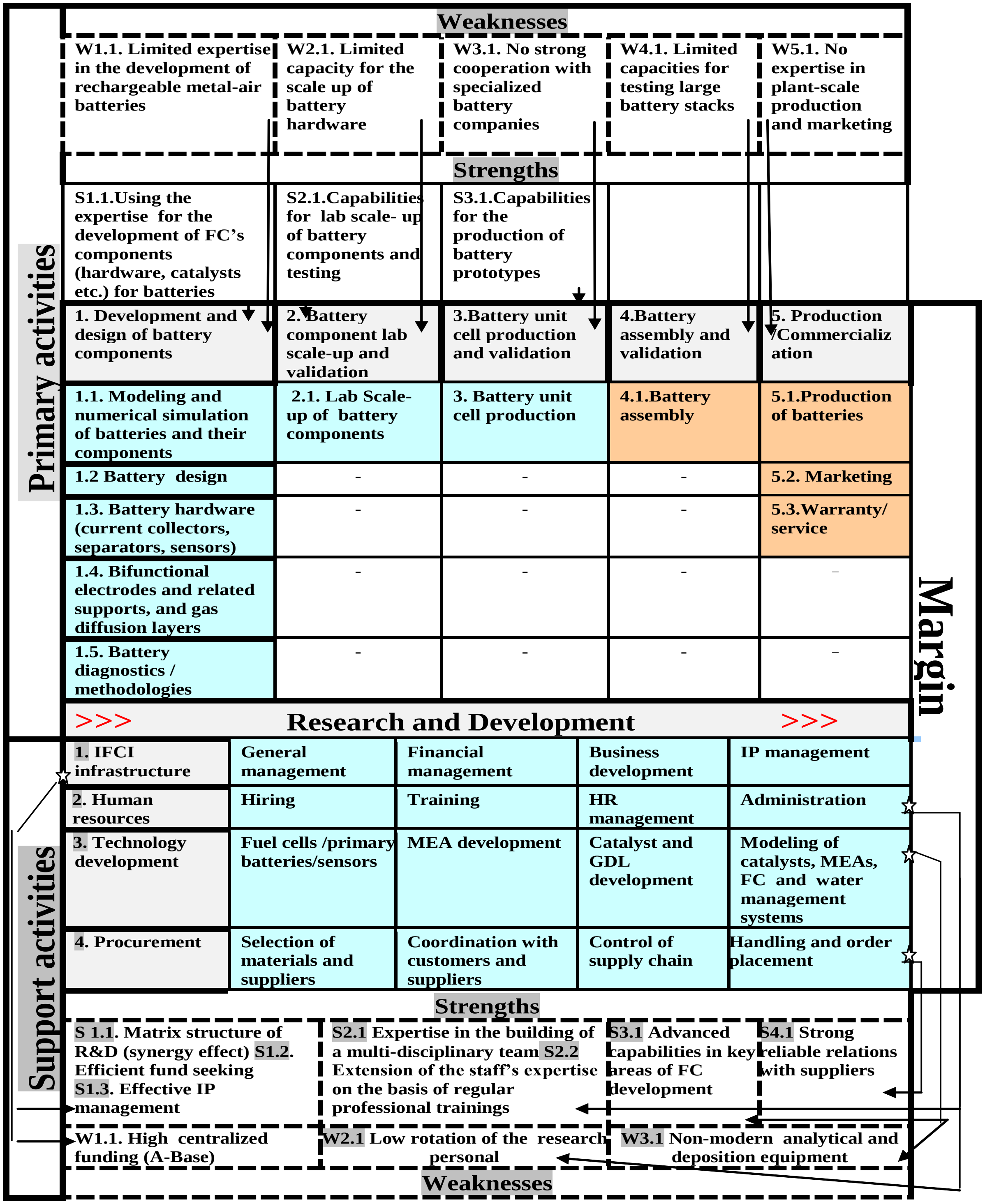
4.3.1.5 Production and Commercialization

The final stage of metal-air battery development is the manufacture of created technologies, materials, battery design and components through the facilities of an industrial partner. NRC-IFCI does not have the required commercial and manufacturing experience for this stage. Significant investment, personnel, and capabilities are needed for the manufacturing process. Therefore, this stage will focus on NRC-IFCI's industrial partners according to partnership agreements or out-licensing deals.

4.3.2 Analysis of NRC-IFCI Strengths and Weaknesses in the Value Creation Process for Rechargeable Metal Air Batteries

The analysis of the NRC-IFCI's weaknesses and strengths of support and primary activities in battery development determines the NRC-IFCI's competitive advantage in the Clean Energy Sector. All activities divided into two groups which are performed by NRC-IFCI (depicted in blue) and NRC-IFCI in the partnership (out-sourced deal, as depicted in yellow) (Fig.4.7). NRC-IFCI is a novice in the development of MABs in contrast with its leading position in the development of FCs. NRC-IFCI has limited expertise, capacity and patents, and collaboration with industrial partners is only at the initial stage. However, the development of FCs and their components is where NRC-IFCI has strong expertise and intellectual property similar MAB development. NRC-IFCI can leverage this FC expertise in the development of MABs. NRC-IFCI's position in the value creation process is as the developer of MABs and their components. The goal is to develop novel patented processes and components for MABs. An alternative is a strategic partnership with a battery manufacturer for sale under licence

Fig.4.7 NRC-IFCI's Strengths and Weaknesses in the Value Creation Process for Rechargeable Metal-Air Battery Companies



Source: by author, adapted from Porter, 1995, and Duncan, 1998

4.4 Summary of NRC-IFCI's Internal Analysis

The analysis of NRC-IFCI's resources and capabilities plus the primary and support activities for the commercialization of fuel cells and batteries demonstrates that the main competitive advantage of NRC-IFCI is in the R&D of novel fuel cells and lab scale up. The analysis of the identified strengths (strong team, effective partnership with industry, presence of lab scale up facilities, and matrix structure of R&D) and weaknesses (high percentage of centralized funding, some limitation of lab scale up) of NRC-IFCI allows the maximization of these strengths and the proper management of weaknesses. These strategies will be discussed in the next chapters.

5: NRC-IFCI'S CURRENT STRATEGIC PLANNING

This chapter outlines the current NRC-IFCI strategy to develop FC intellectual property and FC licence sales to industrial companies for commercialization. NRC-IFCI only recently began the development of certain elements of clean energy technologies (e.g., batteries, supercapacitors). Therefore, only NRC-IFCI's strategy in the FC market is discussed in this chapter. NRC-IFCI's strategy in the newly targeted rechargeable batteries segment is not completely developed. It is clear that the strategy for NRC-IFCI, as a new entrant in this segment, should be different for FCs and based on collaboration with existing companies. Thus, building a consortium for the development of metal-air batteries/supercapacitors would be the optimal strategy (see Chapter 6).

This R&D strategy mainly evaluates four levels: corporate, positioning, competitive, and functional (Grant, 2002). The identification of functional fields (production, financial, organizational) to support the main strategy is not the focus of this project. At the corporate level, NRC-IFCI focuses on the R&D development of FCs and clean energy storage devices, such as metal-air batteries and supercapacitors. A positioning strategy determines the placement of NRC-IFCI in targeted market segments, such as FCs and clean energy technologies. This strategy depends largely on the amount of competitors in each market segment. A competitive strategy provides a method for the realization of NRC-IFCI's competitive advantages as identified during the internal analysis (Chapter 4).

5.1 NRC-IFCI's Current Business Strategy

NRC-IFCI is a provider of scientific services focusing on the development of unique scientific and technical core competencies. This approach determines its current business strategy to develop novel FCs and clean energy technologies (e.g., components of metal-air batteries, super-capacitors, and smart grids), and out-licensing or sale of intellectual property. NRC-IFCI has capabilities and core competencies in the development, testing, and prototyping of fuel cells. NRC-IFCI uses these same capabilities for the development of elements of clean energy technologies. However, it only recently began to focus on energy storage developments, as NRC-IFCI activities are based on the development of parts, rather than whole systems. The development of electrodes for rechargeable metal-air batteries is a good example of the aforementioned.

5.2 NRC-IFCI's Niche Positioning Strategy

According to the available resources, capabilities, and unique core competencies in fuel cells (especially in PEMFCs), NRC-IFCI's development is destined for specific attractive, niche segments (fuel cell electric cars and buses, stationary residential applications and rechargeable metal air batteries). This positioning is based on the differentiation between unique and competitive NRC-IFCI's products. NRC-IFCI's niche positioning strategy is based on the following approaches:

- maximization of the impact on industrial partners through integration of all internal and external resources (including partnership with universities [pan-Canadian network], international organizations, and R&D consortia)

- strengthening business competencies (project management, marketing, and selling competencies of researchers).

5.3 NRC-IFCI's Competitive Strategy

Niche positioning requires strong differentiation of NRC-IFCI's developments like the cost efficiency of FC components (electrodes with low platinum loading; thin catalyst layers in MEA with high platinum utilization). This competitive strategy is based on competitive technologies and materials, numerical modeling, sensing and diagnostics, testing and prototyping (e.g., five PEMFC patent applications, see Section 4.1.4 Intangible Assets) and organizational strengths. This last strategy includes a matrix structure of R&D, effective IP management, expertise in the building of a multi-disciplinary team, advanced capabilities in key areas, and strong, reliable relations with suppliers. Using this strategy**,** NRC-IFCI distributes available resources between the satisfaction of client needs and novel developments. This differentiation also provides a proactive position in the market. This strategy requires permanent scanning of scientific and technical achievements, and technical intelligence.

5.4 Summary: The Critical Challenges for NRC-IFCI's Strategy

NRC-IFCI's current strategy involves patenting promising FC technologies and promoting commercial out-licensing. However, current limited financial support of FC development within the NRC, in addition to the stagnation of the FC market, is the reason for some difficulties with the implementation of this strategy. In fact, it is the primary threat to organizational sustainability. Therefore, new strategic alternatives are discussed in Chapter 6

6: ANALYSIS OF NRC-IFCI'S STRATEGIC ALTERNATIVES

Chapter 6 shows the possible strategic alternatives and their evaluation according to the multi-goal analysis of a non-profit organization (Boardman, Shapiro, and Vining, 2004).

6.1 NRC-IFCI's Strategic Alternatives

According to the internal and external analysis, several strategic alternatives were suggested:

Alternative 1. Follow the current strategy

NRC-IFCI looks for the commercialization of its FC and FC components development. The strategic NRC Technology Development Program (TDP), with the participation of AFCC and Ballard, improve the likelihood of overcoming obstacles in the way of commercialization. According to the U.S. DOE's analysis, membranes are a cost driver for FCs during production at 1000 stacks/year (prices in 2010), while platinum based electrodes determine the FC cost during production at 500,000 stacks per year (James and Kalinosky, 2010). NRC TDP's goal is to decrease platinum loading and corrosion of catalyst supports to increase catalyst durability, which is the main target of fuel cell companies. NRC-IFCI can leverage its FC development to satisfy industrial requirements through funding from the NRCan Clean Energy Fund and U.S. DOE Grants. However, out-licensing or sale of IP leads to IP loss.

Alternative 2. Organization of Several Specialized Consortia for the Commercialization of Main NRC-IFCI Developments (Fuel Cells, Batteries, and Diagnostic methods)

The establishment of the Fuel cell and Battery Consortium with industrial partners for the commercialization of NRC-IFCI developments will minimize the risks of losing IP and secure sufficient funding. Potential consortia and close cooperation with industrial partners, with the support of NRC Technology Cluster Initiative (two years, budget $135M), will improve cost/performance of fuel cells/batteries in global niche/mass markets. The establishment of a battery consortium or participation in an already established consortium such as the Lithium–Air Battery Consortium, led by IREQ (Montreal), will provide the necessary industrial impact.

Alternative 3. Focus on Revenue Generated Fee-for Service (FFS) Contracts for Scientific Services

This alternative allows the NRC-IFCI to focus on revenue-generated projects providing scientific services without positioning itself as a technology developer. NRC is positioning itself as the provider of scientific services with a primary goal to develop unique scientific and technical core competencies. The successful experience of the NRC-IFCI's group "Wear and Corrosion" in FFS projects in the created "Mining Wear Materials Consortium" is a good example of the implementation of this alternative.

Alternative 4. Organization of Several Specialized Consortia and Extension of the Revenue Generated Fee-for Services (FFS) Contracts

This alternative combines the organization of specialized consortia with the extension of the revenue generation FFS contacts for a significant increase of the NRC-IFCI's revenue and funding.

6.2. NRC-IFCI's Goals

The NRC-IFCI's goals are determined by the NRC mandate and NRC-IFCI's strategic R&D planning. The five long- and short-terms goals were selected according to the current NRC-IFCI strategy (NRC-IFCI, 2010):

1. To improve cost/performance of fuel cells to accelerate commercialization in global niche and mass markets

The commercialization of fuel cells is NRC-IFCI's primary goal. Its unique developments and close relations with industrial partners in British Columbia's FC Cluster provide excellent opportunities to commercialize fuel cells.

2. To lead the integration of fuel cells into the Clean Energy Sector supporting Canadian industry

One of the main goals of NRC-IFCI is the support of Canadian industry and to increase its competitiveness in the world market. The NRC-IFCI's R&D is always proactive, which allows for the advancement of innovative technologies and their integration into different Clean Energy Sectors developed by Canadian companies.

3. Expand capacities for the integration of FCs into Clean Energy Sector

According to the NRC-IFCI internal analysis, the presence of scale-up facilities for the production of main fuel cell components is one of NRC-IFCI's competitive advantages. However, these facilities were built mainly for fuel cell development. Nevertheless, they should be expanded according to the diversification of NRC-IFCI business in the direction of other Clean Energy developments (metal-air batteries, supercapacitors, smart grids etc).

4. Increase short-term revenue generation for financial sustainability

NRC-IFCI has a high percentage of centralized funding (A-Base) which will be permanently decreased over the next five years according to the new NRC strategy to increase external revenue generation. The main sources of revenue generation include an increase of fee-for- services contracts, direct investment from the provincial government of British Columbia, broadening the clean energy community stakeholder base, and cash leverage. Thus, the NRC-IFCI's goal to increase revenue generation completely corresponds with the NRC corporate strategy. This will all work to minimize of the effect of the decreasing NRC A-base funding on R&D.

5. Focus on World- Class FCs competencies and systems integration for Clean Energy Sector

NRC-IFCI's R&D focuses on competitive technologies while combining the best world achievements in targeted industries and research including rechargeable metal-air battery development. This allows for the permanent support of its core-competency.

6.3 Assessment of NRC-IFCI's Strategic Alternatives (Multi-Goal Matrix)

The assessment of the multi-goal matrix in Table 6.1 provides a selection of the best alternatives according to a quantitative evaluation of the impact of every alternative on each goal: low (1), medium-low (2), medium (3), medium-high (4), high (5), and the importance of every goal for a combined total of 100%. The impact values were calculated by multiplying goal weight times impact, and were summarized for every alternative. The assessments of these impacts and goals weightings was done on the basis of the author working with NRC-IFCI researchers. This multi-goal matrix shows the strategic alternative to build PEMFC and rechargeable battery consortiums and focus on revenue generation projects is more preferable for NRC-IFCI because of the maximum total impact, value, and positive effect across five main NRC-IFCI goals. This alternative is suggested, assuming that the short-term market of FCs and rechargeable batteries will have similar trends as the described external analysis in Chapter 3. Even in a worst case, when these markets demonstrate negative trends as it happened during the crisis of 2008-2009, this alternative is still the best.

Table 6.1: NRC-IFCI's Strategic Alternatives

Goals	Weight, %	Strategic alternatives							
		1.Follow the current strategy (commercialization of FCs through their out-licensing)		**2.Build PEMFC and rechargeable battery consortia**		**3.Focus on revenue generation projects (fee-for-service, industrial collaboration)**		**4.Build PEMFC and rechargeable battery consortia and focus on revenue generation projects**	
		Impact	Value	Impact	Value	Impact	Value	Impact	Value
1. To improve cost/performance of fuel cells to accelerate commercialization in global niche/ mass markets	30	High (5)	1.5	High (5)	1.5	Low (1)	0.3	High (5)	1.5
2.To lead the integration of FCs into Clean Energy Systems supporting Canadian industry	20	High (5)	1.0	Low-High (4)	0.8	Low (1)	0.2	Low-High (4)	0.8
3.Expand capacities in integration of FCs into Clean Energy Sector	15	Medium-High (4)	0.6	High (5)	0.75	Low (1)	0.15	High (5)	0.75
4.Increase short-term revenue generation for financial sustainability	30	Low (1)	0.3	Medium (3)	0.9	High (5)	1.5	High (5)	1.5
5.Focus on World Class competencies in FCs and systems integration for Clean Energy Sector	5	Medium-high (4)	0.2	Medium-high (4)	0.2	Low (1)	0.05	Medium -high (4)	0.2
Total	**100**		**3.4**		**4.15**		**2.2**		**4.75**

Source : by author

7: SUMMARY AND RECOMMENDATIONS FOR NRC-IFCI

This external analysis of the fuel cell and battery markets, internal analysis of NRC-IFCI, the overall battery industry, and multi-goal evaluation of NRC-IFCI’s strategic alternatives show that FC and battery consortium-building and a focus on revenue generation-specific projects is the best strategy. This strategy is more efficient in comparison to the current strategy, such as the commercialization of fuel cells through out-licensing. Using this new strategy allows NRC-IFCI to accelerate its strengths and innovative competitive developments at earlier stages of the value creation process for FCs and rechargeable metal-air batteries. Diversification of NRC-IFCI’s FC business in terms of the development of rechargeable MABs for EVs, stationary applications (UPS, power generators), and portable electronics, in cooperation with battery producers, will better satisfy NRC goals. It will decrease NRC-IFCI dependence on NRC centralized funding as well. Moreover, this new strategy will save NRC-IFCI's unique core competency, and main stated goal in FC development, while supporting the Canadian fuel cell industry.

NRC-IFCI should actively promote fuel cell development in the NRC. NRC now develops new strategic flagship programs and, depending on a proactive NRC-IFCI position, fuel cells could be part of one of these flagship programs. Going in this direction, NRC-IFCI should use the support of the FC BC cluster and active commercialization of fuel cells by several auto producers, for example Daimler-Benz, which decided to build a fuel cell stack plant in Burnaby in 2012.

The suggested strategy is the best considered during current market conditions. However, the weight of the suggested strategic alternatives for NRC-IFCI could be different in a changing environment (i.e., an economic downturn, increased competition and/or decreased demand on the

FC market). In this new situation, the other strategic alternatives, such as the building of consortia or focus on revenue generation projects (fee-for-service, industrial collaboration) might be preferable. Permanent monitoring of the external environment and the adjustment of NRC-IFCI's current strategies, according to its changes, is the basis of successful competition in a dynamic FC market.

8: REFERENCE LIST

Abuelsamid, S. (2009, August 20). W*hy Choose a Fuel Cell or an Internal Combustion Engine When Using Hydrogen.* Retrieved from http://green.autoblog.com/tag/ hydrogen+fuel+cells

Boston Consulting Group. (2009, January). *Batteries for Electric Cars: Challenges, Opportunities, and the Outlook to 2020.* Retrieved from http:/*/www.bcg.com/documents/file36615.pdf*

Boardman, A.E, Shapiro D.M., and Vining A.R.(2004). A Framework for Competitive Strategic Analysis. *Journal of Strategic Management Education*, 1(2), 1-12.

Brandenburg A.M, Nalebuff, B.J. (1996). *Co-Opetition: A Revolution Mindset That Combines Competition and Cooperation. The Game Theory Strategy***.** New-York**:** Currency Doubleday.

Brodd, R.J. (2005, June 20). National Institute of Standards and Technology. *Factors Affecting U.S. Production Decision: Why are There No Volume Lithium-Ion Battery Manufacturers in the United States?* Retrieved from http://www.atp.nist.gov/eao/wp05-01/chapt4.htm

CBC News (2009, July 15). Ontario Pushes Electric Cars as Auto-Sector Boost. Retrieved from http://www.cbc.ca/canada/story/2009/07/15/ont-electric-cars511.html

Christian, O., Soble, J., & Hille, K. (2010, March 3). Scramble for Lithium Gathers Pace. *Financial Times.* Retrieved from http://www.ft.com/intl/cms/s/0/3cd33dbc-2ae0-11df-886b-00144feabdc0.html#axzz1VsfUGbBO

Cowlishaw, M. F. (1974). The Characteristics and Use of Lead-Acid Cap Lamps. *Trans. British Cave Research Association* 1(4), 199–214. Retrieved from http: /speleotrove.com/caving/ cowlishaw1974-lead-acid-cap-lamps.pdf

Duncan,W.J., Ginter, P.M., & Swayne, L.E. (1998) Competitive Advantage and Internal Organizational Assignment. *Academy of Management Executive*, 12(3), 6-16

Energy Business Reports. (2008, July). *Fuel Cell Technology and Market Potential Report and Manufacturer Directory.* Retrieved from http://www.energybusinessreports.com

Ezinemark.Com. (2011, June 20). *Competitive Analysis of Li-ion Batteries: Lithium-ion Battery Industry: China, Japan and South Korea Take One Third of the World.* Retrieved from http://business.ezinemark.com/lithium-ion-battery-industry-china-japan-and-south-korea-take-one-third-of-the-world-31dcb0bb768.html

FourPxArticles. (2011).*Lithium-ion Battery Industry: China, Japan and South Korea Take One Third of the World*. Retrieved from http:// www.fourpxarticles.com/society/relationships/lithium-ion-battery-industry-china-japan-and-south-korea-take-one-third-of-the-world, January 10, 2011

Frost & Sullivan. (2008, June). *Strategic Analysis of Global Market for Fuel Cell Electric Vehicle.* Retrieved from http://www.frost.com/prod/servlet/report-toc.pag?repid=M2EB-01-00-00-00

Frost & Sullivan. (2010, June 20). *Investments Prospects in Renewable energy Storage Market.* Retrieved from http://www.frost.com/prod/servlet/report-toc.pag?repid=N821-01-00-00-00

Frost & Sullivan. (2007). *World Alkaline Battery Market.* Retrieved from http://www.frost.com/prod/servlet/report-brochure.pag?id=N006-01-00-00-00

Frost & Sullivan (2007, June 20). *World Secondary Lithium-ion Battery Markets.* Retrieved from http://www.frost.com/prod/servlet/report-brochure.pag?id=N18F-01-00-00-00

Gates Energy Products. (1997). *Rechargeable Batteries Applications Handbook*. Newnes, Woburn, Massachusetts: Butterworth-Heinemann.

Grant, R.M. (2002). *Contemporary Strategy Analysis* (4th ed). Oxford: Wiley-Blackwell.

Green Autoblog. (2010, March 11). *Japan's Fuel Cell Market Could Grow 99-fold by 2025*. Retrieved from http://green.autoblog.com/2010/03/11/report-japans-fuel-cell-market-could-grow-99-fold-by-2025

Green Autoblog. (2011, March 23). *Mercedes-Benz Will Produce Next-gen Fuel Cell Stacks in Canada*. Retrieved from http://green.autoblog.com/2011/03/23/mercedes-benz-produce-fuel-cell-stacks-in-Canada

Green Autoblog. (2010, August 30). *Toyota SunHydro to Test 10 Highlander Fuel Cell Vehicles in Connecticut This Fall*. Retrieved from http://green.autoblog.com/2010/08/30/toyota-unhydro-to- test-10-highlander-fuel-cell-vehicles-in-con

IREQ (Institut de Recherche en Electricité du Québec) (2010). Retrieved from http/www.hydroquebec.com/en, June 10, 2011.

Japan Today (2010, March 17). *Japan's Fuel Cell Market Estimated to Expand Nearly 100-fold by FY 2025*. Retrieved from http: //www.japantoday.com/category/ technology/view/japans-fuel-cell-market-estimated-to-expand-nearly-100-fold-by-fy-2025

Japan's Corporate News. (2008, March 12). *Panasonic to Build Lithium-ion Battery Plant in Osaka*. Retrieved from http://www.japancorp.net/article.asp?Art_ID=19219

James, B.J., Kalinosky J. (2010, June 4). *DOE Hydrogen Program: 2010 Annual Merit Review*. Retrieved http://www.hydrogen.energy.gov/annual_review10_report.html

Kempf, H. (2008, October 9). *Limited Lithium Supplies Could Restrict Electric Car Growth, EV World*. Retrieved from http://evworld.com/article.cfm?storyid=1544

Lewis, L. (2007). *Handbook of Batteries* (3rd ed.). New-York: McGraw-Hill.

Linden, D., & Reddy, T.B. (2003). *Handbook of Batteries* (3rd ed.). New-York: McGraw-Hill.

Lux Research. (2010, January). *Panasonic Acquires Sanyo and Becomes a Top Player in Li-ion Batteries and Solar.* Retrieved from http://www.luxresearchinc.com/blog/2010/01/panasonic-acquires-sanyo-and-becomes-a-top-player-in-li-ion-batteries-and-solar/

Neburchilova, E. (2010, January). *NRC-IFCI Report*. *IP portfolio and Technology Transfer Pathways NRC-IFCI Strategic Management IP Committee* (SMIP). Retrieved from http://home.ic.nrc.ca

Pillot, C. (2009, September 30). *Present and Future Market Situation for Batteries, Avicenne Development*. Retrieved from http://www.cars21.com/files/news/present-and-future-market-situation-for-batteries.pdf

Porter, M.E. (1979). How Competitive Forces Shape Strategy. *Harvard Business Review*, 5792, 137-145. Retrieved from http://hbr.org/2008/01/the-five-competitive-forces-that-shape-strategy/ar/1

Power Stream. (2009, April 7*). 2009 Annual Report.* Retrieved from www.powerstream.ca/app/pages/ PUB-2009-AR.jsp

Pretcher, R. (2009, March 29). *Lithium Demand, Pricing, and Supply Forecast Considered as Li-ion in Automotive Use to Surge.* Retrieved from http://www.marketoracle.co.uk /Article9722.html

ReVolt, Inc. (2010, August 10). Retrieved from www.revolt.co.uk/new/website.php

SBI Energy (2009, March 12). *Advanced Storage Battery Market: From Hybrid/Electric Vehicles to Cell Phone.* Retrieved from http://www.sbireports.com/docs/SBI_AdvancedStorage Battery Market White Paper_October2009.pdf

Science-Metrix. (2008, June). The BC Fuel Cell. Retrieved from www.nrc-cnrc.gc.ca

Simon, B. (2010, February 19). Fisker Raises $115M to Fuel Electro-Car Plant. *Financial Times*. Retrieved from http://www.ft.com/intl/cms/s/0/5787fe2c-02b3-11df-86b3-00144feabdc0.html#axzz1VsfUGbBO

Sharma, R. (2006). *Business Model for the Canadian Institutes for Fuel Cell Innovation.* Simon Fraser University, Final Thesis. Retrieved from http://www ir.lib.sfu.ca/retrieve /4248/etd2677.pdf

Sparrow, B., & Whittaker, C.H. (2005). *Technology Roadmap and Resource Allocation Methodology for the Canadian Institute for Fuel Cell Innovation (IFCI).* Simon Fraser University, Final Thesis. Retrieved from http://www.ir.lib.sfu.ca/retrieve/2461/etd2064.pdf

Tech & Industry Analysis from Asia. (2010, July 28). *Sony Leads Ranking of Alloy-based Negative Electrode Patent Holders.* Retrieved from http://techon.nikkeibp.co.jp/english/news_en/20100728/184619

U.S. DOE. (2009). *2009 DOE Hydrogen Program Annual Merit Review*. Retrieved from www.energy.gov

U.S. DOE. (2011, May 15). *Los Alamos National Lab. DOE Report Project ID:FC005.* Retrieved from http://www.hydrogen.energy.gov/annual_progress10.html

Weimer, D.L., & Vining, A.R. (1999) *Policy Analysis: Concepts and Practice* (3rd ed.). Saddle River, NJ: Prentice Hall.