TECHNOLOGY ROADMAP AND RESOURCE ALLOCATION METHODOLOGY FOR THE CANADIAN INSTITUTE FOR FUEL CELL INNOVATION (IFCI)

by

Benjamin Sparrow, P.Eng.
Bachelor of Science, University of Alberta, 1999

C. Helen Whittaker, PMP
Bachelor of Technology, Loughborough University, 1983

PROJECT SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF BUSINESS ADMINISTRATION

In the
Faculty
of
Business Administration

Management of Technology

SIMON FRASER UNIVERSITY

Fall 2005

APPROVAL

Name: **Benjamin Sparrow & Christine Helen Whittaker**

Degree: **Master of Business Administration**

Title of Project: **Technology Roadmap and Resource Allocation Methodology for the Canadian Institute for Fuel Cell Innovation (IFCI)**

Supervisory Committee:

____

Dr. Elicia Maine
Senior Supervisor
Assistant Professor, Faculty of Business Administration

____

Dr. Michael Parent
Academic Director of the Management of Technology MBA,
Faculty of Business Administration

Date Approved: November 18, 2005

Title of Project:

Technology Roadmap and Resource Allocation Methodology for the Canadian Institute for Fuel Cell Innovation (IFCI)

Author's Signature: ______________________________
Benjamin Sparrow

Author's Signature: ______________________________
C. Helen Whittaker

November 18, 2005
(Date Signed)

ABSTRACT

A technology roadmap and research resource allocation methodology was developed for the Canadian National Research Council's Institute for Fuel Cell Innovation (IFCI). This report outlines the roadmap and portfolio mapping tools developed, demonstrates how they were applied to the institute's 2005 portfolio of projects, and outlines a process by which the tools can be applied in the future. This work also includes a review of the relevant literature on technology roadmapping and research portfolio management as well as an internal and external analysis of IFCI.

The technology roadmap and resource allocation methodology will aid IFCI in determining which projects to fund when faced with limited resources. The external analysis shows that IFCI is well positioned to make a substantial contribution to fuel cell commercialisation and to build a world-class reputation. However, being a young institute in an emerging field, IFCI is finding it challenging to define and implement a coherent strategy. IFCI is working to refine its strategic direction and build capabilities that match the needs of the cluster which it is intended to serve. This report closes with recommendations for further improvement.

Keywords: Fuel cell industry, Fuel cell R&D, Research project portfolio management, Technology roadmap, Resource allocation.

ACKNOWLEDGEMENTS

The authors wish to acknowledge Charles Holmes, through whom the initial IFCI and project introductions were made. Furthermore, we are extremely grateful to Dr. Elicia Maine for her guidance, support and encouragement during the course of the project.

Within IFCI, Dr. Yoga Yogendran's support and desire for improvement ultimately led to the development of the technology roadmap and resource allocation methodology. Yoga was essential in providing feedback, the material required and access to various resources. Maja Veljkovic, Dr. David Ghosh, and Lori Law of IFCI also deserve thanks for taking time to contribute to and review components of the work.

TABLE OF CONTENTS

Approval ii

Abstract iii

Acknowledgements iv

Table of Contents v

List of Figures vii

List of Tables viii

Glossary ix

1 Introduction 1

1.1 The NCR Institute for Fuel Cell Innovation (IFCI) 1
1.2 Project Background & Stakeholders 1
1.3 Report Content 2

2 Literature Review 3

2.1 Terminology 3
2.2 R&D Categorisation and Metrics 4
2.3 Portfolio Management Rationale 8
2.4 Portfolio Modelling: Tools and Methods 9
2.5 Technology Roadmapping 16
2.6 Canadian Fuel Cell Industry Background Documents 23

3 External Analysis 26

3.1 Overview of the Global Fuel Cell Industry 27
3.2 Attractiveness of the Global Fuel Cell R&D Sector 31
3.3 Overview of the Canadian Fuel Cell Industry 37
3.4 Canadian Fuel Cell Research Spectrum 42
3.5 IFCI Stakeholder Analysis 43
3.6 Practices at other NRC Institutes 48
3.7 External Analysis Summary 52

4 Internal Analysis 54

4.1 IFCI Organisational Structure 54
4.2 Current Resources and Functional Capabilities 57
4.3 Expertise and Strategic Focus 59
4.4 Resource and Capability Gaps 62
4.5 Internal Analysis Summary 65

5 IFCI's Strategic Summary **71**

6 Portfolio Methodology Development **74**

6.1 Project Classification System and Research Summary 74
6.2 IFCI's Current Resource Allocation Process 77
6.3 Portfolio Methodology Developed 79
6.4 Suggested Application Process 86
6.5 Portfolio Methodology Summary 87

7 Technology Roadmap **89**

7.1 Methodology Employed 89
7.2 Roadmap Summary 95

8 Recommendations and Conclusion **97**

8.1 Recommendations for Roadmap and Resource Allocation 97
8.2 Recommendations based on Best Practices for the Institute 98

CD-ROM Appendices **102**

Appendix A: Target Objectives Map 102
Appendix B: IFCI Technology Roadmap 102

Reference List **103**

LIST OF FIGURES

Figure 2-1: Generic technology roadmap 17

Figure 2-2: Innovation Matrix: required availability against technology uncertainty 19

Figure 3-1: Fuel cell industry technology focus, divided based on revenues and employees 31

Figure 3-2: Fuel cell development spectrum 43

Figure 3-3: IFCI Stakeholder Map 44

Figure 4-1: IFCI Organisational Structure 56

Figure 5-1: IFCI Strategic Summary for 2006 - 2010 73

Figure 6-1: IFCI Program summary portfolio map 2005 82

Figure 6-2: IFCI Demonstration and community stewardship portfolio map 2005 83

Figure 6-3: IFCI Science and Technology PEMFC program portfolio map 2005 83

Figure 6-4: IFCI Science and Technology SOFC program portfolio map 2005 84

Figure 6-5: IFCI Science and Technology Hydrogen program portfolio map 2005 84

Figure 6-6: IFCI's 2005 funding allocation between programs 85

Figure 7-1: Diagrammatic roadmap market driver level 91

Figure 7-2: Diagrammatic roadmap IFCI technology programs 93

Figure 7-3: Diagrammatic roadmap for IFCI community stewardship 94

LIST OF TABLES

Table 2-1: Hauser's 3 tiers of R&D and proposed metrics 6

Table 2-2: Jolly's technological competitiveness and attractiveness 12

Table 2-3: Canadian Fuel Cell Commercialisation Roadmap Challenges and Actions 24

Table 2-4: BC Hydrogen Strategy objectives and action summary 25

Table 3-1: Publicly traded fuel cell firm data on technology focus and revenues 29

Table 3-2: Publicly traded fuel cell firm data on R&D expenditures and employment 30

Table 3-3: Canadian fuel cell organisations by sector and type in 2003 39

Table 3-4: Canadian fuel cell technology, market and demonstration project proportions in 2003 40

Table 3-5: Canadian fuel cell industry 2002 & 2003 revenues and growth by offering 41

Table 3-6: R&D portfolio management questions posed to NRC institutes 49

Table 4-1: IFCI Capabilities 59

Table 4-2: Critical Success Factors for a Research Institute 66

Table 6-1: IFCI 2005 budget data and collaborative measures 85

Table 6-2: IFCI Program funding and leverage summary 85

GLOSSARY

DND	Department of National Defence
DMFC	Direct Methanol Fuel Cell
EC	Environment Canada
ECV	Expected Commercial Value
FCC	Fuel Cells Canada
IC	Industry Canada
IFCI	Institute for Fuel Cell Innovation
NRC	National Research Council
NRCan	Natural Resources Canada
NSERC	National Science and Engineering Research Council
PEMFC	Proton exchange membrane fuel cell
PWC	Price Waterhouse Coopers
PWGS	Public Works Canada
SOFC	Solid oxide fuel cell
TC	Transport Canada
WD	Western Economic Development Canada
IMI	NRC Industrial Materials Institute
BRI	NRC Biotechnology Research Institute
NINT	NRC National Institute for Nanotechnology

1 INTRODUCTION

1.1 The NCR Institute for Fuel Cell Innovation (IFCI)

The National Research Council's (NRC) Institute for Fuel Cell Innovation (IFCI) was established in 2001 with the mandate to support the Canadian fuel cell industry and advance the commercialisation of fuel cell technology. IFCI received $20 million CDN in funding to be spread from 2002 to 2007, with the addition of another $4 million per year in cluster support and another $12 million CDN to be received over the next two years. Located in Vancouver BC, IFCI has established itself as an integral part of the British Columbian fuel cell cluster. IFCI employs a team of approximately 60 engineers and scientists, plus 20 support staff, who are working to fill the technology gaps required for successful widespread commercialisation of fuel cell technology. To address this goal, IFCI's projects fall under one of two broad categories:

i. Demonstration and Community Stewardship Projects

ii. Science and Technology Projects

Projects that fall into the first category directly support the BC fuel cell cluster by building network links, promoting collaboration and knowledge sharing, and aid in moving technology from the lab into the field. Projects that fall into the second category involve innovative research aimed at addressing key technical challenges faced by the fuel cell industry.

1.2 Project Background & Stakeholders

With limited funds and an abundance of potential projects, IFCI required a systematic means of allocating its scarce resources and building a project portfolio. In addition, IFCI wished to summarise its projects on a technology roadmap that would show project relationships and how each project ultimately contributes to the commercialisation of fuel cell technology. Through Charles Holmes, a facilitator and member of Simon Fraser University's Learning Strategies Group, Dr. Elicia Maine was asked to aid in the process. She subsequently recruited the authors: Benjamin Sparrow and Helen Whittaker, to complete the project. Benjamin and Helen worked closely with Dr. Yoga Yogendran, IFCI's Director, Technology Deployment and Commercialisation, to create the research resource allocation methodology and technology roadmap. Yoga delivered these items, along with a summary report and a short document outlining IFCI's strategy, to the institute's advisory board. Helen and Ben also met with and sought input from:

- Maja Veljkovic: IFCI's Director General
- Dr. David Ghosh: IFCI's Director, Science and Technology
- Lori Law: IFCI's Demonstration Project Lead
- six other middle managers and project leads

1.3 Report Content

This report includes a review of relevant literature pertaining to research portfolio management, technology roadmapping and Canadian fuel cell industry strategic documents. An external and internal analysis of IFCI is outlined, followed by a summary of the research resource allocation methodology and a technology roadmap that were created. In addition, recommendations and lessons learned are noted.

2 LITERATURE REVIEW

Extensive literature exists on the topic of research portfolio management, which includes technology roadmapping. In this section, key literature and insights are reviewed. This review is prefaced by a finding that highlights the importance of research portfolio management: all winners of the Product Development and Management Association's Outstanding Corporate Innovator Award over the course of sixteen years had a "robust process at the front end to drive innovation in the product portfolio" (Kahn et al., 2005, p. 529). Thus, for an outstanding research organisation, active research portfolio management appears to be a necessary component.

2.1 Terminology

The following definitions, which were adapted from Patterson's work (2005, p. 46-57), will be used throughout this report. In addition to definitions, some notes pertaining to sound practices are included:

Portfolio: a set of R&D projects, technology and product development efforts that are currently funded and underway; the portfolio should be planned and managed.

Portfolio planning: the creation of a plan for new products and technologies that integrates both market and technology perspectives and is responsive to the firm's overall business strategy. Key outputs of the process are: (1) a roadmap of future products and services, (2) a roadmap for future technology efforts and (3) high quality decisions on whether or not to add candidate new products or technology efforts to the current portfolio.

Portfolio management: a set of activities that includes portfolio assessment, resource management and portfolio review.

Portfolio assessment: based on the objective of ensuring that the current set of new product and technology investments are: (1) likely to provide the desired returns, (2) in line with the firm's strategic directions, (3) continues to reflect the best possible use of available resources.

Resource management: involves knowing who is working on what, estimating the impact of new or proposed projects on resources, deciding whether projects can be adequately supported, and ensuring that the R&D investment is being spent as intended. Room should be left for experimentation in a conscious rather than clandestine fashion.

Portfolio review: should aim to accomplish the following objectives: (1) ensure that new product investment remains on track relative to expectations, (2) enforces a sense of urgency and accountability among project personnel, (3) provides opportunities for correction of project direction or performance, and (4) discovers exceptional performance and provides proper and timely recognition

Technology roadmap: a 'moving belt' representation of future products or technologies versus time that can provide long-term guidance for strategic planning and capability development efforts. Current, unfunded and envisioned future projects should be included in the roadmap with linkages and dependencies noted.

2.2 R&D Categorisation and Metrics

Prior to delving into the details of portfolio management, a higher-level view of research program classification systems will be taken. Mitchell and Hamilton (1988) proposed that there are three, somewhat overlapping, categories of R&D that large firms should finance, with each category having different objectives and project selection criteria. These categories are summarised below:

1. **Knowledge building:** basic research and monitoring; no market analysis; work should reflect wide potential; firms should not attempt to evaluate return on investment; this category should comprise a small part of the R&D budget (2 – 10%).
2. **Strategic positioning:** focused applied research and exploratory development; considers a broad market with wide potential; evaluate using 'options thinking' and fund with 10-25% of R&D budget.
3. **Business development:** product development and engineering; focused on a specific market; evaluate using net present value (NPV) and conventional techniques while recognizing the role of uncertainty in reducing NPV; allocate the majority of a firm's budget to such activities (70 – 99%).

Similar to Mitchell and Hamilton's work (1998), Hauser and Zettelmeyer (1997) noted that firms should focus on three categories of research, yet Hauser and Zettelmeyer used a slightly different classification scheme. Their work was based on a survey of 43 CEOs and CTOs at ten research intensive firms including Bosch GmbH and AT&T Bell Laboratories. Hauser et al. proposed a three tier metaphor, as well as potential metrics for portfolio management within each of the tiers, both of which are summarised in **Table 2-1.**

Table 2-1: Hauser's 3 tiers of R&D and proposed metrics

Tier	Description	Possible Metrics
1	Basic research exploration: • encourage experimentation • encourage research tourism and investigation of all ideas regardless of their source • neglect market potential	• quality of people • refereed papers • internal process measures (percent of goal, overhead cost, etc)
2	Programs to match or create core technological competence: • recognize that research programs differ from applied projects • choose research programs carefully and before effort is expended • encourage the 'right' amount of effort and monitor it • give market potential a small relative weighting	• combine effort and market-based metrics • consider system effectiveness and technology scope • peer reviews • benchmarking • innovation counts & patents • goal fulfilment & yield
3	Applied projects with or for business unit: • business units have say in choice of projects, yet balance this with centralised decisions to promote longer-term projects • consider subsidies to avoid short-termism, risk aversion and scope narrowing • use 'options thinking' to measure value and flexibility in initial funding and continuation decisions • focus on a specific market / customer	• majority of above metrics apply • value top 5 deliverables • productivity and relevance • time metrics: completion, to market, response to customer, etc • competitive response • customer satisfaction and faults found • revenue / gross margin (3-5 years) • economic value added and break even

Source: Hauser, J. R., & Zettelmeyer, F. (1997). Metrics to evaluate RD&E. Research Technology Management, 40 (4), 32-38

Important parallels between the Mitchell and Hamilton, and Hauser and Zettelmeyer approach include:

- the distinction between what can be generalized as basic, applied and commercial R&D
- recognition of the importance of some allowance for research exploration and experimentation
- appropriate consideration of external factors such as ideas generated elsewhere and market potential
- use of non-conventional valuation techniques such as 'options thinking'

Further to the topic of the metrics proposed by Hauser and Zettelmeyer (1997), Godener and Soderquist (2004) noted that extensive literature on performance measurement techniques related to R&D and new product development (NPD) exists, yet little work has been completed on determining the use and impact of performance measurement techniques (Godener & Soderquist, 2004). Based on a study of three R&D intensive firms, Godener and Soderquist (2004) found that measuring performance results in better coherence and relevance of product portfolios. Furthermore, the measurement and evaluation process resulted in reorientation of projects and corrective actions being taken when required. The measurements were also noted to support product launch decisions, enhance staff motivation and facilitate balanced decision making. Interestingly, they found what they considered a serious weakness amongst the three firms surveyed – the lack of post mortem evaluations.

A final categorisation approach, which is worth mentioning since IFCI employs a similar classification scheme, is that of Gonzalez-Zugasti et al. (2001). They proposed that interrelated projects can be categorised and managed as a "research platform." They proposed that research platform and portfolio management can be viewed as a two step optimization problem. The first step involves determining or designing the technical aspects of the platform optimising around a set of objectives subject to technical constraints. The second step involves platform valuation with due attention granted to uncertainty; real options were noted as an appropriate valuation approach. One then rolls-up these two steps into a quantitative measure of platform value to the firm, which can then be used to select the appropriate platform design and make funding decisions.

2.3 Portfolio Management Rationale

The quality management guru Dr. W. E. Deming is noted for saying "All models are wrong. Some models are useful." This quote highlights that models can be important tools, yet should not be solely relied upon in decision making. This theme is echoed in other literature. Nevertheless, models facilitate communication and provide an important structure to what can be a challenging process.

Based on a survey of 35 "leading firms," Cooper et al. (1997) noted that a portfolio management system should satisfy the following three goals:

1. **Maximize the value of the portfolio:** the criteria for value will differ for each firm, but common ones include profitability, return on investment or options value.
2. **Provide balance**: this will be specific to each business, but should reflect long vs. short-term, high vs. lower risk, and a spread between product categories and market segments.
3. **Support the strategy of the enterprise:** the seemingly obvious requirement of alignment between the firm's strategy and its research portfolio should not be overlooked.

In their survey, Cooper et al. (1997) also found that almost all firms experienced the same problems:

- projects are not well aligned with the firm's strategy
- weak or mediocre projects are being funded
- poor projects are not being killed
- success rates at launch are poor
- resources are scarce and there is a lack of focus
- too many trivial projects (modifications and updates) are being funded versus too few projects aiming for technological breakthroughs

In a later work by Cooper et al. (1998a, p. 20), 205 firms were asked to assess the value that they felt they extracted from their research portfolio. The important conclusion was that firms reporting greater success in developing portfolios noted that:

- they had an explicit method for portfolio management with clear rules and procedures
- management buys into and supports the method
- all projects were considered part of the portfolio; no special treatment for outliers
- the method was applied consistently across all projects

Interesting statistics on R&D project success rates were drawn from a comparative study (Mansfield et al., 1972) of forecasts and outcomes for new technology products in a sample of large US firms. The study found the obvious result that it can be challenging to pick technological and commercial winners. The authors calculated the historic probability of technical success to be 80% and subsequent commercial success to be 20%, resulting in a combined probability of 16% for success in both stages. They also found that on average, costs were greatly underestimated and time periods overestimated by 140 – 280% for incremental product improvements and by 350 – 600% for major new products. Another study found that only 50% of R&D expenditures result in project success (Booze & Hamilton, 1982, p. 36). Yet another study found that "R&D scientists and engineers are often deliberately overoptimistic in their estimates, in order to give the illusion of a high rate of return to accountants and managers" (Freeman, 1982). These findings demonstrate the need for a structured portfolio management process that aims to reduce the potential for some of the above outcomes.

2.4 Portfolio Modelling: Tools and Methods

A survey of R&D project evaluation practices in European firms found over 100 evaluation methods in use (EIRMA, 1995). After classifying and assessing these methods they concluded that no method guaranteed success, no single pre-evaluation approach met all circumstances, and that regardless of the method employed the most important outcome was improved communication. The researchers noted that their conclusions revolve around three characteristics of R&D investments: (1) they are uncertain, (2) they involve different stages with unique outputs that cannot be evaluated using the same means, and (3) that the multitude of variables cannot be condensed into a single formula, thus dependence on expert judgment and communication is more appropriate.

The collection of portfolio management tools and methodology noted in literature can be classified under three broad headings as proposed by Cooper et al. (1998b):

1. **Classical**: tools include scoring and sorting models as well as checklists. These tools are typically easy to implement and understand, but offer less quantifiable information as some of the others. For example, Hoechst-A.G., a large chemical company, uses a non financial scoring model in which projects are rated based on a set of five criteria: 1) probability of technical success; 2) probability of commercial success; 3) reward; 4) business strategy fit; 5) strategic leverage. Cooper (1997) noted that Hoechst's scoring model was one of the best reviewed and is summarised in further detail in his work.
2. **Mathematical programming**: optimization of a portfolio's commercial value within resource constraints using a mathematical model. Early modelling techniques focused on maximizing value, but were criticised for paying little attention to balancing or aligning the portfolio with a company's strategy and that the models relied on financial projections with a high degree of uncertainty. An example is that of English China Clay, who uses a program to calculate and rank projects based on their "expected commercial value" (ECV). ECV uses decision tree analysis along with expected sales, costs and probabilities of success to yield and estimate of the projects commercial worth (Cooper et al., 1998b). One other mathematical portfolio management tool worth mentioning is Monte Carlo Simulation, which is used by Proctor and Gamble.
3. **Mapping**: typically, two-axis diagrams are used to display the trade-off between two criteria. These criteria could be risk versus reward, probability of success versus value, or ease of implementation versus attractiveness. For example, 3M uses a bubble diagram to plot probability of success against net present value (NPV); the bubbles are shaped as ellipses to depict uncertainty along two dimensions (Cooper et al., 1998b). Mapping tools

have the benefit of incorporating multiple portfolio criteria into a single diagram, but are not capable themselves of prioritizing projects. Regardless, a survey of 205 firms found that 40% of them use portfolio mapping with the most common dimensions being risk versus reward (Cooper et al., 1998a).

Graphical data summaries are often easier to interpret and allow more information to be condensed into a smaller format than written reports. Portfolio maps, which are described briefly above, are an often cited portfolio management and analysis tool. It appears from literature that the consulting firm McKinsey was the first to propose plotting projects on a portfolio map, noting the advantage of using both a business portfolio map and a technology portfolio map (Harris et al., 1984, p. 535). McKinsey's business portfolio map employed the dimensions of "industry attractiveness" and "technological competitiveness," while the technology portfolio map used "importance for competitive advantage" and "firm's competitive position." The resulting two plots show all projects along all four dimensions, with additional data such as expected cost and profitability shown as bubble size. This tool could then be used in project selection discussion to locate the projects that exhibit high industry attractiveness, are inline with the firm's technological capabilities, are important for competitive advantage and are inline with the firm's competitive position.

Determining the exact meaning of each portfolio map dimension to a firm can be challenging. In this regard, Jolly's work adds some structure (2003). Jolly surveyed literature to create a list of 32 criteria that are identified with either "technological attractiveness" or the "technological competitiveness" dimension. Jolly constructed a panel of twenty "experts" comprising top-managers from high-tech companies and large public laboratories. These experts individually ranked the criteria, which were then pooled to create "average" rankings. Both the criteria identified and the rankings are summarized in **Table 2-2**. The top criterion for technological attractiveness was "impact of technology on competitive issues," which is not surprising since it conjoins, or is mutually inclusive to many of the lower ranked criteria. For technological competitiveness, “development of team competencies” was ranked as number one; confirming that most R&D managers view building competence and promoting excellence in areas that provide advantage as imperative.

Table 2-2: Jolly’s technological competitiveness and attractiveness

Rank	Technological attractiveness	Technological competitiveness
1	Impact of technology on competitive issues	Development team competencies
2	Market volume opened by technology	Distance of technology to the company’s core business
3	Span of applications opened by technology	Timetable relative to competition
4	Performance gap vis-á-vis alternative technologies	Financing capacity
5	Competitive intensity	Applied research team competencies
6	Barriers to copy or imitation	Market reaction to the design proposed by the company
7	Threat of substitution technologies	Quality of relationships between R&D and Marketing
8	Competitor’s level of involvement	Quality of relationships between R&D and Production
9	Position of the technology in its own life-cycle	Registered patents

Rank	Technological attractiveness	Technological competitiveness
10	Potential for progress	Experience accumulated in the field
11	Dominant design	Capacity to protect against imitation
12	Number of stake-holders	Value of laboratories and equipment
13	Market sensitivity to technical factors	Origin of the assets
14	Ability to transfer the technology from one unit to another	Capability to keep up with fundamental scientific and technical knowledge
15	Societal stakes	Fundamental research team competencies
16	Public support for development	Diffusion in the enterprise

Source: Jolly, D. (2003). The issue of weightings in technology portfolio management. Technovation, 23(5), 383-392

Alongside the technology portfolio approach, Ernst and Soll (2003) noted the importance of also considering a market portfolio view. They outlined some history of product market portfolio analysis, noting that it dates back to the late 1960s when companies were faced with strategic planning processes involving diversified products and an increasingly complex environment. The Boston Consulting Group's market share - market growth portfolio approach is noted as being the most widely used. Variants of this approach were developed around the same basic structure of plotting projects, products, or strategic business units as bubbles along two dimensions, with their size representing a third dimension such as sales or profitability.

In an attempt to integrate the value that both the market and technology portfolio offer, and aid in information representation for decision making, Ernst and Soll proposed side-by-side plots with market attractiveness being the common vertical dimension and relative technology share and market share plotted on the horizontal axis. One product or project will have two bubbles, one on each plot with the size representing two other variables. Ernst and Soll outlined an example integrated portfolio of a chemical company. He defined the technology share bubble size as R&D emphasis (patent applications in the field / total firm patent applications); whereas the market share bubble size was based on the aggregated results of a questionnaire. This questionnaire was distributed to marketing managers in an attempt to gauge the potential market share and growth. The resulting plots were then subdivided into grids allowing classification of the attractiveness of projects. Ernst and Soll noted some advantages of the integrated approach being:

- combined consideration of a market and technology orientated view and involvement of staff from both camps
- visualization of complex decision problems
- further knowledge created during the conceptualization and implementation of the approach
- Limitations include:
- complexity in implementation
- requirements for data that are difficult to amass, or almost impossible to predict
- inability to capture future technology developments

A further enhancement of the portfolio management tools noted above is available from a Boeing example (Dickinson et al., 2001). In the late nineties, Boeing began drafting a plan to develop a new version of the world's largest commercial airliner – the 747 – to counter the threat from Airbus Industries A3XX program. Boeing found that its traditional approach to project analysis showed that the proposed work would result in a loss. Therefore, executive direction was given to develop a new project portfolio management process with the aim of achieving "more, with less." This process became known as the Airplane Creation Process Strategy (ACPS) and was developed by a team of area experts from across the company. ACPS comprised two sub-processes: a gate review process and portfolio management process. The ACPS portfolio management process differs from previously practiced methods in that it allows for evaluation of highly coupled projects that could be initiated in different funding cycles. It employed a dependency matrix to document and quantify project interdependencies; this matrix is linked to an optimisation model that considers criteria such as expected cost, added value and risk. The user can make changes to either tool using a spreadsheet program, which provides graphical summaries of key evaluation data. This presumably results in an efficient means to optimise and balance interdependent projects over multiple periods.

Bou-Wen and Ja-Shen (2005) studied patent and financial data of 78 US technology companies from 1976 to 1995 with the goal of determining the business value of a technology portfolio. They found that financially valuable technology portfolios were characterised by patents with higher than average citations, including self-citations. Their findings suggested that large firms possess an advantage for commercially successful innovation owing to their ability to exploit synergies within their diverse technology portfolios. They also found that a technology concentration strategy, or focusing on a very specific area of investigation, did not lead to positive financial performance on the whole. They proposed that this is due to a diseconomy in the number of patents received, with each subsequent patent in a concentrated field holding less value, and that high-quality patents are increasingly difficult to obtain.

Important lessons not already covered were found in the reviewed literature. This includes the importance of high-level support and sponsorship of a research portfolio. This sponsorship should promote communication and diffusion of innovation across departmental, divisional or other functional, intellectual or cost/profit boundaries within the organization (Burgelman & Sayles, 1988). In sum, the reviewed literature shows that research portfolio management is an important organizational tool that can aid a firm in evaluating its current technology portfolio, help it make strategic decisions around future technology scenarios, and plan for the optimal allocation of resources (Capom & Glazer, 1987).

2.5 Technology Roadmapping

Technology roadmapping has developed as a response to the increasingly complex and fast changing needs of the business technology environment (Probert et al., 2003). Probert et al. (2003) stated that "it is ever more important for companies to understand the link between the technological resources at their disposal, their effective deployment and the business goals they aim to achieve." In the late 1970's and early 1980's Motorola and Corning first began using their own variations of the roadmapping process (Probert & Radnor, 2003). Renewed interest by industry and academics in the early 1990's has been attributed to "ever-shortening product development times" (Probert & Radnor, 2003). General Motors (GM) adopted roadmapping techniques when it no longer became possible to maintain projects as "lists of lists" and "linking advanced technology development timing to the product plan was a key success factor" (Grossman, 2004).

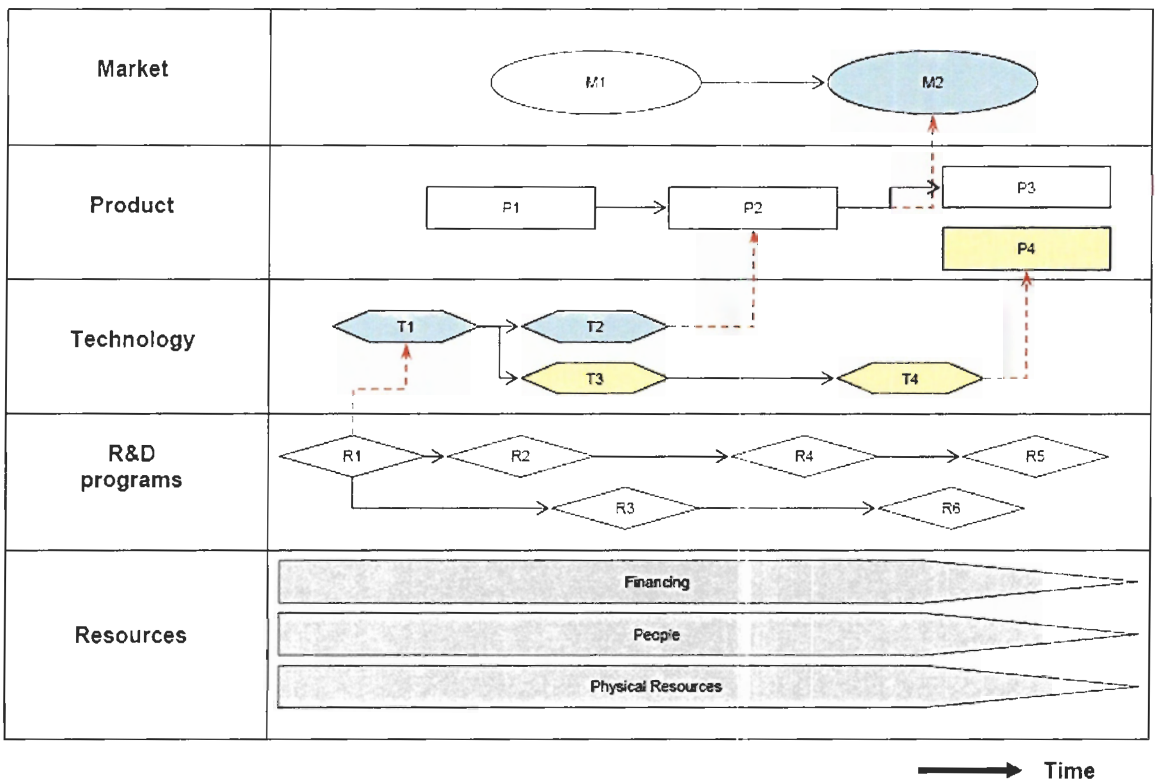
One element of Motorola's process, the "product technology roadmap" (Probert & Radnor, 2003) has become the main feature on which most companies focus. This roadmap is used to define the technologies required for future products. GM uses a simple form of roadmap showing performance improvement on the Y-axis and time on the X-axis. This format is used at the component level and rolled up to form an overview for senior management. The roadmap is used primarily as a means to ensure a common direction across functional groups and to provide a framework for funding discussions (Grossman, 2004). All companies struggle with the amount of time and effort required to develop the roadmap (Probert & Radnor, 2003). Also, the visibility given to potentially redundant projects can cause issues with staff acceptance of the process (Grossman, 2004).

The technology roadmap generally consists of a number of layered elements plotted against time. The nature of the elements and the time scale involved are dependent on the organisation's industry and purpose. A generic formation of a roadmap was developed by the

European Industrial Research Management Association (EIRMA) in 1997 (Probert et al., 2003). This was in response to a general agreement on the benefits of the roadmapping process and the recognition that there were few guidelines for companies on how to get started. Many invented their own processes and formats but all had difficulty in incorporating these into the fabric of ongoing business (Probert et al., 2003).

The roadmap is sometimes generated from a bottom-up (technology push) perspective or more commonly a top down (market pull) perspective (Kostoff & Schaller, 2001). Groenveld (1997) suggests that generating the technology roadmap requires consideration of both the "technology push" and "market pull" drivers and how they come together over time providing a common perspective for the business. A generic technology roadmap is included as **Figure 2-1**.

Figure 2-1: Generic technology roadmap



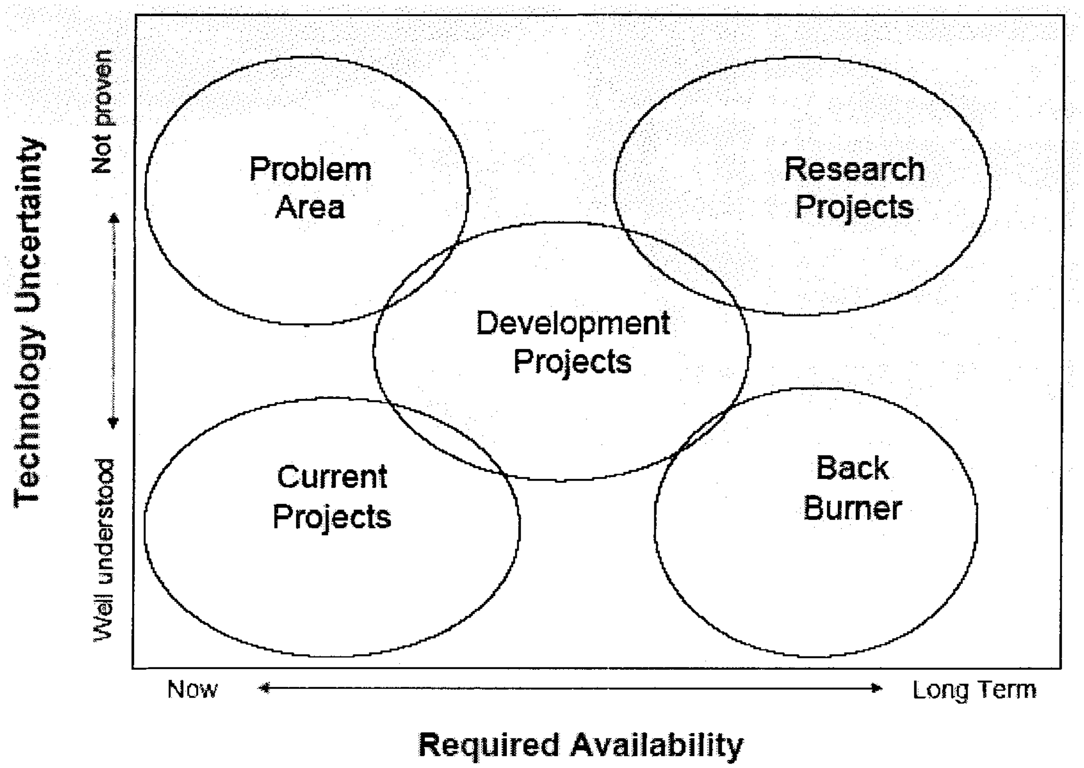
Source: Adapted from EIRMA's "typical technology roadmap" (1997) (Probert et al., 2003).

The top layer of the roadmap shows elements representing market objectives. These can include events, trends or milestones due to government legislation, environmental change or others that form part of the vision for the organisation. The next layer down represents those products, services and systems that will meet the objectives of the market. The middle layer of the map shows the technologies required to support the products, service or systems. Below this are the research and development projects required to develop the technologies. Project selection methodologies, such as those described in **Section 2.4**, are used to determine which technologies and R&D projects should appear on the roadmap. Finally the bottom layer indicates the resources (in terms of money, people and supplies) that are needed to source the selected projects (Probert et al., 2003). As the roadmap travels from left to right, so it moves from the present into the foreseeable future and into the realm of vision. Providing this visible form of roadmap makes it easy to see where the gaps are in knowledge, where projects are not providing value and where resources are best focused. Paradoxically it is this very demonstration of lack of capability and project redundancy that can cause discomfort with the process and lead many managers not to pursue it (Grossman, 2004).

Rockwell's use of the roadmapping process means the company is able to recognise and correct for competency gaps, fully exploit opportunities and more reliably select projects to meet business objectives. Rockwell uses criteria such as market requirements, core competencies and technology timing to determine technology requirements for the roadmap (McMillan, 2003). Technologies are defined and classified with specific definitions for availability (certainty of delivery within timeline) and importance (usefulness to the company). Each was further quantified in terms of impact on a "product dimension (size, performance, cost, manufacturability, etc.)" and "competitive advantage" (McMillan, 2003). Rockwell integrates the resulting technology plan with the market drivers from the business units. The result is a roadmap showing when the technologies required by the business units need to be delivered.

This process leads to the generation of a "core competency matrix" that allows the company to identify required skill sets (McMillan, 2003). Philips uses an innovation matrix similar to that shown in **Figure 2-2** to more fully define the technologies in terms of uncertainty and required availability for strategic corporate needs (Groenveld, 1997).

Figure 2-2: Innovation Matrix: required availability against technology uncertainty



Source: Adapted from the innovation matrix (Groenveld, 1997)

The benefits of roadmapping are the ability to make more informed decisions in areas of uncertainty, communicate across functional teams and provide a common framework for development. The roadmap and the roadmapping process provide an excellent means of communication among various stakeholder groups (Probert & Radnor, 2003). Albright and Kappel (2003) describe the benefits of roadmapping as "the base for corporate technology planning, identifying needs, gaps, strengths and weaknesses in a common language across the corporation." Kostoff and Schaller (2001) state "the main benefit of science and technology roadmapping is the provision of information to help make better science and technology investment decisions." Those experienced in roadmapping often claim that the most benefit is derived from the process rather than from the roadmap itself (Probert & Radnor, 2003).

Although the most common form of roadmapping is product-technology planning, Probert et al. (2003) show that the process can be customised to fit a number of different business problems. The authors demonstrate that the same process can be adapted to problems as diverse as business reconfiguration and sector foresight. Roadmapping is also popular at the industry level as a means for governments and industry bodies to understand where national research should be focused in order to coordinate most effectively with commercial activity. For example, in recent years Industry Canada has sponsored roadmapping initiatives for Wood Based Panel Products (1998), Electric Power Technology (2000), Medical Imaging Technology (2000), Fuel Cell Commercialisation (2003) and Transition to the Hydrogen Economy (2004). One of the concerns expressed for this type of roadmapping is that the participants, being well immersed in the industry, may not be able to conceive of futures that are very different from current state (Probert & Radnor, 2003). In some cases, retrospective analyses using roadmapping techniques are used in an attempt to understand what "right" paths were taken in developing a new product or technology (Kostoff & Schaller, 2001). These meet with limited success. Kostoff and Schaller (2001) also describe a computer based approach to roadmapping. In this process the program uses large textual databases to construct a network of research areas quantified for importance and links. The results of the analysis are used to provide direction in determining the availability of future technologies. This method has the benefit of being objective but has only recently been demonstrated. It is too early to determine whether there is merit in this technique.

Strauss and Radnor (2004) identify a number of issues with the roadmapping process:

- the roadmap is often seen as a stand-alone deliverable and not incorporated into ongoing business processes

- roadmapping can become unwieldy and inflexible in a rapidly changing environment
- the process may become more focused on the technology than business objectives
- the surfacing of gaps in knowledge becomes uncomfortable for some managers to deal with
- not all of the discussion and commentary can be captured in the roadmap format and some may be lost to readers not involved in the original process

In addition, low levels of adoption are attributed to difficulties in getting started and maintaining the process through existing company procedures (Probert et al., 2003). The process can also suffer from "group-think" (Probert & Radnor, 2003). Motorola recognised this issue early in the development of the program and addressed it through the use of a "minority report" (Probert & Radnor, 2003). The "minority report" documented those ideas that were dismissed or not agreed upon by the group but were possible scenarios put forth by a minority. Upon regular review of the roadmap, these scenarios are also considered to determine their possible relevance.

Strauss and Radnor (2004) recommend combining roadmapping with scenario planning to overcome the weaknesses and reap the benefits of both. Roadmapping is perceived as lacking vision and flexibility, whereas scenario planning lacks the level of detail required for the integration of business unit operations. In a combination of the two, scenario planning would add the concept of "flex-points" into the roadmap. In this case more than one possible path can present itself dependent on how the scenarios progress. Both these tools are currently under utilised due to the time and effort involved in using them effectively and combining the two would be a complex and daunting task.

Probert et al. (2003) recommend the following factors as critical to the success of the roadmapping process:

- information and data quality will be the key to the successful development of the roadmap, this implies that those involved in its creation must be those that have the most up to date and in depth knowledge on the subject

- developing and maintaining the roadmap will take considerable time and effort and successful companies have resources dedicated to the process
- there must be a clear business objective and sponsor for the business problem that roadmapping seeks to solve, without this the process will never be fully incorporated into the business function and will not succeed other than as a one-off planning exercise
- there can be no hard and fast rules about the roadmapping structure or approach, it has to remain flexible enough to meet the business problem to which it is applied

McMillan (2003) also states the importance of keeping the roadmap flexible and recognising that it is useful in providing direction only at a point in time. It must be updated at a rate relevant for the organisation in order to remain valid.

In addition Kostoff and Schaller (2001) define the following as critical to the successful generation of roadmaps:

- senior management commitment
- experienced and empowered roadmap manager
- fully competent and diverse roadmap team
- driven by the stakeholders for whom the roadmap is developed
- standardisation of format across organisation
- definition of criteria for roadmap inclusion
- review for reliability based on different input team
- relevance for recommendation of future action
- recognition of true cost of development
- inclusion of all data that might have an impact

Kostoff and Schaller (2001) warn "roadmaps that are restricted to internal agency or corporate programs only could be misleading." "These incomplete roadmaps would portray fragmented and isolated non-coordinated programs, where none of these gaps might exist in reality."

The primary challenge is to integrate roadmapping into the accepted business processes. This has been achieved at Motorola "where roadmaps take a central place in planning and communication processes" (Probert et al., 2003). This integration means that companies can more effectively benefit from the roadmapping process in terms of strategic planning and implementation. In addition a regular review of the roadmap ensures ongoing relevance.

2.6 Canadian Fuel Cell Industry Background Documents

Two key documents contributed to the development of IFCI's research portfolio and deserve mention. These are the Canadian Fuel Cell Commercialisation Roadmap (Government of Canada, 2003) and the BC Hydrogen strategy (Angstrom et al., 2004), both of which are summarised below:

The Canadian Roadmap to Fuel Cell Commercialisation

In 2003, Industry Canada in partnership with Fuel Cells Canada and Price Waterhouse Coopers developed the Canadian Fuel Cell Commercialisation Roadmap (Government of Canada, 2003). The roadmap was created over the period of eight months with input from the CEOs of all major Canadian organisations involved in the fuel cell sector[1]. This document outlined six technology gaps that require bridging before fuel cells can compete with incumbent technology.

---

[1] Alberta Research Council, Angstrom Power, Automotive Parts, Manufacturers' Association, Ballard Power Systems, BC Ministry of Competition, Science & Enterprise, BC Hydro, Cellex Power Products, Centre for Automotive Materials and Manufacturing, Chrysalix Energy Management, DuPont Canada R. & B. D. Centre, Dynetek Industries, Enbridge Gas Distribution, Energy Visions, Environment Canada, Fuel Cell Technologies, Fuel Cells Canada, General Hydrogen, Global Public Affairs, Greenlight Power Technologies, Heating, Refrigeration and Air Conditioning Institute of Canada, Human Resources Development Canada, Hydrogenics, IESVic, University of Victoria, Industry Canada, Kinectrics, Korn/Ferry International, Methanex Corporation, NRC DND, National Research Council, Institute for Fuel Cell Innovation, Natural Resources Canada - CANMET, Energy Technology Centre, NORAM Engineering & Constructors, Ontario Ministry of Enterprise, Opportunity and Innovation, Palcan Fuel Cells, Powertech Labs, PricewaterhouseCoopers, SatCon Power Systems Canada, SMC Pneumatics (Canada), Sofinov Socièté Financière d'Innovation, Stuart Energy Systems Corporation, Technology Partnerships Canada, TeleflexGFI Control Systems, Transport Canada, Research and Development, University College of the Fraser Valley, AUTO21, University of Windsor, Western Economic Diversification Canada, Xantrex Technology

These six gaps are: performance, reliability, durability, longevity, safety and environmental standards. The document also outlined the industry needs, challenges and recommended actions for Canada to stay competitive. These needs, challenges and actions are summarised in **Table 2-3.**

Table 2-3: Canadian Fuel Cell Commercialisation Roadmap Challenges and Actions

Industry Need	Challenges	Actions
Stimulate early market demand	Creating market awareness Gaining market knowledge	1. Develop demonstration projects and public information programs 2. Establish early purchase programs to encourage product procurement and benchmarking
Improve Product Quality and Reduce Cost	Improving quality and reducing cost Developing a coordinated supply chain	3. Identify and overcome performance and cost barriers 4. Collaborative R&D, product standardisation and integrate production plans 5. Fuel cell performance database 6. Establish an information sharing forum
Financing	Gaining access to capital	7. Financing incentives 8. Identify and pursue development partners across various industries
Create Supporting Infrastructure	Obtaining Skilled Resources Developing Fuelling Infrastructure Developing Codes and Standards	9. Develop a human resources strategy to supply skilled resources to the fuel cell sector 10. Incorporate a training component into demonstration projects and government purchases 11. Demonstrate fueling infrastructure systems solutions 12. Take a lead role in setting codes and standards for fuel, fuel cell and fueling systems 13. Develop curriculum for post-secondary institutions

Source: Government of Canada, Price Waterhouse Coopers, Fuel Cells Canada (2003), Canadian fuel cell commercialisation roadmap

The BC Hydrogen Strategy

The BC government outlined a BC Hydrogen strategy (Angstrom et al., 2004) with the goal of making BC a world leader in the hydrogen and fuel cell sector and a functional hydrogen economy by the year 2020. Three activities outlined in the BC Hydrogen strategy designed to meet this goal are developing the Hydrogen Highway, building a globally leading energy technology cluster, and revitalising BC's resource heartland through hydrogen generation and conversion to hydrogen based communities. The report lays out four objectives, with three actions for each objective. These objectives and actions are summarised in **Table 2-4**. The report also notes three tools that should be used to realise the objectives: championing, policy support, and funding.

Table 2-4: BC Hydrogen Strategy objectives and action summary

Objectives	Actions
Securing our Global Leadership	1. Aggressively champion the Hydrogen Highway™ as our path to the hydrogen economy. 2. Work with the federal government and other provinces to make Canada an early adopter. 3. Obtain $135 million in government and industry funding for the Highway and Strategy.
Developing our World Markets	4. Strike a government-industry committee to get global partners for the Hydrogen Highway. 5. Pursue west coast collaborative opportunities, with a focus on the Hydrogen Highway. 6. Make British Columbia the place to grow energy technology companies.
Investing in our Knowledge Base	7. Plan and develop a world-class, integrated energy technology R&D cluster. 8. Fund researchers, infrastructure and demonstrations at universities and colleges. 9. Define an energy technology curriculum and build college and university enrolment.
Sustaining our Resource Based Sectors	10. Integrate this strategy into British Columbia's long-term sustainable energy plan. 11. Work with Alberta and other partners on sustainable hydrocarbon initiatives. 12. Integrate clean energy technologies into the provincial Resorts Strategy.

Source: Angstrom et al. (2004), BC Hydrogen and Fuel Cell Strategy

3 EXTERNAL ANALYSIS

"The ability to learn faster than your competitors may be the only competitive advantage" (De Geus, 1988)

The first step in an external analysis involves defining the industry, which can be broad or specific depending on the analyst's preferences and expectations. For the purposes of this work, an industry sector view is taken: the global fuel cell and hydrogen technology research and development sector. This definition is appropriate because IFCI is striving to fill a specific need related to fuel cell technology – research, development and deployment while strengthening the BC and Canadian fuel cell clusters. Although focused on Canadian technology, IFCI works with firms and institutes from around the world and the sector is truly a globalised one. IFCI has international clients and partnerships, which currently include Taiwanese and Japanese organisations. For these reasons, the specific, yet global, industry definition noted above was used. However, IFCI is a Canadian institution intended to serve the local cluster and strengthen Canada's national competitiveness, so it is also important to consider the Canadian context. Therefore, the external analysis is split into two – one global and one national.

In **Sections 3.1** and **3.2**, the global environment is considered by describing the industry and then assessing the attractiveness of the global fuel cell R&D sector. In **Sections 3.3** and **3.4,** a Canadian viewpoint is taken. This viewpoint includes further industry description and consideration of the Canadian fuel cell industry and research spectrum. This is followed by an IFCI stakeholder analysis. This chapter closes with a review of practices at other NRC institutes.

3.1 Overview of the Global Fuel Cell Industry

The global fuel cell industry can be classified under four broad categories: portable, stationary, mobile and infrastructure. The US military is currently the major pre-commercial user of portable fuel cell technologies. A few firms are working to commercialise portable micro fuel cells that could provide a suitable replacement option for the power needs of devices such as notebook computers, cell phones and personal digital assistants. The stationary fuel cell market includes a wide range of power capacities; from a single kilowatt for residential type applications to several megawatts for industrial installations. The mobile fuel cell market is viewed as having the largest financial potential, with the possibility that fuel cell technology could begin to replace internal combustion engines that power scooters, cars, trucks and buses. The infrastructure market includes fuel generation, distribution and storage technologies. A number of public and private firms are competing for stakes in the above mentioned markets.

An overview of the public firms that constitute the global fuel cell industry is presented in **Table 3-1**. The data of **Table 3-1** demonstrates the strength of the Canadian cluster within the global sector while also revealing the fact that the industry is still in its infancy. This data was obtained from studies conducted by Price Waterhouse Coopers (PWC, 2005). PWC has been completing annual fuel cell industry surveys since 2003. In 2005, they expanded the scope of their survey beyond the borders of North America for the first time (PWC, 2005). The 2005 PWC survey was based on publicly available information from twenty international publicly traded companies involved in the fuel cell sector. The twenty firms, their location and area of focus are listed in **Table 3-1** in order of decreasing revenue. **Table 3-2** includes the R&D expenditures and number of employees for the same twenty firms, in the same order.

Only three of these publicly traded firms are located outside North America, leading one to infer that much of the sector's strength is within Canada and the USA. Ballard Power, a British Columbian firm, ranks the highest in revenues, R&D expenditures and employees. This provides an indication of the prevalence of the BC cluster in the global realm. Additional data to support this claim is reviewed in **Section 3.3**. All of the companies included in the PWC survey have been operating at a loss as they continue to push toward commercialisation. Aggregation of key financial figures from the 2004 annual reports of the twenty firms included in the PWC survey reveals the following:

- revenues were $234 million US, a 4% decrease from 2003
- research and development (R&D) expenditures were $221 million US, a 2% increase from 2003
- number of employees decreased by 2% to 2,789
- market capitalization decreased by 11% to $3.2 billion US

The combination of decreasing global revenues and only marginal increases in R&D expenditures forces one to question the attractiveness of the industry – a topic that is expanded upon in **Section 3.2**.

Figure 3-1 was included to show the divisions between technological areas of focus in terms of both firm revenues and employees. This figure shows that firms focusing on infrastructure are earning more revenues with fewer employees, while firms working on PEMFC technology require more employees to earn their lower revenues. Therefore, one can infer that infrastructure technologies are more financially efficient to develop and market and that this area of focus could be more attractive in the short term. One can also infer from **Figure 3-1** that PEMFC technologies consume more resources than SOFC technologies in order to generate revenue. This assumption is supported by the fact that SOFC fuel cells are currently more prevalent, yet it is noted that SOFC technology is thought to be limited to stationary applications owing to the fragile nature of their ceramic membranes. Therefore, SOFC fuel cells will likely not compete in the potentially huge automotive market.

Table 3-1: **Publicly traded fuel cell firm data on technology focus and revenues**

			Revenues	
Company	**Country**	**Focus Area**	**2004**	**2003**
Ballard Power Systems	Canada, BC	PEMFC	$81,373	$119,566
FuelCell Energy Inc.	US	SOFC/MCFC	31,386	33,790
Quantum Fuel Systems	US	Infrastructure	28,119	23,639
Distributed Energy Sys	US	Infrastructure	22,460	4,194
Dynetek Industries Ltd.	Canada, AB	Infrastructure	20,337	14,556
Hydrogenics Corp.	Canada, ON	PEMFC/Infr.	16,656	26,660
Plug Power Inc.	US	PEMFC	16,141	12,502
Stuart Energy Systems	Canada, ON	Infrastructure	13,203	4,208
QuestAir Technologies	Canada, BC	Infrastructure	2,266	1,262
Fuel Cell Technologies	Canada, ON	SOFC	715	1,823
Ceramic Fuel Cells Ltd.	Australia	SOFC	254	916
Millennium Cell Inc.	US	Infrastructure	198	467
Manhattan Scientifics	US	DMFC	150	300
Pacific Fuel Cell Corp.	US	PEMFC/DMFC	114	0
Palcan Power Systems	Canada, BC	PEMFC/Infr.	114	57
Astris Energi Inc.	Canada, ON	AFC	68	48
Medis Technologies Ltd.	US	DLFC	0	131
Alternate Energy Corp.	US	Infrastructure	0	0
Ceres Power Holdings	UK	SOFC	0	N/A
ITM Power Plc	UK	PEMFC	0	N/A

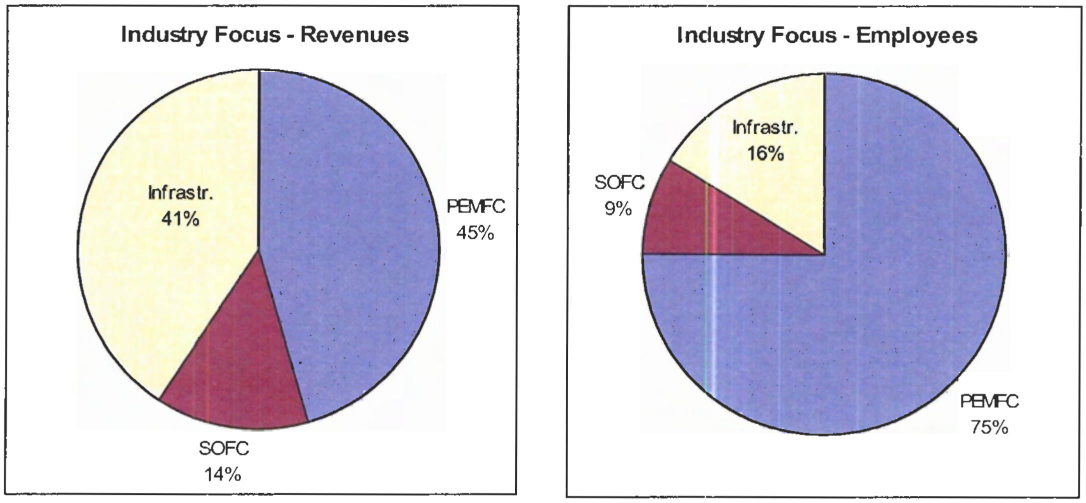
Source: Price Waterhouse Coopers (2005), 2005 Fuel Cell Industry Survey: a survey of 2004 financial results of public fuel cell companies

Table 3-2: **Publicly traded fuel cell firm data on R&D expenditures and employment**

	R&D Expenditures		Employment	
Company	**2004**	**2003**	**2004**	**2003**
Ballard Power Systems	$91,737	$103,863	976	1,099
FuelCell Energy Inc.	26,677	8,509	346	372
Quantum Fuel Systems	15,657	15,062	138	134
Distributed Energy Sys	6,253	7,716	241	227
Dynetek Industries Ltd.	2,744	3,408	215	250
Hydrogenics Corp.	9,069	7,038	330	343
Plug Power Inc.	35,203	40,070	165	186
Stuart Energy Systems	4,913	7,696	74	N/A
QuestAir Technologies	3,546	4,748	26	26
Fuel Cell Technologies	1,795	2,367	91	84
Ceramic Fuel Cells Ltd.	7,261	8,299	32	31
Millennium Cell Inc.	475	1,020	2	2
Manhattan Scientifics	125	286	3	3
Pacific Fuel Cell Corp.	57	71	15	20
Palcan Power Systems	642	554	25	12
Astris Energi Inc.	1,033	877	72	58
Medis Technologies Ltd.	9,799	4,804	8	8
Alternate Energy Corp.	31	0	21	N/A
Ceres Power Holdings	2,531	N/A	9	N/A
ITM Power Plc	992	N/A	2,789	2,855

Source: Price Waterhouse Coopers (2005), 2005 Fuel Cell Industry Survey: a survey of 2004 financial results of public fuel cell companies

Figure 3-1: Fuel cell industry technology focus, divided based on revenues and employees



Source: Price Waterhouse Coopers (2005), 2005 Fuel Cell Industry Survey: a survey of 2004 financial results of public fuel cell companies

A collaboration trend has been emerging in the fuel cell industry over the last few years. Several fuel cell companies are collaborating in the areas of marketing and distribution. Such partnerships include Fuel Cell Technologies and Seimens Westinghouse, Dynetek and Veecon, Proton and General Electric (PWC, 2005). All of the twenty fuel cell companies included in PWC's 2005 survey participated in government sponsored demonstration projects, which provide a means for collaboration of several fuel cell firms from across the value chain to test their products and improve market visibility.

3.2 Attractiveness of the Global Fuel Cell R&D Sector

The analysis that follows considers the attractiveness of the global fuel cell R&D sector. The analysis shows that although rents in the short-term are unattractive, there is significant potential to earn high returns for long-term, wisely allocated, and diversified investments. In performing this analysis, the authors combined elements of Porter's five forces framework with observations drawn from industry documents (Angstrom et al., 2003; PWC, 2003; PWC & FCC, 2004; PWC, 2005).

Porter's five forces framework can be used to identify four structural variables that can influence a firm's competitive environment and its profitability. The framework enables the analyst to understand the competitive environment in terms of "horizontal" competition from substitutes, entrants and established rivals and "vertical" competition in the form of buyer and supplier bargaining power (Grant, 2005, p. 73). The competitive environment considered herein is the sector in which fuel cell research institutions (FCRIs) operate. It is assumed that FCRIs exclude university laboratories. It is also assumed that almost all FCRIs receive a substantial portion of their funding from large bodies such as governments or major corporations.

Substitutes: Potential direct substitutes for FCRIs include universities and other governmental organisations, who are interested in, or currently undertaking, fuel cell research. The challenges facing the fuel cell industry are so broad that additional players tend more to strengthen the industry and increase the chances of accelerated commercialisation rather than threaten current players. In this regard, FCRIs should try to build relationships and partnerships rather than attempting to compete with other organisations. By striving to offer unique services and testing facilities not available elsewhere within their geographic proximity FCRIs will prevent duplication of effort and decrease the overall cluster R&D costs. When providing such services they must price them carefully, aiming to extract sufficient revenue at a sensible price.

Most FCRIs face a greater threat from rival governmental programs seeking funding than from other FCRIs. Although the fuel cell industry's goals are long-term it could take years to witness the fruits of their labour. In order to convince funding bodies of the value of their investments FCRIs should strive for short-term, visible and quantifiable gains such as fuel cell performance and reliability improvements, catalyst reductions (a pricey raw material) and demonstration of technologies with commercial potential. FCRIs must demonstrate that they are adding more value than other candidate programs could. Thus, the threat that direct substitutes have on the attractiveness of the global fuel cell R&D sectors is low since additional players will strengthen the industry's chances of accelerated commercialisation. On the other hand, the threat from indirect substitutes that compete for funding, but do not compete in the sector, is medium-low. Combined, the authors conclude that the overall impact of substitutes on the attractiveness of the global fuel cell R&D sectors is low.

Threat of entry: Since fuel cell research organisations are not earning a return in excess of their cost of capital, they are not acting as a magnet for entry. In fact, government programs around the world have been established to promote the industry and encourage private investment. In spite of that, entry barriers are high owing to the capital required to set-up laboratories and hire qualified scientists, who are themselves in short supply. More importantly, intellectual barriers are very high owing to the extensive scientific and technical background required to undertake fuel cell research and the time required to build a reputation. Interestingly, some FCRIs, such as IFCI, encourage entry of new firms and help university laboratories by sponsoring graduate and post-doctoral research projects.

The greatest threat of entry facing FCRIs is from university or government laboratories that do not participate in one of their programs. Such university or government laboratories might compete for government funding through programs such as NSERC[2] in Canada. Nevertheless, this threat is small and FCRIs should encourage additional fuel cell research outside of their facilities while working to build collaborative relationships. This way, more R&D work can be completed, overlap can be avoided, and researchers can leverage each others capabilities and resources. Thus, entry threats have a low negative impact on the attractiveness of the global fuel cell R&D sector. If entry threats are from players who are attempting to innovate rather than emulate, the impact of entry could be positive.

---

[2] The National Science and Engineering Research Council (NSERC) provides research funding to Canadian researchers

Rivalry between Established Competitors: Competition in the fuel cell research sector is not concentrated. There are many firms vying for a leadership position and attempting to build valuable intellectual property portfolios. In addition, there is much diversity in research between organisations competing to gain an IP foothold, leaving room for complementary discoveries. Typical factors that affect rivalry such as excess capacity and exit barriers are not prevalent in this analysis. Currently, the rivalry between established competitors is medium. The rivalry largely has to do with securing IP, funding, talent and in some cases attention in the money markets. Given the industry's infancy and the huge amount of R&D work to be completed, FCRIs should attempt to reduce rivalry and promote cooperation over competition.

Bargaining Power of Buyers: On one level, FCRIs' buyers are those who secure intellectual property (IP) rights or contract research services. Unless the IP is of high quality and wide interest, the buyers would likely hold most of the bargaining power owing to the uncertainty around commercialisation and protection of most IP. FCRIs should therefore work to develop a portfolio of key patents, which address fundamental problems facing the industry and ideally lead to the production of other related IP. With respect to contract research services, the buyer's bargaining power depends mainly on whether other options are available elsewhere. FCRIs that focus on building facilities that are not currently available, such as IFCI's hydrogen test chamber, can establish a local monopoly on these services. FCRIs can increase their value to customers as well as the local cluster if they develop unique expertise that is too expensive for one firm to fund since independent organisations cannot reap the economies of scale. IFCI's modelling capabilities provide one such example of an FCRI building valuable unique expertise that that would be too costly for any single firm.

In addition to considering actual buyers, it is also worthwhile to consider FCRIs' customers with whom they do not have a financial relationship. These customers include organisations and individuals who may not provide a revenue stream, but still benefit from the institute's work. Because FCRIs are mainly funded by government bodies, they should be motivated to please both direct and indirect customers in exchange for support and recognition. This support and recognition will aid them in securing continued funding. In sum, the current bargaining power of buyers is medium-high if they are seeking widely available research services or licenses for questionable IP. If however the buyers are seeking unique services or licenses for key patents, their bargaining power is low.

Bargaining Power of Suppliers: FCRIs' most important suppliers are those that provide capital and human resources. The suppliers of capital hold most of the bargaining power owing to the high demand for and the liquidity of the asset which they offer. Owing to scarcity of talent, and lack of "ownership" rights around human resources, potential employees have some bargaining power. FCRIs operated by governments, or large corporations, have a strong bargaining position with potential recruits owing to the perception of increased job stability, the potential for access to extensive facilities, and the likelihood that a diverse research portfolio is being pursued.

Suppliers of laboratory equipment and materials are of little concern since purchase quantities are small. However, it is important to give consideration to any services that an FCRI contracts out, such as machining. It would be wise for FCRIs to avoid amassing expertise in a single external organisation as it could reduce the organisation's bargaining power. The authors conclude that the current bargaining power of suppliers is low, with the exception that major funding bodies hold increased bargaining power.

Summary of Porter's five forces: The global fuel cell R&D sector is unattractive in the short-term, but as an emerging market it could become highly attractive for organisations with high quality IP, research staff and unique resources and capabilities. The sector faces the greatest threat from other programs competing for their funding and talent. By encouraging the entry of new participants that will collaborate on R&D projects, as well as building relationships with incumbents, FCRIs can both strengthen their chances for successes as well as their clusters'. Most FCRIs strive to build a valuable IP portfolio, while some also want to earn revenues off their resources and capabilities. By focusing on unique areas of discovery and the provision of services not available elsewhere, FRCIs may increase their chance of earning above average rents in the long-term.

Global fuel cell industry trends: Fuel cells can still not compete with incumbent technologies on both price and performance with the exception of a few low-value niche markets. Nevertheless, energy supply and security concerns continue to push certain countries, albeit in small increments, toward hydrogen based economies. Trends of increasing interest in energy conservation and concerns over air quality also favour the adoption of fuel cell technologies. The industry is yet to answer the major question of what will be the fuel of choice and how it will be generated and distributed. The industry also faces the major problem of a lack of infrastructure. Infrastructure such as fuelling stations is required to promote adoption, yet widespread construction of such facilities will not occur without market demand. However, infrastructure is slowly being built around fuel cell clusters through government sponsored programs.

Summary of the fuel cell R&D sector's attractiveness: It is likely that fuel cell technologies will continue to improve and become more pervasive. The authors conclude that the global fuel cell industry will progress slowly in the near future, yet with time the industry will become more and more attractive as conventional energy options are depleted and fuel cell technological and prices improve. Thus, the fuel cell R&D sector could transform from its currently low attractiveness to medium-high attractiveness for those organisations with valuable IP and unique resources and capabilities.

3.3 Overview of the Canadian Fuel Cell Industry

Canada is currently considered a leader in the emerging global fuel cell industry. However, this leadership position is being challenged by other nations who see the value in establishing a foothold in an industry with long-term potential. It will be shown that Canada's planned level of R&D funding is dwarfed by other nations and therefore it is essential that Canadian firms use their combined resources in the most effective manner.

Ballard Power set the stage for the Canadian fuel cell industry in the late 1980's with the invention of a more compact and efficient proton exchange membrane fuel cell (PEMFC). Until that time, fuel cells consisted largely of the bulky Alkali type, which were used mostly in aerospace applications. With technology originally developed under a Canadian Federal Government contract, Ballard Power received recognition as a leader in the fuel cell industry with the high profile delivery of the first road-approved fuel cell powered vehicles: two buses for the city Chicago in 1996. Canada emerged as an early leader in the fuel cell industry owing to Ballard Power's early success. Furthermore, a fruitful cluster of expertise and companies amassed around the Vancouver area.

Canada's leadership in the fuel cell industry has been challenged recently by others such as the USA, Japan and Europe. In an attempt to maintain its leading position, the Canadian Government supports fuel cell technology through scholarships, development grants and funding with a total investment of approximately $20 million from 2002 to 2007 (Angstrom et al., 2005). Data from 2003 showed that Canada's provincial and federal governments have invested $133 million in fuel cell and hydrogen technology since the 1980's (Price Waterhouse Coopers, 2003). By comparison, the United State's federal government plans to spend $2.7 billion from 2004 to 2008 on hydrogen and fuel cell research and development and advanced automotive technologies. The European community plans to spend $3.3 billion from 2003 to 2006 on renewable energy, with a large component going to hydrogen and fuel cell research, while the Japanese government has committed to spending $380 million a year on fuel cell research. IFCI's budget of $4.5 million per year, which represents the bulk of Canadian government support for the sector, is dwarfed by programs elsewhere. Thus to maintain their world-class status IFCI must allocate and use their scarce resources effectively.

Canadian fuel cell industry data reveals the Canadian Fuel cell industry is growing, despite lower levels of government support relative to other nations. PWC and Fuel Cells Canada (FCC) surveyed 112 Canadian organizations involved in the Canadian hydrogen and fuel cell sector (Price Waterhouse Coopers & Fuel Cells Canada, 2004); 98 organizations responded. High level statistics from the survey include:

- industry revenues grew 40% from $134 to $188 million in 2003
- R&D expenditures grew 5% from $276 to $290 million in 2003
- patent holdings grew 35% to 581 in 2003
- participation in demonstration projects increased by 232% to 262 individuals and organizations in 2003
- sector employment stands at 2,685; a slight decline from 2002

IFCI attempts to provide R&D services that reflect the Canadian fuel cell industry's composition. Canadian firms and organisations that constitute the fuel cell industry can be considered by industry sector or technology and market focus. **Table 3-3** outlines the number Canadian fuel cell firms according to industry sectors; it shows that IFCI is one of twenty-seven organisations offering professional services and one of twenty-six organisations undertaking research. The professional service and research sectors rank in the top two in terms of number of participants. Therefore, both sectors are likely the most attractive while also having the greatest potential for rivalry.

The split between technological areas of focus within the fuel cell industry is captured in **Table 3-4**. This split that is roughly emulated by IFCI's budget division amongst various science and technology projects. **Table 3-4** also shows the organisational and demonstration project split between various fuel cell applications. IFCI tries to emulate the technology division present in the Canadian fuel cell sector when reviewing their portfolio of projects. With this in mind, **Table 3-4** could be used as a guide when determining how much of IFCI's budget should be allocated to broad technology groups.

Table 3-3: Canadian fuel cell organisations by sector and type in 2003

Organisations	
Industry Sector	No. of Firms
Research	26
Professional services	27
Supplier to developer or manufacturer	24
Developer or manufacturer	17
Distributor or agent	2
User	8
Utility	4
Other	18
Type of organisation	**No. of Firms (%)**
Not for profit & governmental organizations	5 (6%)
Public company division	7 (8%)
Educational organization	10 (12%)
Public company with fuel cell focus	23 (29%)
Private company	38 (46%)

Source: Price Waterhouse Coopers & Fuel Cells Canada (2004). Canadian Fuel Cell Sector Profile 2004

Table 3-4: Canadian fuel cell technology, market and demonstration project proportions in 2003

Technology Focus		Market Focus[3]		
Proton exchange membrane	50%	**Application**	**Organizations**	**Demonstration Projects**
Solid oxide	22%	Stationary	33%	42%
Direct methanol	10%	Mobile	24%	26%
Molten carbonate	4%	Portable	15%	8%
Alkaline	2%	Fuelling infrastructure	29%	24%
Other	12%			

Source: Price Waterhouse Coopers & Fuel Cells Canada (2004). Canadian Fuel Cell Sector Profile 2004

Regionally, Western Canada accounts for 77 % of Canadian public company fuel cell revenues in 2004 or 45% of global fuel cell revenues (PWC, 2005). This demonstrates the BC cluster's leadership position. However, it is important to note that 78% of the Western Canadian revenue in 2004 can be attributed to Ballard Power. Thus, cluster performance on this metric is highly concentrated and at risk, since it depends on a single firm's performance. The PWC 2004 survey also revealed some interesting revenue data. For example, approximately 50% of globally reported fuel cell company revenues were from Western Canadian firms; demonstrating the cluster's current leadership position.

Table 3-5 shows Canadian fuel cell industry revenues broken down according to their offering. It shows that product sales grew by 50% in 2003 and account for the bulk of revenues. It also shows that it is risky for firms and organisations to rely solely on contract R&D and licenses

[3] Some firms pursue work related to more than one application. In addition, demonstration projects typically involve more than one firm from across the fuel cell value chain. Therefore, there is overlap within the percentage data noted in Table 3-4.

to earn revenues in the short-term. In 2003 Canadian fuel cell contract R&D and license revenues grew 1% to a total of $14 million. In order for IFCI to rely solely on contract R&D and license revenues by 2007 to support its current $4.5 million budget, it would have to capture 31% market share[4]. Data on IFCI's current contract R&D and license market share is not available, yet was estimated to be less than 10%. It is a lofty proposition for IFCI to capture an additional 21% market share in the next two years while also promoting a collaborative environment. Since IFCI's governmental funding is only guaranteed until 2007, and it appears unrealistic that they could rely solely on external revenues beyond that date.

Table 3-5: Canadian fuel cell industry 2002 & 2003 revenues and growth by offering

	2002		2003		
Offering	**$ millions**	**%**	**$ millions**	**%**	**Growth**
Product Sales	77.8	58%	145.1	77%	50%
R&D Contracts[5]	10.4	8%	11.5	6%	1%
IP Licensing[5]	0	0%	2.5	1%	2%
Other	46	34%	29.2	16%	-13%
Total	134.2		188.3		40%

Source: Data from Price Waterhouse Coopers & Fuel Cells Canada (2004), Canadian Fuel Cell Sector Profile 2004

In summary, the data outlined above shows that: the Canadian fuel cell industry is still growing, Western Canada has the highest concentration of revenue generating fuel cell companies in the world, and R&D contracts and licensing represent an almost negligible portion of industry revenues. These observations are important to IFCI in order to justify its location and growth in human resources. However, they provide an indication that it could be challenging for

[4] Assumes continued R&D contract and license revenue growth at 1% from 2003 to 2007

[5] One of IFCI's revenue streams

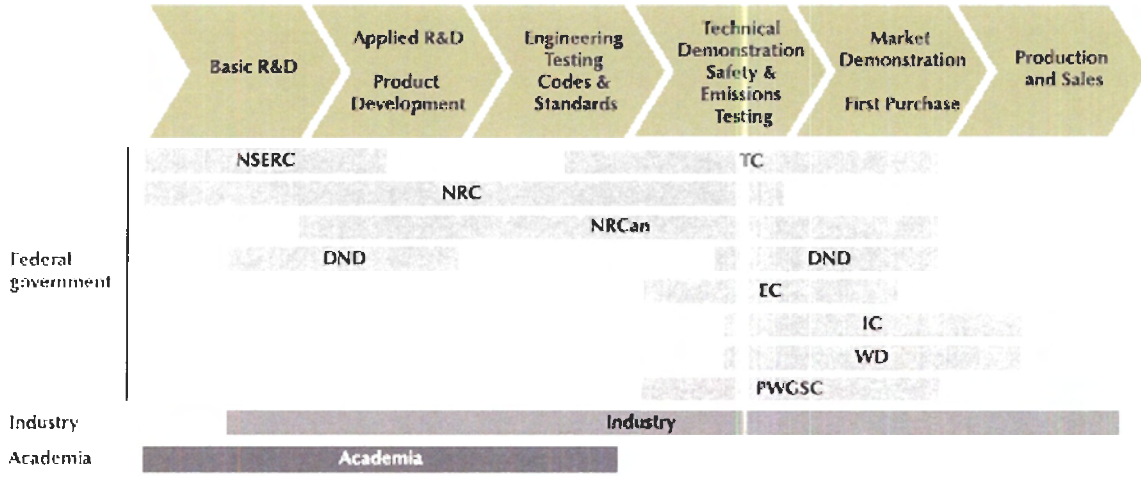
the institute to rely on contract research and license revenues after their current federal government funding ends in 2007. IFCI should therefore pursue additional funding ahead of that time. Although this section outlined some factors that demonstrate the strength and current leadership of Canada in the global fuel cell industry, it also shown that other nations are outspending Canada by an order of magnitude and therefore could catch-up in the near future.

3.4 Canadian Fuel Cell Research Spectrum

Figure 3-2 demonstrates how IFCI contributes to the R&D spectrum for fuel cell technology in comparison to other federal bodies involved in fuel cell work. The organisational acronyms are outlined below **Figure 3-2**, with IFCI noted as "NRC."

Figure 3-2 shows that IFCI is involved in a wide portion of the development spectrum. What it does not show is that IFCI is integral in allowing the other federal government departments to accomplish their work. In addition, IFCI is helping to build a strong fuel cell industry network and bolster the Canadian industry. IFCI's contribution also includes availability of expertise for consultation, facilities, and data gathered from demonstration projects. **Figure 3-2** was created in 2003 and shows that IFCI has not been contributing to market demonstration and first purchase programs. The situation has since changed with the construction of a hydrogen fuelling station at the institute.

Figure 3-2: Fuel cell development spectrum



DND: Department of National Defence
EC: Environment Canada
ICIndustry Ca nada
NRC: National Research Council – IFCI
NRCan: Natural Resources Canada
NSERC: National Science and Engineering Research Council
PWGS: Public Works Canada
TC: Transport Canada
WD: Western Economic Development Canada

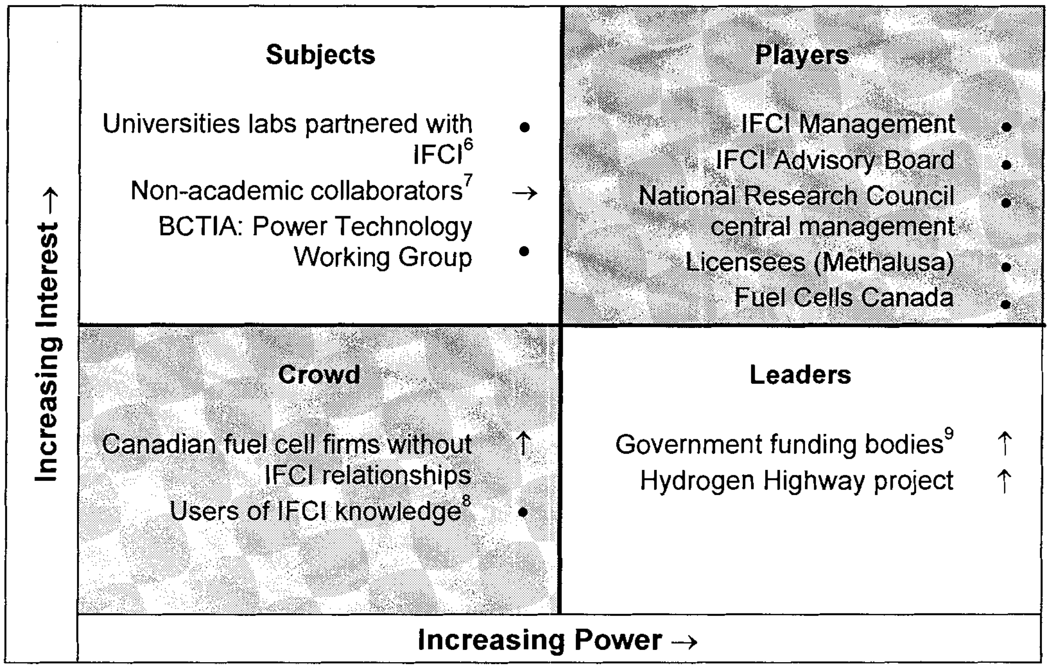
Source: Government of Canada, Price Waterhouse Coopers, Fuel Cells Canada (March, 2003), Canadian fuel cell commercialisation roadmap, Retrieved June 2, 3005 from www.fuelcellscanada.ca/french/Roadmap.pdf, reproduced with permission

3.5 IFCI Stakeholder Analysis

Stakeholders include individuals and organisations that interact or are affected by the organisation. Multiple and conflicting stakeholder interests can occur, and must be managed, while looking for areas where stakeholder interests overlap – a community of interests (Grant, 2005, p. 41). This section considers IFCI's key stakeholders, their relative interest and power, and how IFCI might manage these stakeholders.

A stakeholder map approach was taken (Johnson & Scholes, 2002, p. 209), which involves plotting stakeholders on a grid showing the relative power and interest. Bullets on the map indicate if IFCI should attempt to keep the stakeholder in its current position, while the arrows show if IFCI should attempt to move the stakeholder toward a different quadrant. Using this approach, one can map out if, and begin asking how, a firm should influence stakeholders. One approach to stakeholder management involves attempting to move all stakeholders to either the "crowd" or "player" quadrant such that their power and interest are in alignment, supposedly leading to less chance of conflict (Johnson & Scholes, 2002, p. 209). IFCI's stakeholder map is included as **Figure 3-3**, with further stakeholder details and discussion outlined below. The stakeholder summaries included below are in the approximate order of decreasing power.

Figure 3-3: IFCI Stakeholder Map



Source: Created by authors based on Johnson & Scholes' stakeholder mapping approach (2002, p. 209)

[6] University labs investigating fuel cell and hydrogen technology and partnered with IFCI: UBC, UVic, National University of Taiwan

[7] Non-academic collaborators include firms and other institutions with, or considering contracts / partnerships with IFCI.

[8] IFCI knowledge disseminated through publications and patents

[9] Industry Canada, NSERC, Transport Canada

IFCI Management: IFCI has three senior managers responsible for the strategic direction of IFCI, and roughly one dozen senior scientists. Good management and sound scientific direction are essential since the institute is faced with constrained resources. Developing and retaining leadership talent is essential owing to IFCI's high visibility and the multitude of stakeholder interests that require consideration.

IFCI Advisory Board: the institute's senior management reports to a thirteen member[10] advisory board. The advisory board is similar to the board of directors of a public company. IFCI must work to educate the advisory board while leading the institute in a direction that is best for industry, not a single board member or collaborator. Concise and honest communication that shows progress will build IFCI management's credibility with the board. This will be enhanced if they address issues and concerns in a timely manner.

National Research Council central management: IFCI is an 80 employee institute within the 4000 employee NRC, yet the details of IFCI's relationship with NRC management are not clear. IFCI obviously has to manage its relationship with the NRC, showing that it is enhancing the organisation's reputation and adding more value than other candidate programs. A key strength of IFCI is that it has prime access to the NRC network of scientists and engineers; it is advisable that IFCI employees begin to learn of the expertise spread throughout the NRC, seek it when required and inform others in the organisation of their own capabilities.

Licensees: Since development and licensing of intellectual property signals quantifiable progress and commercial value, IFCI is wise to strive for this goal. However, it also leads to licensees holding a certain degree of power. At a project proposal session, there was much talk

[10] Tapan K. Bose (Canadian Hydrogen Association); Ron Britton (Fuel Cells Canada); David Frank (Hydrogenics Technology); Michael Isaacson (UBC Dean of Applied Sciences), Michael McDonald (Methanex); Ardath Paxton Mann (Western Economic Diversification Canada); Heinz Portmann (Dynetek Industries), Bruce Sampson (BC Hydro), Vesna Scepanovic (Natural Resources Canada), Mike Singleton (Suncor Energy), Charles Stone (Ballard Power Systems)

about comments from IFCI's first and only licensee, who cannot be named. Rather than relying on comments exchanged through third parties, IFCI management should build relationships with licensees such that the institute understand how to best aid them, learn from them and work with them to build upon past inventions.

Fuel Cells Canada (FCC): FCC is a national industry association with 52 members including all major Canadian fuel cell companies. The president of FCC, Ron Britton, is on IFCI's advisory board. Since part of IFCI's mandate is to support the fuel cell cluster, the FCC provides an ideal focal point for IFCI to link into and learn from the network. Synergies and co-branding can be achieved through combined FCC and IFCI sponsorship of events. Players external to IFCI might see FCC as more impartial and representative of their interests since FCC does not conduct contract research nor build commercially orientated collaborative relationships like IFCI. IFCI management should attempt to "listen" to the fuel cell community through FCC since it could provide a more balanced and accurate signal than they would receive otherwise.

Government funding bodies: IFCI is currently funded through a five year grant from Industry Canada, in addition to the support it receives from the National Science and Research Council (NSERC) in the form of graduate student scholarships. Securing additional funding will depend on IFCI demonstrating that further investment is warranted and that such investment is in the best interests of British Columbia and Canada. IFCI has not received any provincial funding and should explore this option since Premier Campbell has signalled his interest in supporting BC R&D through establishment of the Premier's Technology Council. If IFCI had secured additional funding of $650,000 in 2005, all formally presented project proposals could have been pursued. Therefore, IFCI should work to secure additional government funding by increasing its visibility and highlighting its accomplishments to the appropriate government bodies.

Hydrogen Highway Project: This is a government funded and industry supported large scale demonstration project that involves building hydrogen fuelling stations at Whistler and the Vancouver airport, in addition to the stations already located at IFCI and PowerTech Labs in Surrey. Most of IFCI's demonstration projects, which consume 15% of their operating budget, are related to the Hydrogen Highway Project. IFCI should establish solid relationships with the project team, teach and learn from those constructing new fuelling stations, and ensure that sufficient and meaningful data is garnered from the project.

Universities labs partnered with IFCI: In addition to the National University of Taiwan, the institute has collaborative R&D relationships with UBC and Simon Fraser University, which includes a co-chair professor from each. The University of Victoria carries out fuel cell research through its Institute for Integrated Energy Systems (IESVic). IESVic does not have a formal relationship with IFCI, yet one could emerge in the near future. IFCI should work to maintain a level of interest from the academic community while simultaneously trying to bridge the gap between university and commercial labs. University relationships should focus on knowledge sharing, network building, sharing resources to reap economies of scale and combining project and portfolio planning in order to diversify research across a number of bodies while avoiding unneeded overlap.

Collaborators: IFCI's industry collaborators cannot be mentioned in this work, however some discussion is warranted. Without spreading itself too thin, collaborative relationships are important to IFCI such that governmental funding can be leveraged with external funds while also providing the strategic benefits of partnerships. It is important that IFCI select collaborators whose research interests and direction are in line with its own. IFCI should attempt to extract as much value from these relationships as possible including funding, equipment, personnel, knowledge and contacts.

BCTIA - Power Technology Alliance: BC Technologies Industry Association's Power Technology Alliance was formed as part of the Premier Campbell's Alternative Energy and Power Technology task force. The task force is in the process of implementing a vision document for the BC power technology cluster. Since a large portion of the cluster comprises fuel cell companies, IFCI should remain involved with the task force and determine how they could better align their activities with the cluster's needs. However, IFCI is pressured by certain members to alter its focus to areas other than fuel cells. This could lead to the institute spreading its resources too thin and decreasing the chances of making a significant impact in fuel cell technology.

Canadian fuel cell firms without IFCI relationships: Through its demonstration and community stewardship projects, IFCI interacts with a large number of Canadian fuel cell firms. IFCI should work to increase its visibility and the level of cluster interest in the institute. This involves educating the cluster on what the institute can currently offer as well as learning what the cluster needs.

Users of IFCI knowledge: IFCI aims to publish or patent its work such that some of the knowledge generated can be disseminated. In addition, publications and patents provide a quantifiable measure of research productivity. Much of the focus with respect to this stakeholder group should be internal. Publications and patents can vary widely in their value and IFCI's team of highly qualified scientists and engineers should aim for higher quality work. In the case of patents, IFCI should market them, but publications will generally market themselves if submitted to prestigious journals or conferences.

3.6 Practices at other NRC Institutes

IFCI's practices were compared to those of three other NRC institutes. By means of telephone interviews, based around six semi-structured questions, the authors determined how other institutes manage their research portfolios. The three institutes are: NRC Industrial Materials Institute (IMI), NRC Biotechnology Research Institute (BRI), and NRC National Institute for Nanotechnology (NIN). **Table 3.6** depicts the questions used when interviewing each of these NRC institutes. The remainder of this section summarizes each institute's objectives and R&D portfolio management practices.

Table 3-6: R&D portfolio management questions posed to NRC institutes

No.	Questions
1.	Are you faced with constrained resources and many viable projects?
2.	Is the above true across all departments?
3.	How do you make resource allocation decisions?
4.	Do you have a structured portfolio management process in place? What is it? How well do you think it works?
5.	Do you employ a technology roadmap?
6.	Do you have a process for killing projects?

Source: Created by authors.

NRC Industrial Materials Institute (IMI)

NRC's twenty year old Industrial Materials Institute (IMI) has two centres, one in Boucherville and another Saguenay, Quebec. These two centres are organised based on IMI's two main groups: the Aluminium Technology Centre and the Advanced Materials, Modelling and Diagnostics group. IMI's stated goal is to "increase Canada's scientific and technical capabilities, as well as the innovation potential of Canadian companies, by streamlining the development and adoption of new emerging technologies" (NRC Industrial Materials Institute, 2005). IMI completes research on metals, polymers, and ceramics, and their composites and alloys. They focus on the application of such materials within aerospace and biomedical sectors. An interview with Ngoc Huynh, IMI's business development officer (Huynh, 2005), revealed the following about IMI's resource allocation practices:

- IMI is faced with many potential projects and limited internal funding, while employing many older scientists who are resisting a commercial approach to resource allocation
- large prior budgets meant funding decisions were based almost exclusively on project technical merits
- 1/3 of IMI's revenue comes from provision of third party services
- IMI's objective is to be revenue neutral and grow their resource base using external funds
- IMI's licensing revenues are negligible
- IMI does not employ a structured resource allocation process, but they do use a three level prioritisation process
- projects are either focused on developing IP or completing contract based service work
- due consideration is given to the applicable sector for the materials research work with the current focus on biomedical applications
- a study is performed every two years to determine if new attractive sectors should be considered
- projects are categorised and prioritised according to three groups, with the first groups being given higher priority for resources: (1) projects entirely funded by a third party, (2) projects partially funded by a third party; typically more risky than the former, (3) internally funded projects with a three to five year time horizon
- IMI encourages its scientists to transfer to private industry and fulfils a training and knowledge building function for Canadian industry
- milestones are set and monitored for all projects, yet a new project management review process is being implemented; past projects have been typically over budget by 100% yet Ngoc noted that customers felt they had extracted more value than they paid for
- project valuation models such as net present value (NPV) and options thinking are not used; sector attractiveness, third party funding, and alignment with internal competencies are given the most consideration when allocating resources to projects
- projects funded by a third party can only be killed with the support of the third party; internal projects may be killed if multiple milestones are missed (history has shown that most projects were killed due to technical reasons, not market reasons)

NRC Biotechnology Research Institute (BRI)

Located in Montreal, BRI has 800 employees and shares its building with 17 biotechnology companies; thus the institute fulfils an industry incubator role in addition to its research pursuits. An interview was conducted with Yves Quenneville, BRI's business development officer. This interview revealed the following (Quenneville, 2005):

- BRI has had its budget frozen since 1994 and faces the problem of many projects competing for scarce resources
- BRI focuses on projects with 3-5 year time horizons
- project proposals are first reviewed by BRI management and in addition to consideration of technical merits, a "market study" is performed to gauge if valuable intellectual property could be generated
- financial analysis techniques such as NPV or options thinking are rarely employed; a "strategic" view dominates
- an independent consultant is hired to assess all project proposals and BRI's market study; this consultant then drafts a recommendation that is sent to the advisory committee
- a committee comprised of BRI managers and external advisors review all project proposals and determine the level of funding projects will receive
- the above-mentioned committee performs annual reviews on all projects and can elect to cancel projects that are not meeting expectations
- BRI encourages young scientists to leave the institute and transfer to industry in parallel with intellectual property licenses; older scientists are encouraged to stay with the institute

NRC National Institute for Nanotechnology (NINT)

The National Institute for Nanotechnology (NINT) was formed in 2003 and is located on the University of Alberta campus. NINT's stated goal is to be Canada's premier nanotechnology institute and internationally recognized for excellence in nanotechnology research and development. NINT has the long-term goal of discovering the "design rules" for nanotechnology. In this regard the work is based around four interdisciplinary research groups: Molecular Scale Development, Supramolecular Nanoscale Assembly, Materials and Interfacial Chemistry, Theory and Modelling.

In NINT's short history it has not been faced with the typical problem of scarce resources. Instead it has had an abundance of resources compared to project requirements. However, as the centre grows and projects progress NINT is finding more demands placed on funding and staff such that a systematic allocation process is required. As a result, the institute recently appointed a project selection committee and is currently in the process of developing a resource allocation methodology.

3.7 External Analysis Summary

The global fuel cell R&D sector is unattractive in the short term, but attractive in the long-term owing to environmental and political trends favouring adoption of fuel cell technology and the potential to earn high rents. Western Canada is currently a leader in the global fuel cell R&D sector, yet this leadership position is being challenged by more heavily funded programs in other nations. It is therefore essential that the Canadian Government and industry make the best use of their investment in fuel cell related R&D projects and industry building initiatives. The proposition was set forth that fuel cell research organisations will be more successful and better enable their local cluster if they collaborate on R&D projects while establishing unique services and expertise. They should understand how they fit into the complete research spectrum and work to leverage resources across the industry, just as IFCI has.

It is imperative for IFCI to proactively manage its diverse stakeholders, in particular governmental funding bodies and those who can influence such funding decisions. With guaranteed funding ending in 2007 and the low likelihood of reaching self-sufficiency through contract R&D and license revenues, IFCI should begin working to secure additional governmental and industry support. Moreover, since IFCI is faced with limited resources and the necessity to complete high impact R&D and market visibility work, they require an effective means by which they can build and manage their portfolio of R&D projects. Other NRC institutes have, or are building, R&D portfolio management processes. IFCI can both learn from, and contribute to, the portfolio management process of other NRC institutes.

4 INTERNAL ANALYSIS

The purpose of an internal analysis is to assess the structure, processes, resources and culture of an organisation as an appropriate fit for achieving its strategic goals in the current environment. Based on its 2005 vision and mandate, IFCI has defined a number of goals centred on two programs: Science and Technology and Community Stewardship.

IFCI vision: To be recognized as a world leader in fuel cell and hydrogen systems and technologies, and supporter of clean energy technology development (NRC-IFCI, 2005).

IFCI mandate: To support the growth of British Columbia's fuel cell cluster and Canada's leadership in fuel cell and hydrogen technologies through excellence in research, innovation, partnerships and cluster building (NRC-IFCI, 2005).

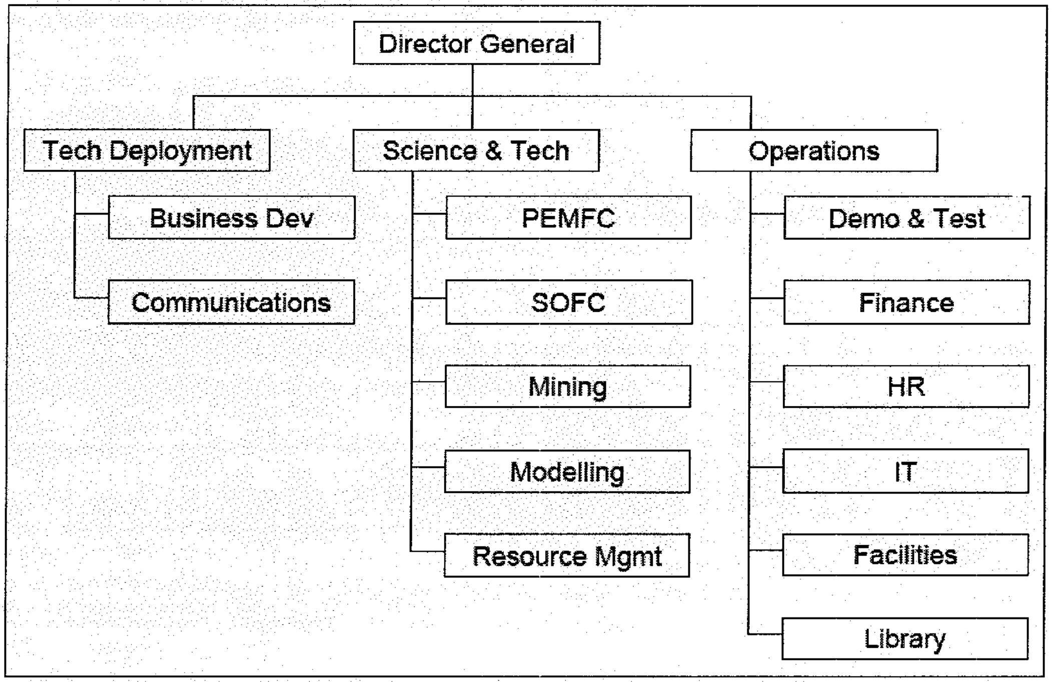
First, the organisation structure is defined and assessed using the definition of Mintzberg's (1981) five idealised forms and best practices based on the study by Rush et al. (1996, pp. 174-198). Second, the processes, culture and resources are reviewed based on the framework of strategic capability as defined by Leonard (1995, p. 4). Third, the strategic goals of the organisation are identified and described. Fourth, the ability of the organisation to fulfil the strategic goals is assessed and gaps identified. Finally, the summary to this section explores how well IFCI aligns with the best practices for a research institute.

4.1 IFCI Organisational Structure

IFCI is structured as two core functional groups, the science and technology department and the business administration department **(Figure 4-1)**. These two departments are both overseen by the Director General, Maja Veljkovic. The science and technology department is a very flat structure led by Director, Science and Technology, Dr. David Ghosh. The department consists of six groups aligned by area of research and each group has a Group Lead, generally the scientist with most experience in the field. The groups range in size from 5 to 20 persons including Research Officers, Postdoctoral Fellows, Visiting Workers, Students and Technical Officers. Project teams are formed within and across these groups in collections of 2 to 5 staff members. There is an overall Resource Manager, reporting directly to the Director, Science and Technology, whose job is to help resolve finance and human resource conflicts between projects. Within project teams scientists act completely autonomously, determining their own schedule and deliverables except where they are involved in joint projects with an industry or university partner. In these cases, project objectives, direction and deliverables are worked out in conjunction with the partner organisation. Research scientists use their connections inside and outside the institute to inform their research and attend seminars and conferences to gain and disseminate information as they see fit.

The business administration department consists of two separate elements: business development and operations. The operations group includes finance, facilities, information technology, human resources, library, administration and most recently demonstration projects and testing services. Business development includes technology transfer and business agreements, communications, workshop and other cluster building activities. Several people wear a variety of hats in the institute, for example doubling as both demonstration project and administrative staff. This flexible structure means that IFCI can adapt to the changing needs of the organisation.

Figure 4-1: IFCI Organisational Structure



Source: Compiled by authors based on information provided by IFCI, 2005

IFCI's secondary mandate, to be the centre for community cluster building, is driven from the business administration department. Within the operations group are the demonstration projects and test services. While seminars and workshops that promote cluster activity are organised by the technology deployment group. This group is headed up by Dr. Yoga Yogendran, Director, Technology Deployment and Commercialisation, also responsible for developing business partnerships for both demonstration and scientific research projects. IFCI does not have a group to develop standards and processes for the industry however the operations group does provide data to the Canadian Standards Organisation and International Standards Organisation (ISO) from fuelling station and hydrogen quality projects.

IFCI's organisational structure closely resembles the professional bureaucracy defined by Mintzberg (1981). In this type of organisation structure, professional employees usually work completely autonomously. A large middle management layer is not required although there will often be a large administrative support staff. Mintzberg (1981) notes that this type of structure is best suited to those organisations that have highly complex and yet standardised practices such as hospitals or schools, where the training and professionalism of the staff is the key to success. At IFCI the practices are highly complex and yet not standardised. In fact the requirement is for innovation rather than standardisation. One way to encourage innovation in this type of structure is to foster interaction both internally and externally (Leonard, 1995, p. 8-14). Rush et al. (1996, p. 195) recommend that an institute include researchers with industry experience in project teams to encourage innovative thinking that is also relevant to industry. The authors (Rush et al., 1996, p. 178) also advocate the use of strong project management and monitoring as leading to project success.

4.2 Current Resources and Functional Capabilities

Resources at IFCI can be divided into two categories: people and physical assets. Given IFCI's primary purpose of scientific research, the capabilities of the people are core to the function of the institute. IFCI has approximately 80 staff members, of these there are about 60 research staff including 5 senior researcher officers, the rest are administrative staff. Of the researchers, primary areas of expertise are in "advanced materials and processes, numerical simulation and modelling, novel design, sensors and diagnostics and component and system testing" (NRC-IFCI, 2005). IFCI has also co-hired five university professors and employs about 25 graduate students. In addition to the scientific staff, IFCI also has competence in the area of developing partnerships and leveraging sources of income other than government funding. This capability is provided by the technology deployment and commercialisation group. Within the administrative staff, IFCI has four full time and eight part time personnel dedicated to demonstration projects and cluster building.

IFCI's core functions can be described as science and technology research projects, collaborative research with industry and academia, training staff for industry needs, hosting demonstration projects and knowledge dissemination activities and providing testing facilities and data for standards development for the industry. IFCI's researchers are dedicated to the science and technology goals and objectives and are hired specifically for their individual skill sets. For example expertise in computational fluid dynamics and modelling relates specifically to the ability to increase performance of the fuel cell without extensive physical testing. Expertise in materials technology relates directly to the ability to reduce the cost of the fuel cell through the use of innovative materials. IFCI also has a number of staff dedicated to developing the fuel cell community and cluster building activities in BC. These staff members have a diverse range of expertise in prototyping and testing, evaluation, communications and training. Strong capabilities in business development allow IFCI to develop partnerships with a variety of organisations. These partnerships result in the development of consortia that address many of the needs of the industry. They also allow IFCI to play an important role in solving industry's problems.

IFCI has a number of physical assets that contribute to fulfilling the core functions. The institute is located on the University of British Columbia (UBC) site, allowing for close collaboration on projects and the ability to share resources and facilities. IFCI has nine hydrogen safe labs and ten testing stations supporting electrochemical and analytical equipment (NRC-IFCI, 2005). The institute also boasts one of the only publicly available hydrogen technology environmental chambers in North America. IFCI is a key component in B.C.'s Hydrogen Highway project with a hydrogen re-fuelling station.

Leonard (1995, p. 4) describes three types of capability within an organisation: supplemental, enabling and core. Supplemental capabilities are defined as those that enhance the core capabilities of the organisation. They are important but can easily be copied by others. Enabling capabilities are those required by the organisation simply in order to compete. These might be defined as table stakes, required in order to play the game, but not the key to winning. Core capabilities are those that distinguish the organisation from the competition. These are the capabilities that are "developed over time and not easily imitated by others" (Leonard, 1995, p. 4). Using the categories of core, enabling and supplemental the following capabilities are identified for IFCI:

Table 4-1: IFCI Capabilities

Core	Enabling	Supplemental
Creating and leveraging partnerships to accomplish fuel cell research and development goals	Hydrogen Environment Chamber prototype testing services Laboratory testing services Refuelling station service Research scientists with expertise in PEMFC, SOFC and Hydrogen technologies Administration staff with communications and partnership expertise	Collaborating with industry and academia Expertise in advanced materials, fabrication and design Expertise in mathematical modelling Expertise in sensing, testing and diagnostics

Source: Created by authors based on capability definitions (Leonard, 1995, p.4)

Leonard (1995, p. 4) describes the fundamental aspect of the innovative organisation as its ability to gain and retain knowledge. Knowledge and knowledge management are at the heart of the strategic innovative organisation. IFCI manages its capabilities through quantifiable targets for a number of objectives that relate directly to the capabilities described in **Table 4-1**. Refer to **Appendix A** for details.

4.3 Expertise and Strategic Focus

IFCI follows two main strategic programs: science and technology and community stewardship. The objectives and goals for the two programs are based on national and provincial strategies documented in the Canadian Fuel Cell Commercialisation Roadmap (2003) and the BC Hydrogen strategy (2004) summarised in **Section 2.6**. IFCI also drew input from a recent survey, conducted in March, 2005, to better understand the expectations of its stakeholders. The Canadian Fuel Cell Commercialisation Roadmap (2003) describes the needs, challenges and actions required to successfully commercialise fuel cell technology (**Table 2-3**). IFCI is specifically contributing to nine of the thirteen actions identified (1, 3-6 and 9-12). The remaining four actions pertain to financing programs and education curriculum development. IFCI is contributing to six out of twelve action items (1, 2 and 5-8) described in the BC Hydrogen strategy (2004) (**Table 2-4**). It could also support additional actions at little additional cost or loss of focus. These include curriculum development, contributing to industry committees and better integration of industry strategies with IFCI's work. The report also notes three tools that should be used to realise the objectives: championing, policy support, and funding. IFCI provides a suitable venue for the first two tools, and supports the third tool indirectly through sponsorship of network events. The institute also aids companies in securing funding through the transfer of technology and intellectual property.

The goals for the science and technology program are focused in three areas: filling the gaps in knowledge and technology for the commercialisation of fuel cells, providing collaborative research services to industry and building the human capability in fuel cell technology. The gaps in knowledge and technology are identified as cost, performance, reliability and adaptability. The fuel cell industry has developed specific targets in each of these areas for the next five years. The goals for community stewardship are focused on demonstration projects and community outreach programs, providing publicly available testing and research facilities, building partnerships and consortia and providing a forum for information sharing and dissemination. IFCI identified specific targets for integration activities such as seminars and workshops and providing services for testing and standardisation. For detailed information on these goals and targets refer to **Appendix A.**

Science and technology program: The strategy for filling the gaps in knowledge and technology is defined as three platforms: Solid Oxide Fuel Cell technology (SOFC), Permeable Membrane Fuel Cell technology (PEMFC) and Hydrogen technology. Within SOFC the focus is on developing new materials and reducing temperatures to improve performance. Within PEMFC the focus is on reducing cost through reductions in the catalyst layer thickness, increasing temperature for increased performance and improving power density ratios. Within Hydrogen the focus is on developing new ways to generate and store hydrogen gas as a fuel. In addition the modelling group is focused on building new mathematical models leading to cheaper and more effective research. The strategy for collaborative research services includes surveying companies for requirements and applying the feedback. IFCI actively seeks out and promotes collaboration projects and is looking to dedicate 50% of current resources to this end (NRC-IFCI, 2005). Finally, the strategy for building a human resource capability is two fold. IFCI created joint academic positions at both the University of British Columbia (UBC) and Simon Fraser University (SFU) and provides many opportunities within its research programs for graduate students. Recent feedback from the board suggests that IFCI is not yet successful in providing industry with resources that are highly skilled in fuel cell technology.

Community stewardship program: The demonstration project and community outreach program is focused on the development of the re-fuelling station for the "Hydrogen Highway" project and the creation of a demonstration centre to showcase Canadian technology. IFCI also hosts fuel cell events designed to raise the profile of the industry in the media and general public. The institute will be moving to a new facility in 2006. It is hoped that this facility will be powered by fuel cell technology at some time in the future. The industry testing and standardisation strategy focuses on extending use of the institute's facilities to industry users.

The institute has a hydrogen environment chamber and ten testing stations that are available for projects and is in the process of developing a standard test cell for use as a benchmark in future testing activities. IFCI gathered data from the re-fuelling station and other test projects which will prove useful to others in developing standards and codes for the industry. The strategy for building partnerships and consortia with industry and academia is realised through representation from both groups on the Board of Directors. In 2004 IFCI successfully established a sensor consortium comprising twenty companies from all over the world. IFCI was also instrumental in establishing a Testing Working group to develop test standards and procedures (NRC-IFCI, 2005). The strategy for collaborative research has resulted in over 50% of IFCI's resources being dedicated to collaborative projects. This includes a number of major industry partners, local as well as international academic partners and international research organisations. IFCI is the recipient of a grant from Japan's New Energy Development Organisation (NEDO) for research on a hybrid multi-layer membrane for Hydrogen separation (NRC-IFCI, 2005). Lastly, the strategy for information sharing and knowledge dissemination takes two forms. The first is to host and facilitate workshops and seminars at the IFCI facility. The second is for researchers and staff to publish articles and academic papers and attend conferences and seminars held elsewhere. IFCI senior management and group leaders are also involved in the various committees dedicated to fuel cell technology in Canada. These include the sub-committee to develop the National Fuel Cell and Hydrogen Strategy, the Canadian Transportation Fuel Cell Alliance, the Fuel Cells Canada Executive Committee, Fuel Cell Symposium (COM 2005) and the 2005 International Conference on Green Energy (NRC-IFCI, 2005). IFCI is also heavily involved in the B.C. Innovation Hub along with UBC, SFU and University of Victoria (NRC-IFCI, 2005).

4.4 Resource and Capability Gaps

Since inception, IFCI has made good progress developing the physical assets and capability to be a prime resource for the fuel cell industry. The institute must still find a way to take full advantage of these assets to position itself as a primary service provider and industry problem solver. Rush et al. (1996, p. 175) suggest that research institutes must fully understand their role in order to be successful. The role of the institute is not to provide the breakthrough innovative research that will launch successful new products, that is the role of industry. Nor is their role to carry out basic research and provide education and training like the universities. The institutes have their own role "based on acquiring, maintaining and supplying technologies and technology related services which industry needs but cannot readily access in house" (Rush et al., 1996, p. 175). The institute exists to fill a gap in activities not provided by industry or academia and can act as a "useful middle ground" (Rush et al., 1996, p. 175) for graduate students on their way from academia to industry. Within the institute they will begin to learn the needs and language of industry. To this end the institute must have a strong quota of industry professionals to guide staff members to become successful future employees in industry. Rush et al. (1996, pp. 175-176) suggest the following as a "common set of activities related to the needs of established industry large and small":

- large R&D or engineering projects in new technologies
- collaborative projects, tracking or adapting technology for the benefit of a group of firms
- problem solving
- technology demonstration and advice
- subject-matter-expert oriented services
- test and information services

This list matches well with IFCI's core functions however there are two areas where the focus is not fully aligned. The first is the lack of industry experience of senior research staff and their ability to guide and mentor more junior researchers. A certain amount of turnover is desirable in order to keep the ideas fresh and to circulate engineers between positions in industry and the institute. The second is IFCI's major focus on new technologies research at the expense of problem solving and expert services. The resource split in terms of human effort must be more even between science and technology and community stewardship demonstration, information and testing services. IFCI does well in separating the funding for these two distinct activities as well as achieving a good balance between public and private funding. The institute has used the core capability of creating and leveraging partnerships to fund a number of collaborative projects. These projects not only support industry in solving their technology problems, they also help to finance longer term projects.

In the science and technology area, there are a number of projects not relating directly to the technical goals of the organisation. In these cases the purpose is often collaboration with the universities and the goal is educational. A better scenario would be to only pursue those projects that address the technical goals and use them as a theatre for collaboration with the universities. In this way the resources of the institute are not wasted, the students gain a valuable experience and industry a more prepared potential employee. IFCI must guard against spreading themselves too thin across a large number of concurrent projects.

One key to successful research projects has been identified as "good project management and monitoring of projects" (Rush et al., 1996, p. 178). IFCI recently introduced a matrix organisation structure to gain greater visibility into project progress. However the culture of the organisation must be aligned and move from an academic to more of an industry type focus in order for project management to be effective. There must be an understanding from all teams of the importance and benefits of monitoring. In addition, the project manager must be skilled in the art of communication and be prepared for pushback from staff.

IFCI does not yet have the capability to provide a full range of services, particularly to smaller companies. These companies may need not only technical support but also some basic consulting, quality assurance, testing or informational services that the institute could provide.

The institute is focusing on testing type services but does not provide the softer services that young companies might need.

It is early days yet to determine whether IFCI is successful in terms of leadership. Successful leadership can be measured through quantifiable metrics such as turnover, operational efficiencies and meeting strategic targets; however, leadership's positive influence on the underlying culture and values held by the organisation is harder to gauge. Leonard (1995, p. 25) distinguishes between those "big V" values at the core of an organisation's stated vision and culture and "little v" values that are demonstrated in the daily routines surrounding technology, knowledge and operations. A measure of strong and effective leadership is the ability to align the "big V" and "little v" values of the organisation. For example, if IFCI's "big V" values state that it is committed to serving the interests of its stakeholders, but its "little v" values of technology portfolio management demonstrate aspirations to be a premium basic research institute, then the organisation values are misaligned. Rush at al (1996, p. 179) state that successful institutes "are run by powerful, entrepreneurial personalities." The leader's vision and ability to drive and align the organisation's culture and values is critical to the success of the institute.

4.5 Internal Analysis Summary

Rush et al. (1996, pp. 179-180) categorise the success factors for an institute as three types: internal (under the direct control of the institute), external (outside the control of the institute) and negotiated (can be effected by the institute to some degree). **Table 4-2** shows the full list of critical success factors in each category as identified by Rush et al. (1996, pp. 179-180). Each of the elements is considered in order to assess the extent to which IFCI is positioned for success.

Table 4-2: Critical Success Factors for a Research Institute

Internal	Negotiated	External
Leadership	Industrial Input	Stable Policy
Defined Strategy	Market Responsiveness	Consistent Funding
Flexible Structure	Networking	Demanding users
Training	Learning from Firms	Government commitment
Technical competence	Links to Policy making	Macro-economic growth
Project Management	Links to Universities	Industrial development
Good Communications	Image and Awareness	
Technology Search		

Source: Adapted from Rush et al. (1996, p.179)

The focus of the institute should be on the first and second columns although many of the factors have linkages across columns. "Leadership" and "Defined Strategy" are essential to successful delivery of all other items. "Good Communications" and "Technology Search" reflect the need for porous boundaries and absorptive capacity (Leonard, 1995, p. 136) in order to continually increase knowledge from outside the organisation. This aspect of success is also reflected in "Learning from Firms." The following is a review of each of the factors.

Leadership: IFCI's leadership team has a diverse mix of backgrounds ranging from academic to energy industry to consultants. This provides for a strong science and business development team. IFCI may need to consider adding some senior staff with specific fuel cell industry experience to help bring the needs of this group to the table.

Defined strategy: IFCI is struggling to define its strategy and find the right balance between science and technology and community stewardship activities. The institute is putting much focus on a business plan incorporating feedback and advice from the board into the vision and goals for the next five years.

Flexible structure: IFCI recently imposed a matrix structure on the organisation reflecting the need to improve project management effectiveness (NRC-IFCI, 2005). The resulting structure is flexible enough to allow research staff to move between projects. Administration staff members also perform multiple roles and are able to flow within the organisation based on need.

Training: IFCI has a large number of graduate students working on research teams. However, there are few senior researchers with industry experience. There is a need to improve the mentoring of these students and prepare them for roles in industry. Rush et al. (1996, p. 195) recommend a ratio of one third industrial to two thirds academic.

Technical Competence: IFCI has hired a number of senior researchers with high levels of competence in SOFC materials, PEMFC and mathematical modelling. IFCI also has deep competence in hydrogen fuel generation techniques.

Project Management: IFCI is very weak in this area particularly in relation to the science and technology projects. Given the nature of research, project management in this type of organisation is not easy. Technical targets are difficult to define and even more difficult to meet with any certainty. The project manager must set goals and targets in terms of measurable objectives and stage gates not necessarily technical achievement. Progress must be measured on a regular basis and hard decisions made on the future of projects. Project and team performance must be peer based and systematically applied.

Good Communications: Internally, there have been a number of initiatives designed to foster good communication including diversity training (NRC-IFCI, 2005). However, project teams work very independently from each other and communicate more with those external to the institute that share the field of expertise than internal. This is despite having the benefit of management support for a portfolio approach and inter-departmental collaboration. Both internal and external communication initiatives are handled by the Communications Officer. Currently this effort is focused on informational materials and a website. Feedback from firms shows that some are confused over the role of IFCI and don't have a clear sense of how it adds value. In this situation IFCI must pay more attention to the informal communication channels between themselves and their industry partners. A strong project management team with defined communication plans and skills in facilitation could improve this situation and develop strong relationships between IFCI and the rest of the fuel cell community.

Technology Search: IFCI recently conducted a "cluster study and technology scan" (NRC-IFCI, 2005) in order to gather insight for an upcoming technology roundtable. IFCI staff members continue to participate in knowledge exchange activities with external sources at home and abroad. There is an opportunity here for IFCI to become a central collector of knowledge from across the industry that could then be made available to local firms.

Industrial Input: IFCI gathers most of its industrial input from its board. The board has a large contingent of members from industry, others are government and academia. IFCI has some ex-industry employees that can help to guide the institute in a direction more aligned with the needs of industry. However, a more structured exchange program with industry might help to develop an improved understanding of the industrial perspective.

Market Responsiveness: IFCI responds to the market it serves in Canada through the strategic focus of its research projects. The institute serves both the SOFC and PEMFC industries. IFCI could improve in this respect by dedicating more resources to the non-scientific activities that are part of the strategic focus. For example responding to the market need for more public awareness.

Networking: This is a successful area for IFCI. The institute has developed some prestigious relationships with firms and other organisations such as Ford through the Hydrogen

Car demonstration project. IFCI also makes use of its network of National Research Council (NRC) organisations to share knowledge and resources. The institute includes members from all the major Canadian fuel cell firms on the board. IFCI shows considerable commitment to building international R&D networks (Grandstrand, Hakanson, Sjolander, 1992) and internalizing technology by means of contract research and inter-company collaboration (Moenaert, 1990); both of these schemes were noted in the literature as being imperative in a globalised R&D environment such as the fuel cell industry.

Learning from Firms: IFCI is partnered with a number of firms on collaborative projects. These are more in the nature of problem solving relationships rather than an information gathering experience. IFCI spearheaded the development of hydrogen sensor testing for a consortium of firms. The institute hosts roundtables and workshops on a variety of subjects and recently launched an industry scan to better respond to the needs of firms (NRC-IFCI, 2005). IFCI could extend this role to include a knowledge gathering and sharing exercise. Specifically IFCI may want to institute an employee exchange program.

Links to Policy making: IFCI's senior management are involved in all the major national committees responsible for developing policy in the area of fuel cell technology.

Links to Universities: IFCI has strong ties to the local universities specifically UBC, SFU and UVic. The institute is located with in the grounds of UBC. It also has ties to a number of international universities through staff member connections. IFCI has co-founded a number of university research positions and currently employs 25 graduate students.

Image and Awareness: IFCI needs a greater emphasis on communication and public relations specifically in answering to the concerns of the board. Within the industry, companies are not sure of the role or significance of IFCI. Externally, the public is aware of the institute only in its relation to the B.C. Hydrogen Highway project.

Reviewing each of the success factors shows that IFCI is addressing all the aspects suggested by Rush et al. (1996, p. 179). However, slight changes in emphasis are needed for the institute to be successful. A recent survey conducted by the institute among local industry shows that IFCI still has a way to go in finding an "effective role in the national innovation program" (Rush et al., 1996, p. 174). Specifically the institute must address communication issues between the research staff and industry partners. The lack of project management capability must be addressed in order to develop confidence with the industry stakeholders. IFCI leadership must be prepared to not only listen and respond to constituent feedback but also to take a leading position on the focus of the institute and the cultural shift that must occur from basic research to research services.

5 IFCI'S STRATEGIC SUMMARY

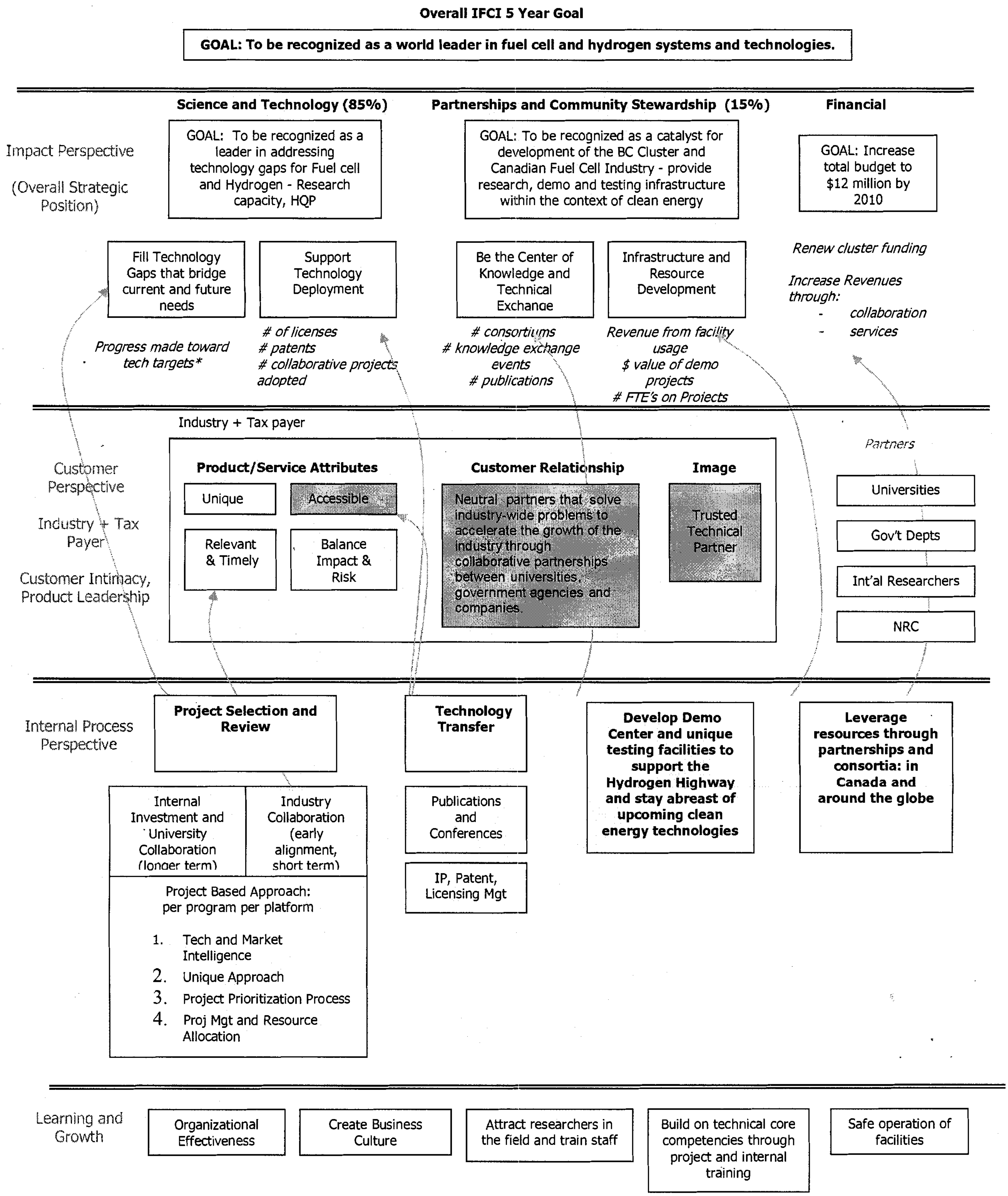
The authors contributed to the creation of a strategic summary for IFCI; a process that was spearheaded by Dr. Yoga Yogendran, IFCI's Director, Technology Deployment, and facilitated by Anja Haman, an independent consultant. The strategic summary is included in **Figure 5-1.** It is outside the scope of this work to review and critique this summary in detail. However, owing to the fact that it was developed in conjunction with the roadmap and resource allocation methodology, it is therefore worth a brief review.

The summary diagram is structured somewhat like a roadmap except that there is no concept of a timeline. The top level of the summary shows IFCI's five year goal with subsequent levels describing the means by which IFCI intends to fulfil that goal. The objectives and goals are based on national and provincial strategies documented in the Canadian Fuel Cell Commercialisation Roadmap (2003) and the BC Hydrogen strategy (2004) summarised in **Section 2.6** and **Section 4.3**. IFCI also drew input from a recent survey, conducted in March, 2005, to better understand the expectations of its stakeholders. The second level describes the foci of IFCI's activities split between "Science and Technology" and "Community Stewardship." The activities, programs and technologies defined are based on an internal assessment of available resources and capabilities. Arrows show the "Science and Technology" projects being supported through a "Project Selection and Review Process." IFCI requires a means by which to select projects in order to get maximum benefit from limited resources. The criteria that IFCI uses in the selection process must match the objectives from the strategic summary. Hence, the need for the project selection methodology developed as part of this work.

The external and internal analyses included in this report show that IFCI understands the focus of its mandate however there is an opportunity to fine tune the organisation to more effectively communicate and fulfil its goals. A series of recent interviews with local industry leaders indicate that IFCI has not fully communicated the what, how and when of the organisation's objectives. Industry believes that IFCI is not set up to deliver on technical promises due to lack of project management and limited sharing of ideas between research groups. Respondents to the survey also do not believe that IFCI is doing a good enough job of preparing potential employees for industry. Underlying these concerns is a general sense that the cultural divide between industry and a government sponsored organisation is too great to effectively achieve good synergy. Specifically a lack of urgency on the part of IFCI and a perceived lack of communication on the subject and content of research programs have led to an atmosphere of distrust. Issues spawning from concerns over rights to intellectual property (IP) make this communication gap ever more critical. The roadmap development is an attempt by IFCI to fully communicate the nature, goals and timeline for their science and technology programs. Specifically, the programs described by the roadmap can be assessed by industry for collaboration or avoidance of overlap.

In order to make more effective use of their scarce resources and begin addressing some of the issues noted above, IFCI determined to proceed with developing a formal project selection methodology and roadmap. These two tools will allow IFCI to more closely align with the goals and objectives of the organisation and communicate effectively with industry and others to pursue research goals more effectively. If IFCI does not engage in these activities it runs the risk of directing resources into areas that do not meet the needs of the organisation or its constituents. In turn this leads to IFCI's increasing irrelevance to the community it serves.

Figure 5-1: IFCI Strategic Summary for 2006 - 2010



Source: Created by Haman Consulting in conjunction with IFCI management (2005). Reproduced with permission.

6 PORTFOLIO METHODOLOGY DEVELOPMENT

6.1 Project Classification System and Research Summary

Prior to the initiation of this work, IFCI already had a project classification system in place. Their system has three levels, which are listed in descending hierarchical order: program, platform and project. There are four programs, with each one focusing on a different technological area of discovery. The four programs are outlined below:

1. Demonstration and Community Stewardship

Projects in this program are intended to deploy recently developed technology and test it under realistic conditions. In addition, the program's aim is to increase market visibility, establish an early adopter network, explore technology integration, and gather the knowledge and data required to create standards. These projects will leave BC with a legacy of a skilled workforce and infrastructure that will be essential in building a hydrogen economy. The program also strives to provide venues and opportunities for relationship building and knowledge sharing within the cluster. This program does not have a platform level; instead it comprises six related projects.

2. Science and Technology – PEMFC

If investments are an appropriate gauge, the fuel cell industry predicts that proton exchange membrane fuel cells (PEMFC) are most likely to prevail in automotive and compact portable power applications. That is because PEMFCs operate at temperatures near 30 °C and require a few minutes to start-up. IFCI is working to address a number of key technology gaps related to this technology; further details follow in the platform description section.

3. Science and Technology – SOFC

Solid oxide fuel cells (SOFC) operate at much higher temperatures than PEMFCs (near 700 °C) and therefore require sufficient time to warm-up before full power can be reached. In addition, SOFCs use a ceramic membrane rather the polymer membrane used in PEMFCs. Owing to temperature, start-up time and the fragility of ceramic membranes, most SOFC applications are for stationary power production with some using the waste heat in secondary processes.

4. Science and Technology – Hydrogen

Many predict that hydrogen will be the fuel of choice for automotive fuel cell applications – the largest potential market. However, a number of technical and market hurdles must be overcome before hydrogen could be viable as mass scale portable fuel. This is IFCI's smallest program and they are working to address a few technological issues related to hydrogen generation and storage. More importantly, IFCI's demonstration and community stewardship program is building the foundation for a viable hydrogen economy.

Within the three science and technology programs outlined above, there are a number of platforms. The platforms consist of related projects that that revolve around a common area of discovery or are aimed at addressing a key technological gap. The science and technology platforms are summarised below:

PEMFC Program Platforms:

High Temperature: Increasing the temperature of PEM fuel cells will improve efficiency and utilisation of the expensive platinum catalyst. A number of issues such as water management and catalyst activity will be addressed through experimentation, modelling and knowledge gained from other platforms.

Direct Fuel: Methanol is seen as potential fuel for valuable niche fuel cell markets such as battery replacements and a possible alternative to hydrogen. IFCI is working further develop its micro direct fuel cell competency and contribute to fabrication techniques, device simplification and sensor technology.

High Performance: Improving the performance of membrane electrode assembly (MEA), the core of the fuel cell, will lead to increased reliability, cost reduction and efficiency improvements. IFCI is focusing on such goals through a combination of modelling and experimental projects.

Low PGM and non-noble catalyst: The high cost of current fuel cells can be largely attributed to the amount of platinum required. IFCI has identified projects and talent that can reduce the amount of platinum required whilst maintaining, and possibly even improving performance.

Modelling: IFCI has a distinct capability in computer modelling of all key fuel cell design parameters, with these resources being utilised by many IFCI projects and simultaneously supporting Canadian fuel cell companies that do not have the scale to develop such capability in house.

SOFC Program Platforms:

Low Temperature: SOFCs currently operate at temperate in excess of 600 C, leading to start-up, safety and material issues. IFCI has selected projects with the goal of reducing the operating temperature without compromising performance, enabling use of multiple input fuels and developing novel catalysts.

Proton Conducting Ceramics: In partnership with NEDO Japan, IFCI is working to develop a novel proton conducting ceramic membranes that could both improve power density and reduce operating temperature.

Hydrogen Program Platforms:

Generation: Addressing the clean and reliable generation of hydrogen is essential to commercialising fuel cells and building the foundation for the hydrogen economy. Novel production and purification techniques are being explored.

Infrastructure: Key hydrogen infrastructure gaps being addressed include sensor development and infrastructure modelling.

Each of the platforms outlined above includes a number of projects. It is beyond the scope of this document to summarise all the projects. However, the platform descriptions give a general idea of the research being pursued. Further, project details can be found in both the technology roadmap and the project information summary chart.

6.2 IFCI's Current Resource Allocation Process

The authors were originally asked to develop a technology roadmap for IFCI; however they found that the institute was having problems allocating their scarce resources to a number of potential projects. IFCI's original plan for reassigning resources in 2005 was to hold a two day meeting in which project proposals were presented. A one hour session was planned for the end of the meeting for management and senior scientists to make funding decisions. The authors observed the second day of this meeting. It was revealed in this meeting that the institute did not have a good handle on how the level of funding requested fit with their budget, nor did they have a transparent selection process in place. The former is merely an accounting exercise, but more importantly the latter meant that they did not have a structured means of reviewing and rating projects such that educated budgeting decisions could be made. Thus the authors were engaged in a more comprehensive effort than their originally planned work of creating a technology map. This effort involved devising a resources allocation methodology that aligned with IFCI's mandate and strategy. The remainder of this section and **Chapter 7** describe the results of this effort.

The methodology developed was done so in tandem with the 2005 resource allocation process. The 2005 resource allocation process consisted largely of mutual negotiation between project leads and IFCI management, using some of the author's tools that were being developed. General budget guidelines were set to indicate the approximate proportion of funding each program should receive. These guidelines were developed by IFCI management and were based on combined consideration of the institute's mandate and the rough composition of the Canadian fuel cell sector. The guidelines were:

- approximately 50% of operating and payroll funds should be allocated to collaborative projects; collaborative projects span all programs
- approximately 15% of operating funds should be allocated to demonstration and community stewardship projects
- approximately 85% of operating funds should be allocated to science and technology projects with a 60:30:10 split between the PEMFC, SOFC and hydrogen programs representing the rough composition of the Canadian fuel cell sector[11]

Problems were encountered during the 2005 resource allocation process, which led to increased support for the creation of a structured methodology. These problems included a lack of process transparency, incompatible versions of budget summary data, and frustration amongst the scientists and engineers with frequent changes and adjustments. The methodology presented herein was developed in tandem with the 2005 resource allocation process and applied in parts to aid decisions, test the process and tools, train IFCI management on its use, and summarise the

[11] Table 3-2 of this work outlines the Canadian fuel cell industry composition

resulting portfolio. The methodology is now ready for full deployment at the start of the 2006 budgeting cycle.

6.3 Portfolio Methodology Developed

The methodology is built around the application of three tools using portfolio map principles similar to those outlined in Cooper's work (1997). These three tools provide structure for managing the information used in the decision process, while also creating useful facts and displaying them in a readable manner. The tools are intended to facilitate communication during the resource allocation process and were designed to be relatively simple to use and edit. The tools are built into a custom spreadsheet and are listed below:

i. objective target map
ii. portfolio maps and financial data
iii. technology roadmap

The following subsections, the tools are outlined in further detail along with the 2005 portfolio results. The technology roadmap, however, is described in its own section owing to the fact that it comprised a large component of this project.

Objective target map:

In order to develop a detailed understanding of how each project contributes to the institute's objectives, a target map was created. The target map is similar to Boeing's approach outlined in Dickinson's paper (2001) that was summarised in **Section 2.4** of this work. The target map also serves a secondary purpose as a performance tracking tool. The 2005 objectives map is included in **Appendix A** for reference.

The objectives map is structured as a table, with the objectives plotted along the upper horizontal axis and the individual projects plotted down the side. The high level objectives were extracted from the strategy summary of **Chapter 5**, while the more detailed objectives were arrived at by the combination of condensing prior IFCI strategic planning documents and extracting insights from discussions with IFCI management. These objectives have three levels: overall strategic goals (extracted from the strategy summary), the internal process perspective, and measures and growth. Each measures and growth column includes a target for 2005, 2007 and 2010. A series of measures and growth columns roll-up into one internal perspective column, which in turn rolls up into one strategic goal column.

With the individual projects plotted down the vertical axis; the user can enter a score, or yes/no answer, for each applicable measures and growth column. The resulting data distribution among the columns will provide the user with an understanding of how each project contributes to the institute's objectives. The objectives map can also be used for the purpose of performance monitoring. Metric scores can be entered for each project and used to track progress at the project, platform, program, or institute level.

Portfolio maps and financial data

The objectives map shows the user how individual projects contribute to the institute objectives and provides a convenient means to record performance. However, it does not allow for the projects to be ranked and compared. The portfolio maps are intended to fulfil this purpose. The maps are built in a spreadsheet, which includes rows for each project and columns to allow for entry of key data. The data columns can be expanded upon and altered; this chart serves the dual purpose of being a repository for any information related to the projects and the data source for the portfolio maps. During the 2005 process the most important columns were the cost figures, project links, project goals, and ratings according to the two portfolio map dimensions: impact of success and probability of technical success. Respectively, these two dimensions are plotted on the horizontal and vertical axis of the portfolio maps. Scores for each of these dimensions are arrived at through the process described later, but some discussion pertaining to their meaning is warranted. Probability of technical success is a relative ranking compared to other projects of the probability that the project could achieve its technical objectives with the funding assigned. Impact of success is based on the combined consideration of six components of IFCI's mandate:

- aid BC Cluster Mandate & Grow Canadian FC Industry
- grow R&D Capacity in Canada
- opportunity for NRC to make an impact (tech gap)
- grow competencies and facilities
- opportunities to grow and sustain IFCI

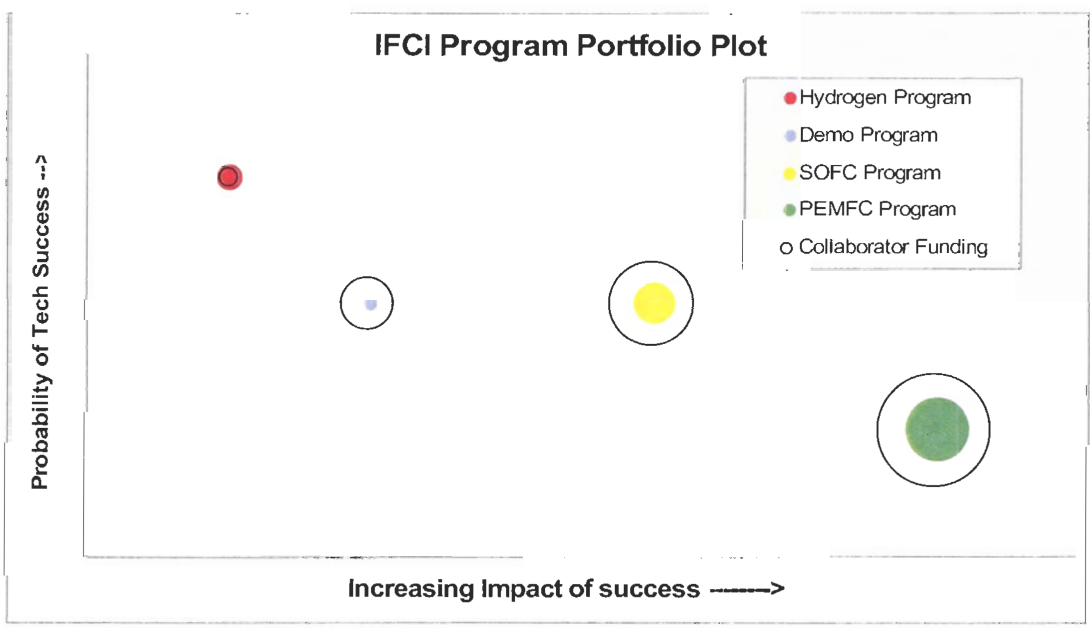
As shown in **Figure 6-1** through **Figure 6-5** bubbles and 'wire rings' are plotted on the portfolio maps. The solid bubble is proportional to the operating funds requested, with the 'wire ring' being proportional to the external funds secured. The bubble and ring together provide an indication of project cost and leverage of external funds. This style of plot allows for two additional dimensions to be plotted and compared, which is similar to 3M's approach to portfolio management as outlined in Cooper's work (1998b). Using the plots, the projects can be easily compared along the above mentioned four measures:

- impact of success
- probability of technical success
- IFCI operating funds requested
- external funds secured

After plotting the projects, attention should be focused on low ranking, large solid bubbles to determine if their requested funds would be better allocated to another project. These plots will be automatically revised as users discuss and alter rankings, and reallocate funds to different projects. A series of budget summary tables are included with the portfolio maps to provide the users with an understanding of their budget, the funds requested and currently allocated, and the funding division between programs.

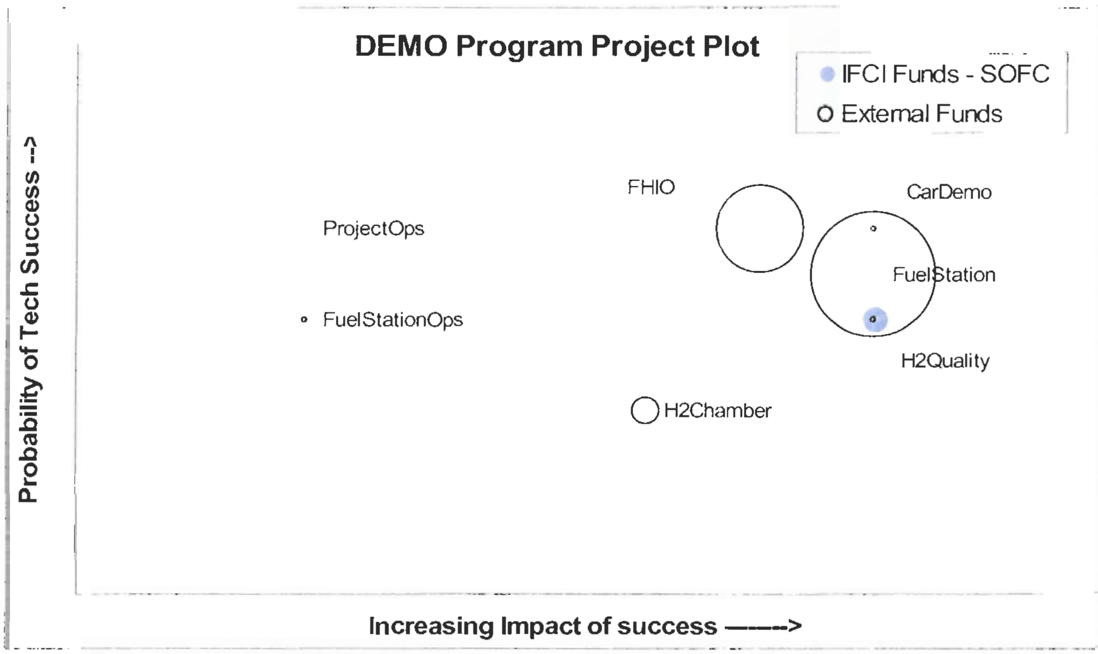
The final plots for each of IFCI's 2005 programs are included below. **Figure 6-1** is a summary plot showing all four programs according to the same dimensions, while **Figure 6-2** through **Figure 6-5** are individual plots for each program. For the summary plot of **Figure 6-1**, the cost data is aggregated from project level data, however the probability and impact of success scores are based on the user's entry for that specific program as a whole. In addition to the portfolio plots, the custom spreadsheet provides data summaries on the budget, funds allocated, fund distribution amongst programs, usage of internal versus external funds and collaboration measures. **Table 6-1** summarises total funding, operational funds and the allocation to collaborative projects. **Figure 6-6** shows the funding division between the programs, while **Table 6-2** shows the same data with the addition of program leverage. Application of the portfolio map tool revealed that, in the future, IFCI should plot cost based on the total project cost, which includes labour and a portion of the institute's overhead, rather than plotting project cost based on operating funds requested.

Figure 6-1: IFCI Program summary portfolio map 2005



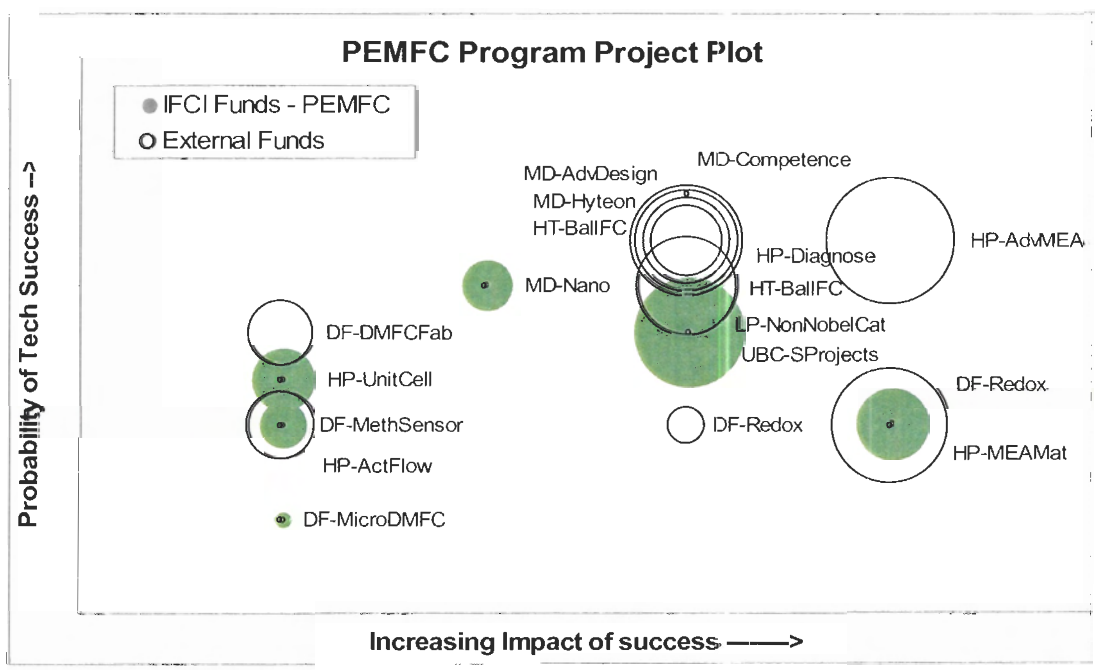
Source: Created by authors with data from IFCI.

Figure 6-2: IFCI Demonstration and community stewardship portfolio map 2005



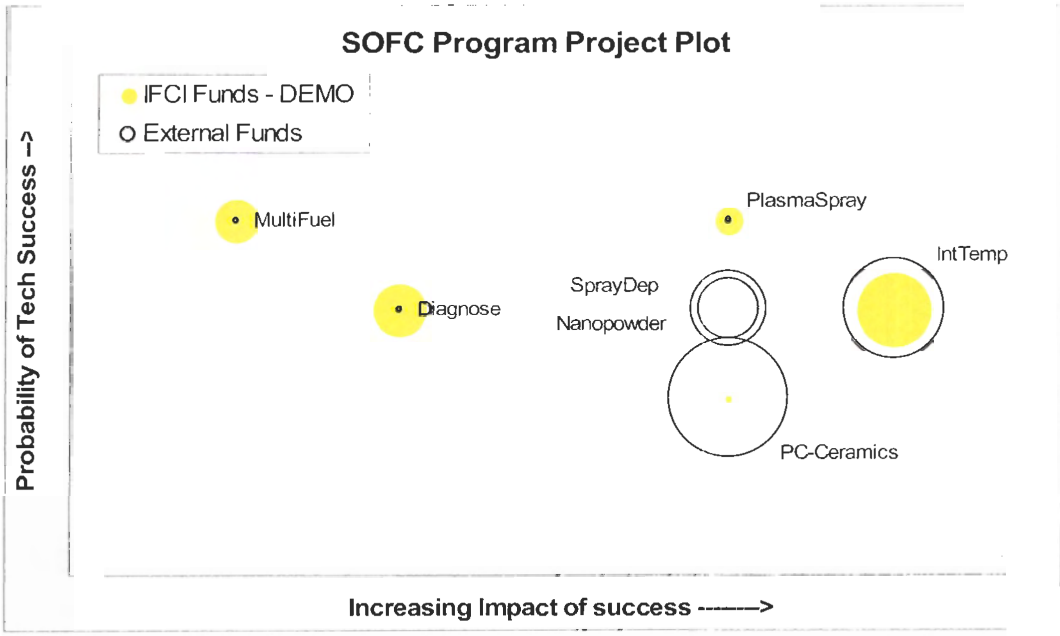
Source: Created by authors with data from IFCI.

Figure 6-3: IFCI Science and Technology PEMFC program portfolio map 2005



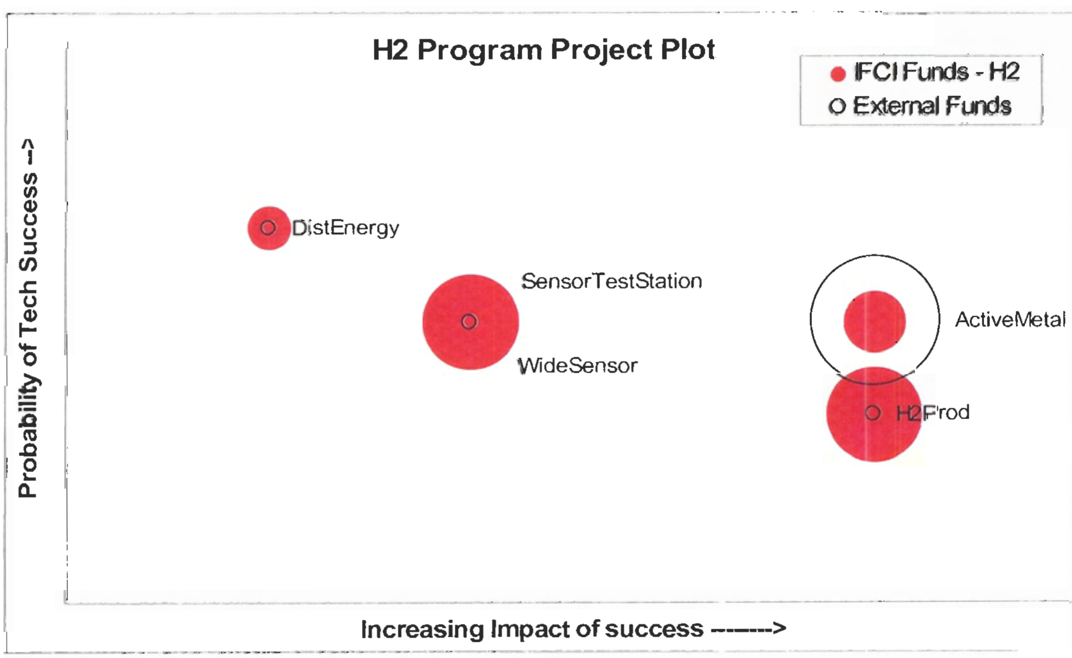
Source: Created by authors with data from IFCI.

Figure 6-4: IFCI Science and Technology SOFC program portfolio map 2005



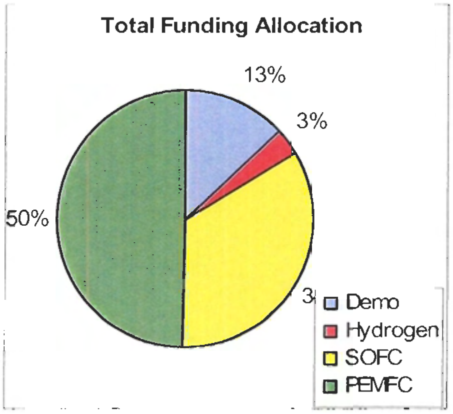
Source: Created by authors with data from IFCI.

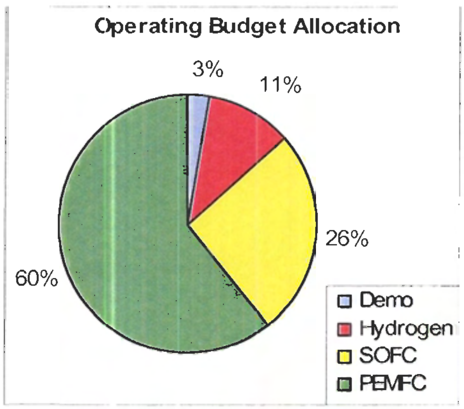
Figure 6-5: IFCI Science and Technology Hydrogen program portfolio map 2005



Source: Created by authors with data from IFCI.

Figure 6-6: IFCI's 2005 funding allocation between programs





Source: Created by authors with data from IFCI.

Table 6-1: IFCI 2005 budget data and collaborative measures

	Op's Funds	Total Funds
Budget	$ 467,000	$ 10,752,920
Allocated to Collaborative	$ 112,000	$ 6,729,220
% to collaborative	24%	63%

Source: Created by authors based on IFCI budget data.

Table 6-2: IFCI Program funding and leverage summary

Platform	Total Funds	External Funds	IFCI Op's Funds	External Funding Leverage
Demo	$ 356,034	$ 144,700	$ 100,000	1.4
Hydrogen	$ 77,984	$ 26,000	$ 44,000	0.6
SOFC	$ 791,340	$ 442,000	$ 103,000	4.3
PEMFC	$ 1,158,696	$ 799,320	$ 245,000	3.3

Source: Created by authors based on IFCI budget data.

6.4 Suggested Application Process

The methodology was not applied from the start of the 2005 budgeting cycle, and thus the process outlined below has neither been implemented nor tested. However, it will act as a convenient guide during the 2006 budgeting cycle since many of the issues encountered in 2005 can be avoided. The six step process created by the authors is outlined below:

Step 1: Information must be shared with the project staff regarding the goals and objectives of the institute.

Step 2: Given the unique view of the industry that the research staff have, they can then propose, at a high level, projects that they believe will contribute significantly to meeting the institute's goals. These projects should be assessed using the objective target map to weed out any that do not contribute significantly. Prior to detailed costing, the projects can also be assessed using the portfolio maps to see if there are any that fall into the low probability of success / low impact quadrant. In this way, the projects can be initially prioritised.

Step 3: The third step involves a detailed costing and proposal of the projects. The portfolio plot spreadsheet can be used to track all funds, project data and constraints such as "committed funding." During this time, high-level deliverables for each of the projects should also be developed and an estimate of how the projects contribute to the target objectives. This information can be pre-filled into both the objective target map and the roadmap. Review the portfolio plot for budget vs. requested funds to determine whether the institute is over or under budget. Review the percentages for allocation to determine general trends that can be discussed at the following meeting.

Step 4: This step will be the most difficult. At this time all the project leads should gather to review the projects. Start with the objective target map. Ask the project leads to fill this out as a group paying particular attention to those elements that are qualitative rather than quantitative. This exercise will give the leads an opportunity to develop a picture of the value of the projects relative to each other. Next review the portfolio plot. The costs and budget numbers will already be entered. Ask the project leads to enter the values for "probability of success" and "impact of success" based on their review of the projects and their understanding of the relative merits. Review the budget impacts and the allocation and then review the portfolio plots for the requested projects. Ask for opinions on how to resolve inconsistencies. Highlight those projects that do not seem to offer the value of the others. Refer back to the target map and the roadmap. Ask: "What would be the consequence of not funding this project?" "What would be the impact on other projects, on the targets, on academic or industry partners?"

Step 5: Try to reconcile the project budget requests to the overall strategy. The tools that you have used can only be a guide. The final decision will be based on the accumulated information from the tools, the project leads, the advisory board and finally your own best judgement.

Step 6: Communicate the decisions to the staff. Update the roadmap and the target map. Revisit both of these documents at the start of each quarter to check that you are still on track.

6.5 Portfolio Methodology Summary

Using IFCI's existing project classification system of program, platform and project, a series of tools and processes were developed such that IFCI could have structured discussions around the important variables related to resource allocation. These variables are project cost, external funding leverage, probability of technical success and impact of success. By first gathering economic data and then involving relevant project staff in a discussion around the weighting of the later two variables, plots can be developed that facilitate communication and resource allocation decision making. The tools developed also allow for aggregation of economic data such the budget allocation between different programs and internal versus external funding can be compared. The combination of the tools and process make up the resource allocation methodology, which was applied to IFCI's 2005 project portfolio and should be useful in making future portfolio management decisions. It is recommended that IFCI revisit their portfolio resource allocation process bi-annually, or when a major new project is being considered.

7 TECHNOLOGY ROADMAP

The technology roadmap for IFCI is essentially a subset of the greater technology roadmap for the Canadian fuel cell industry. The generic roadmap as defined in **Figure 2-1** by EIRMA (Probert et al., 2003) consists of a number of layers plotted against time. The top layer is the market and the lowest layers are resources. In IFCI's case the top two layers are already defined by the Canadian Fuel Cell Commercialisation Roadmap (Industry Canada, 2003). In addition, the bottom resource layer is defined as a constraint, i.e. there are a limited number of resources with specific skill sets available. The institute's roadmap defines the middle two layers depicting technology and research and development projects. It answers questions such as: "What are the technologies required in order to make the SOFC, PEMFC and DMFC products achievable?" and "What are the projects for which IFCI has resources that will allow the technologies to be developed?" The final roadmap may seem "fragmented and isolated" (Kostoff and Schaller, 2001) since IFCI's annual budget of $4.5 million is very small in comparison to Canadian fuel cell research spending overall ($290 million). Diagrammatic roadmaps showing all levels are included to provide context.

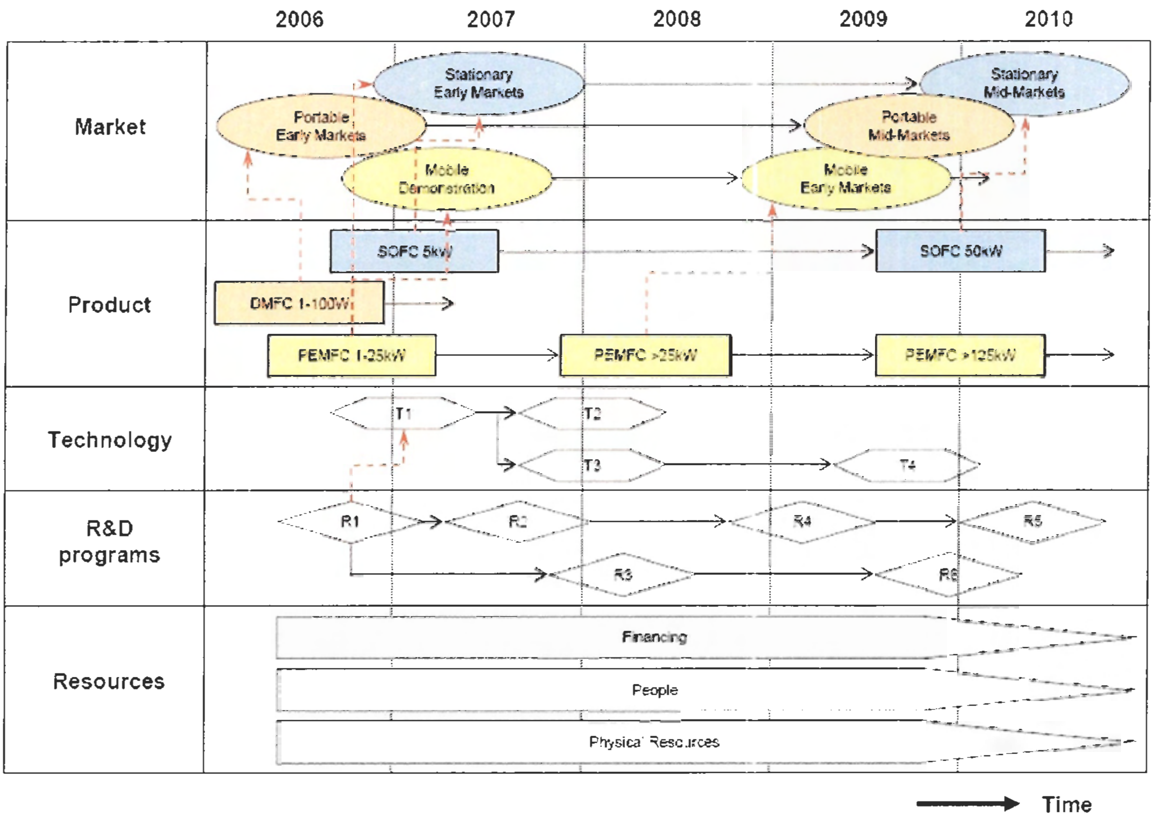
7.1 Methodology Employed

Prior to the authors working with IFCI, the institute put considerable thought into determining organisation objectives and research projects for the next five years. The institute drew these objectives from the roadmapping work already completed by Price Waterhouse & Coopers in conjunction with Industry Canada and Fuel Cells Canada, the Canadian Fuel Cell Commercialisation Roadmap (Industry Canada, 2003). This work formed the top portion of what would normally be included in a roadmap i.e. the market drivers and products. In this sense IFCI technology roadmapping is a technology pull (top down) exercise. The technologies identified in the roadmap are currently of three main types being developed in Canada, SOFC, PEMFC and DMFC. In addition to developing products, a significant infrastructure must be in place before hydrogen can be used effectively as a fuel e.g. re-fuelling stations. The focus for IFCI in developing this roadmap is to identify the research programs that will make a contribution to the technology and eventually provide the market requirements. These research programs are constrained by the resources that IFCI has available and form only a small portion of the overall effort in Canada. These projects should also be those that are not easily performed by individual firms within the industry. In addition to the technology aspect of the roadmap, IFCI is also required to fulfil the community stewardship portion of its mandate. A second diagrammatic roadmap shows how these elements are included and met by specific IFCI projects.

The IFCI roadmap was not generated in an ideal way. The literature recommends that all stakeholders participate in the development of the roadmap in order to understand the nature of all aspects. The majority of the IFCI researchers were not involved in the Canadian Fuel Cell Commercialisation Roadmap (Industry Canada, 2003). However, they are well versed in the current state of technology in the industry and understand fully the technical objectives for the industry as a whole over the next five years. In addition the roadmap falls into the trap expressed by Kostoff and Schaller (2001). Since the roadmap is depicted for only one agency in a field in which multiple organisations are participating, the view is at once "fragmented and isolated" with large gaps in technology (Kostoff and Schaller, 2001).

Referring to EIRMA's generic form of roadmap (Probert et al., 2003) from **Figure 2-1** in **Section 2.5**, the upper market driven layer can be deduced from the Canadian Fuel Cell Commercialisation Roadmap (Industry Canada, 2003).

Figure 7-1: Diagrammatic roadmap market driver level



Source: Adapted from EIRMA (Probert et al., 2003) typical roadmap and Canadian Fuel Cell Commercialisation Roadmap (Industry Canada, 2003).

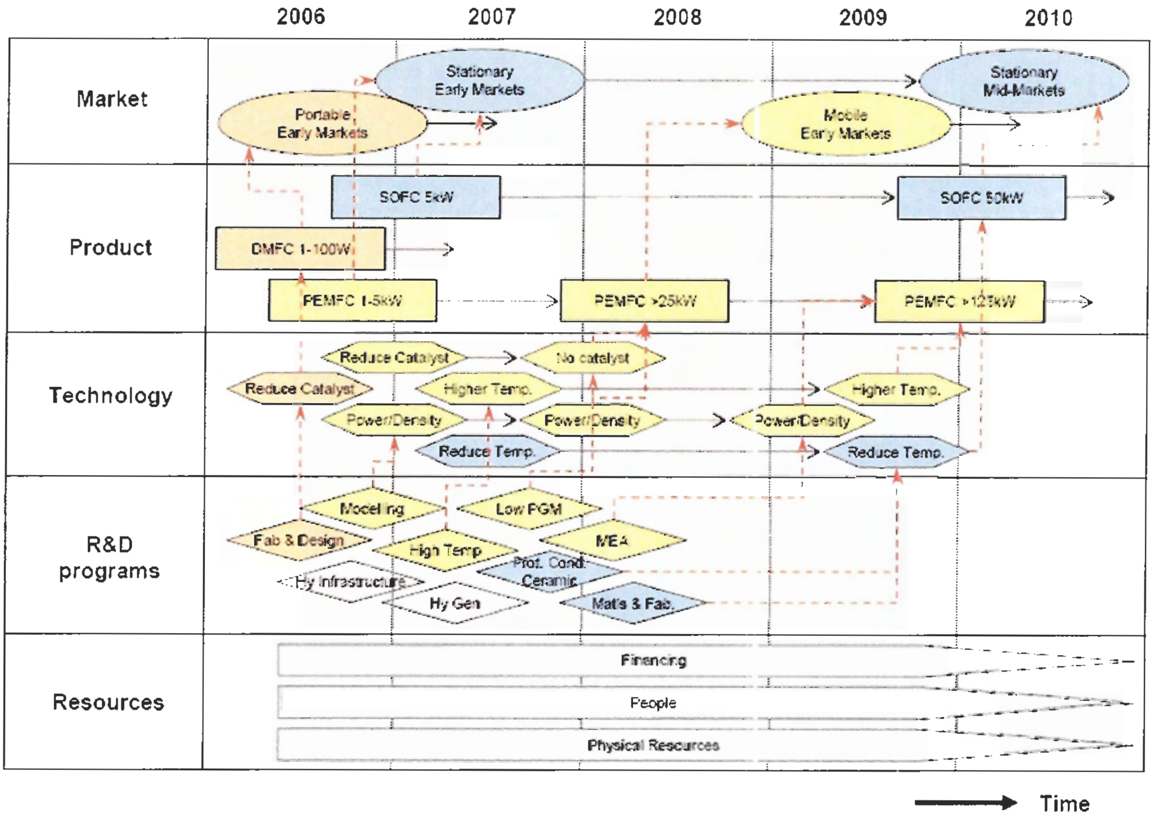
Figure 7-1 shows the market segments defined as stationary, portable and mobile. Currently all three segments are in the demonstration and early market stages. Portable markets require less power making it likely that they will take the lead hence they are shown to be in the "Early Market" stage earlier than either stationary or mobile. Since portable products also require fewer infrastructure elements than mobile, specifically small portable applications such as laptops and mobile phones, DMFC is an early contender due to availability of fuel and small power requirements. Stationary markets are more easily serviced and are shown to be in the "Early Market" stage earlier than mobile. Stationary markets are currently served by both the Proton Exchange Membrane Fuel Cell (PEMFC) and the Solid Oxide Fuel Cell (SOFC) products. Given the nature of the two products the current technology favourite to fulfil this market is SOFC.

PEMFC is the frontrunner for the mobile market. Current products are being developed to lower the cost and increase the efficiency of the fuel cell. The availability of matching infrastructure is key to the success of this product, hence the focus on the hydrogen highway and hydrogen generation and storage capability.

Given limited resources and available capabilities at IFCI, the institute has decided to focus efforts on some key technology areas. The technology platforms fall into the three product categories, PEMFC, SOFC and Hydrogen. Within PEMFC research is focused on reducing cost, specifically through reducing the platinum catalyst layer, increasing temperatures and increasing power to density ratio. The DMFC research focuses on fabrication and design techniques with the goal of reducing cost and preparing for mass manufacture. In SOFC technology focus is on designing materials for high temperature applications and improving efficiencies at lower temperatures. Within the Hydrogen platform the emphasis is on the safe and efficient production and storage of hydrogen.

IFCI has designed a number of research programs that specifically address these technology platforms (refer to **Appendix A** for details on how the programs address the technology platform targets). **Figure 7-2** shows a diagrammatic version of the roadmap in which the research programs are described by the titles given in **Section 6.1** of this document. This figure demonstrates how each program supports advances technology platforms which in turn allow the development of products that will meet the demands of the market.

Figure 7-2: Diagrammatic roadmap IFCI technology programs

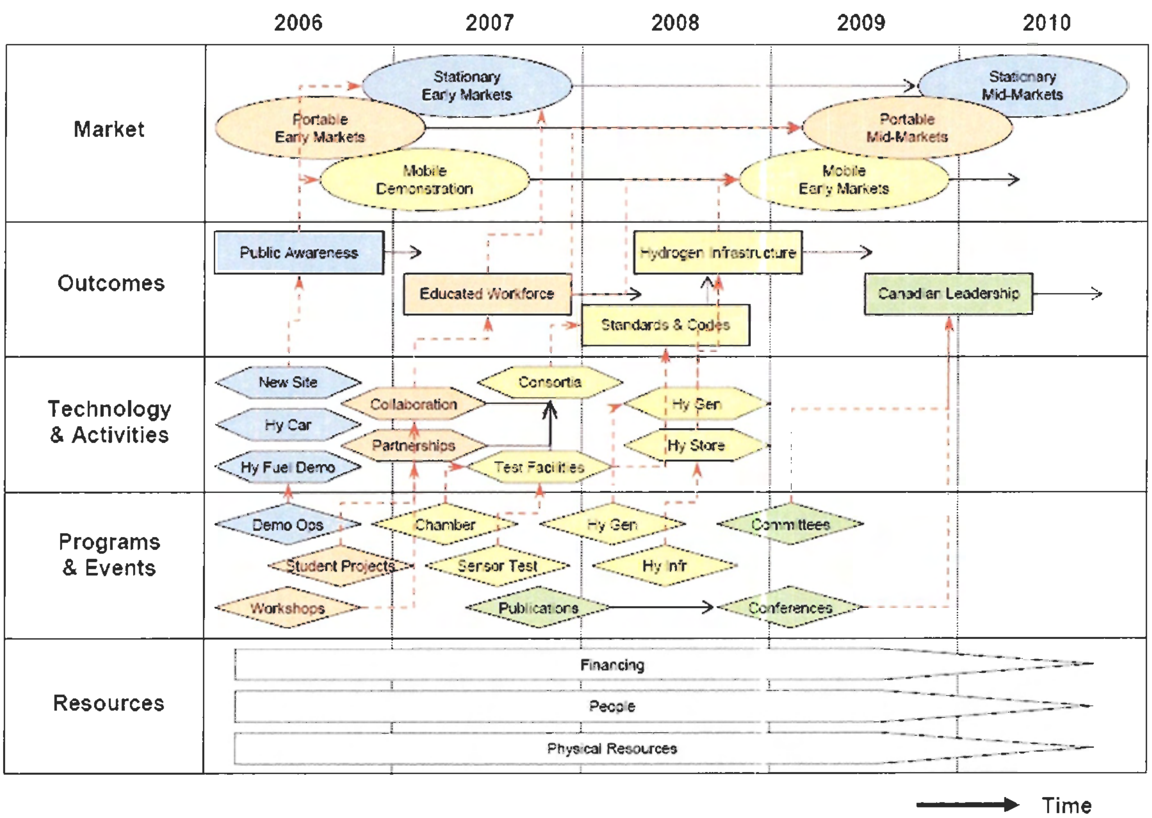


Source: Adapted from the typical roadmap produced by EIRMA (Probert et al., 2003) and information from IFCI..

The next step in the roadmapping process is to drill down into the research projects in more detail, providing specific targets and resource requirements for each. This information is used to inform the project selection process described in **Section 6.3**. In addition it allows for the projects to be laid out on a more detailed timeline that forms the basis of a project plan. Refer to **Appendix B** for the completed roadmap. The detailed project roadmap is created by placing the deliverables from the projects, as defined by the project leads, onto a time scale. Each project deliverable is mapped to the higher level technology targets for the platform where appropriate. In some cases, projects will not map directly to technology targets but are fulfilling some other objective of the institute. Hence it is necessary to view both the roadmap and the objective target map together to get a complete picture of a project's contribution.

Non-technology objectives of the institute fall under the umbrella of community stewardship. In this case the market level of the roadmap is defined in the same way as for science and technology. However, the products defined to meet the market needs have a different focus based on outcomes related to the community, for example public awareness or an educated workforce. Some of the outcomes have a technology basis whereas others are more activity based. **Figure 7-3** shows a diagrammatic roadmap for community stewardship identifying the technologies and activities designed to produce the required outcomes. The "programs and events" level defines the research and other general projects that IFCI is pursuing as a result. As in the science and technology roadmap, each of the programs or events supports a technology or activity designed to achieve a specific outcome. These outcomes are required as a direct response to a demand from the market.

Figure 7-3: Diagrammatic roadmap for IFCI community stewardship



Source: Adapted from the typical roadmap produced by EIRMA (Probert et al., 2003) and information from IFCI..

Details of these projects are shown in the IFCI roadmap in **Appendix B** and in the Objective Target map, **Appendix A**. Technology projects e.g. hydrogen generation or test facilities were drilled down to create a project that could be plotted against a timeline. The result of this drilldown is shown in **Appendix B**. Those projects that are ongoing e.g. development of consortia or partnerships, have specific quantifiable targets and are defined in the Objective Target map, **Appendix A**.

7.2 Roadmap Summary

The technology roadmap allows one to understand the links between the projects and how they meet the target objectives over time. This is the final piece required in the project selection process since the impact of removing any one of the projects is clearly shown in this view.

The technology map for IFCI is intended to directly fulfil some of the gaps indicated in the Canadian Fuel Cell Commercialisation Roadmap and the BC Hydrogen strategy, both of which were developed in 2003 and outlined in **Section 2.6** of this work. IFCI's portfolio of projects allows it to pursue the following advances that were noted as required in the two strategic documents:

- stimulate early market demand:
  - creating More Market Awareness
  - demonstrations
- create supporting infrastructure:
  - develop skilled resources
  - develop infrastructure
  - developing codes and standards
- improve product commercial potential:
  - improve product quality and reliability

    - reduce costs
- developing breakthrough technologies that will allow BC and Canada to become truly competitive

In future years, IFCI should refer back to the original conceptions regarding the development of the roadmap i.e. the Canadian Fuel Cell Commercialisation Roadmap in order to confirm the current situation. As research progresses, more and different options may become available.

The roadmap, included in **Appendix B**, is intended to act as a visual description of the proposed deliverables and outcomes of the projects as they are envisioned today. However, since the roadmap extends over a period of 5 years it is a living document that must be updated in order to continue to be relevant. The roadmap is an extremely useful tool for demonstrating how IFCI's resources are aligned with the needs of stakeholders. If updated bi-annually with meaningful data it can be used to communicate with IFCI's board of advisors. For internal use, the roadmap must also be updated if there are any major changes in the environment that would change the underlying assumptions regarding the market drivers or resources available.

8 RECOMMENDATIONS AND CONCLUSION

In conclusion, the authors worked with the staff at IFCI to develop a project selection methodology and technology roadmap. In addition, during the analysis of the organisation, the authors compared IFCI's structure, resources and processes with those of other research institutes in order to gain insight into areas for improvement. In this section, recommendations are outlined firstly for the resource allocation process and secondly for the institute as a whole.

8.1 Recommendations for Roadmap and Resource Allocation

The roadmap is only as valid as it is current. The initial premise on which the IFCI roadmap was determined was that of the Canadian Fuel Cell Commercialisation Roadmap (Industry Canada, 2003). As technologies continue to evolve, the assumptions and conclusions of the roadmap will need to be revisited. IFCI may wish to consider adding alternate scenarios to the map in which one or other of the leading technologies benefits from a major breakthrough. At the very least, IFCI must revisit the roadmap at regular intervals. Given the rate of change in the industry and the need to communicate with the board, every six months could be appropriate. At each review the progress is assessed and differences in direction accounted for due to changes in strategy or the environment. All key stakeholders should participate in the generation of the roadmap and understand their role in maintaining and implementing it. In this way all will understand the underlying assumptions and conclusions that drive the direction of the institute.

Maintaining the roadmap in this way will require the institute to regularly perform the type of external and internal analysis followed by the authors in **Chapters 3 and 4**. These analyses define the context in which the institute can develop a clear strategy and direction. This in turn will provide the framework to develop the high-level roadmap and allow the institute to work through the resource allocation methodology as outlined in **Chapter 6**.

The following are additional detailed resource allocation methodology recommendations:

- in using the spreadsheets to determine cost allocation, IFCI should work with and track total costs, including appropriately allocated overhead expenses
- IFCI should strive to reduce the resource spread on projects - the institute must find a balance between the range of projects and the most effective team size
- the institute must be particularly careful in categorising projects as meeting a specific objective; for example, a technology project that is funded because it is a partnership with a university should be allocated under "community stewardship" if it does not add to a known technical objective - all projects and activities must map to a relevant product, outcome and market driver

8.2 Recommendations based on Best Practices for the Institute

In order to fulfil its mandate, IFCI must fully understand the role it plays in the national and local innovation system and respond to the requirements of industry in order to be relevant. This will have a two-fold effect; industry will view the institute as a valuable resource and more private funding will be available; feedback from industry will be good and public funding will be forthcoming. The underlying culture and values held by the organisation will greatly impact its role in the fuel cell industry and local cluster. IFCI must develop and demonstrate a culture not only of technical excellence and expert knowledge but also of service to its stakeholders specifically industry, academia, government and the public. With this mindset in place, IFCI can begin to alter the perception of the institute as significantly closer to the academic model than that of industry. It can do this through two major strategies, first review the balance of focus between science and technology and community stewardship and second review the types and range of services offering. IFCI must then focus on improving the internal processes that support these services.

Primarily, the institute must review the human effort and resource allocation between science and technology and community stewardship. Given the requirements of the local cluster as expressed in this work and others (Canadian Fuel Cell Commercialisation Roadmap, 2003 and BC Hydrogen Strategy, 2004), IFCI may be focusing too much on the basic and applied research and not enough on the experimental development, technical services, standards and especially diffusion of knowledge and information. A much greater focus should go toward communication and transfer of knowledge. Currently, only a small fraction of the human resources (approximately 12 out of 80) and 15% of financial resources are dedicated to community stewardship activities. The authors recommend that this allocation be adjusted to more accurately reflect the importance of the community stewardship role. In addition, IFCI must review the target of 50% resource allocation to collaborative projects in science and technology. The authors recommend that the percentage be significantly higher, of the order of 80%. This change in emphasis will require IFCI to significantly improve its project management and communication practices while aligning the institute's work closer to the needs of the industry.

Project management is an area that requires strong resource commitment from IFCI and is vital to the success of both science and technology and community stewardship programs. A strong project management team will be able to develop a communication plan that will allow for structured and relevant delivery to all stakeholders. The project management team would also be responsible for the maintenance and review of the roadmap and be able to develop it further to become an overall project plan with stage gates and processes that allowed for better project tracking. Most importantly, it will be able to develop the processes to "kill" or move forward with projects as they progress thus maintaining the relevance to the overall goals and objectives of the institute.

As IFCI shifts its focus to those activities that align more with provision of services to stakeholders, the institute must adjust structure, people and processes accordingly. The authors recommend that IFCI create a functional department purely devoted to community stewardship and free from the general administrative duties of the organisation. The project management team would span both science and technology and community stewardship departments to allow for integration and sharing of information. IFCI must review the human resources available and confirm that capabilities match the new strategic focus. In particular, the leadership of the institute must be able to work within the government and academic worlds but most importantly in the realm of the fuel cell industry. Within both leadership and R&D personnel there must be a good portion of fuel cell industry experience. The authors recommend 30% of staff with significant fuel cell industry experience spread throughout the organisation. This is particularly important as it relates to the ability of senior researchers to mentor juniors and prepare them for successful careers in industry. One suggestion is for IFCI to sponsor an industry exchange program as a way to promote knowledge transfer.

As mentioned in **Chapter 3**, IFCI's governmental funding is only guaranteed until 2007, and it appears unrealistic that they could rely solely on external revenues beyond that date. Hence, the authors recommend that IFCI make it clear to government stakeholders that it will require continued funding beyond 2007 whilst highlighting the effectiveness of how current funds are used. From the stakeholder analysis of **Chapter 3**, IFCI has not received any provincial funding and should explore this option since Premier Campbell has signalled his interest in supporting BC R&D through establishment of the Premier's Technology Council and the BC Hydrogen Highway project.

Collaborative relationships remain critical to IFCI such that governmental funding can be leveraged with external funds. It is important that IFCI select collaborators whose research interests and direction are in line with its own. IFCI must extract as much value from these relationships as possible including funding, equipment, personnel, knowledge and contacts. IFCI has regular interactions with a large number of Canadian fuel cell firms. It should use these opportunities to increase visibility and level of cluster interest in the institute. This involves educating the cluster on what the institute can currently offer as well as learning what the cluster needs.

The authors recommend that IFCI focus its basic research on those projects not easily performed by industry or on projects that supplement outside effort. Requirements for science and technology services will vary depending on the firm. Large firms may want long term research projects whereas small firms may require more basic assistance with test facilities and even operations or project management type consulting. In general, the type of services offered must be those that are not available elsewhere within geographic proximity of the BC cluster and relevant to small local, as well as large international, firms.

In conclusion, IFCI has all the elements to become a world-class institute, fulfil its vision and mandate, and find a position of relevance in the national innovation system. With some changes to the structure and a more clearly defined strategy the institute will see continued success. The authors believe that the institute must change its culture and values to match those of a service organisation not a basic research organisation. To do so, IFCI must first view itself primarily as a service organisation. This change in perspective will give the institute the direction it needs to secure its place as a first class institute of innovation serving the fuel cell industry.

CD-ROM APPENDICES

- Appendices A and B form part of this work, and may be found on a CD on inside of back cover.
- These files may be opened in MS Excel.

Appendix A: Target Objectives Map

Appendix B: IFCI Technology Roadmap

REFERENCE LIST

Albright, R., & Kappel, T. (2003). Roadmapping in the corporation. *Research Technology Management, March-April 2003,* 31-40.

Angstrom, Ballard Power, Chrystalix, Fuel Cells Canada, Methanex, National Research Council, BC Hydro, Price Waterhouse Coopers, QuestAir, IESVic (2004), *BC Hydrogen and Fuel Cell Strategy*, Retrieved June 15, 2005, from http://www.fuelcellscanada.ca/BC%20Hydrogen%20Strategy.pdf.

Booz, Allen & Hamilton (1982). *New Product Management in the 1980s.* New York: Booz, Allen & Hamilton.

Bou-Wen Lin, & Ja-Shen Chen (2005). Corporate technology portfolios and R&D performance measures: a study of technology intensive firms. *R & D Management, 35 (2),* 157-171.

Burgelman, R.A., & Sayles, L.R. (1988). *Inside Corporate Innovation: Strategy, Structure and Managerial Skills.* New York: The Free Press.

Capon, N., & Glazer, R. (1987). Marketing and technology: A strategic co-alignment. *Journal of Marketing, 51 (3),* 1-15.

Cooper, R. G., Edgett, S. J., & Kleinschmidt, E. J. (1997). Portfolio management in new product development: Lessons from the leaders-II. *Research Technology Management, Nov. 1997,* 43–52.

Cooper, R. G., Edgett, S. J., & Kleinschmidt, E. J. (1998a). Best practices for managing R&D portfolios. *Research Technology Management, 41 (4),* 20.

Cooper, R. G., Edgett S. J., & Kleinschmidt, E. J. (1998b). *Portfolio Management for New Products.* Reading, Massachusetts: Perseus.

De Geus, A.P. (1988). Planning as Learning. *Harvard Business Review, March/April,* 70-74

Dickinson, M. W., Thornton, A. C., & Graves, S. (2001). Technology Portfolio Management: Optimizing interdependent projects over multiple time periods. *IEEE Transactions on Engineering Management, 48 (4),* 518-528.

EIRMA: European Industrial Research Management Association (1995). *Evaluation of R&D Projects.* Paris.

Ernst, H., & Soll, J. H. (2003). An integrated portfolio approach to support market-oriented R&D planning. *International Journal of Technology Management, 26 (5/6),* 540-561

Freeman, C. (1982). *The Economics of Industrial Innovation.* London: Pinter.

Godener, A., & Soderquist, K.E. (2004). Use and impact of performance measurement results in R&D and NPD: an exploratory study. *R&D Management, 34 (2),* 191-219

Gonzalez-Zugasti, J. P., Otto, K. N., & Baker, J. D. (2001). Assessing value in platformed product family design. *Research in Engineering Design, 13 (1),* 30-41

Government of Canada, Price Waterhouse Coopers, Fuel Cells Canada (2003). *Canadian fuel cell commercialisation roadmap*. Retrieved June 2, 3005 from www.fuelcellscanada.ca/french/Roadmap.pdf.

Grandstrand, O., Hakanson, L., & Sjolander, S. (1992). *Technology Management and International Business: Internationalization of R&D Technology*. Chichester and New York: John Wiley and Sons.

Grant, R.M. (2005). *Contemporary Strategic Analysis, 5th Edition*. Malden, Massachusetts, USA: Blackwell Publishing.

Groenveld, P. (1997). Roadmapping integrates business and technology. *Research Technology Management, Sep-Oct 1997, 40 (5),* 48-55.

Grossman, D. S. (2004). Putting technology on the road. *Research Technology Management, Mar-Apr 2004, 47 (2),* 41-46.

Harris, J. M., Shaw, R. W., & Sommers, W. P. (1984). The strategic management of technology. In R. B. Lamb (ed.) *Competitive Strategic Management* 530-55. Englewood Cliffs, New Jersey: Prentice Hall.

Hauser, J. R., & Zettelmeyer, F. (1997). Metrics to evaluate RD&E. *Research Technology Management, 40 (4)*, 32-38.

Huynh, N. (2005). Personal communication: telephone interview, August 19 2005, NRC's Industrial Material Institute business development officer, Ngoc.Huynh@cnrc-nrc.gc.ca.

Johnson, G., & Scholes, K. (2002). *Exploring Corporate Strategy*, (6th Edition). Delhi: Pearson Education.

Jolly, D. (2003). The issue of weightings in technology portfolio management. *Technovation, 23 (5),* 383-392.

Kahn, K. B., Castellion, G., & Griffin, A. (2005). *The PDMA Handbook of New Product Development*. New Jersey: John Wiley and Sons.

Kostoff, R. N., & Schaller, R. R. (2001). Science and Technology Roadmaps. *IEEE Transaction on Engineering Management, 48 (2),* 132-143.

Leonard-Barton, D. (1995). *Wellsprings of knowledge: building and sustaining the sources of innovation*. Boston, Massachusetts: Harvard Business School Press.

Mansfield, E., Raporport, J., Schnee, J., Wagner, S., & Hamburger, M. (1972). *Research and Innovation in the Modern Corporation*. London: Macmillan.

McMillan, A. (2003). Roadmapping – Agent of Change, *Research Technology Management. Mar-Apr 2003, 46 (2),* 40-47.

Mintzberg, H. (1981). Organization Design: Fashion or Fit? *Harvard Business Review, Jan-Feb 1981,* 1-16.

Mitchell, G., & Hamilton, W. (1988). Managing R&D as a Strategic Option. *Research Technology Management, 31,* 15-22.

Moenaert, R. K. (1990). Organizational Strategy and Resource Allocation for Technological Turnaround, *R & D Management, Oxford: Oct 1990, 20 (4),* 291.

NRC Industrial Materials Institute, webpage content (July 21, 2005): Retrieved August 2, 2005, from http://www.imi.cnrc-nrc.gc.ca/english/

NRC-IFCI (2005). *NRC-IFCI Goals, Progress Review and Outlook*, National Research Council of Canada, March 2005.

Patterson, M. L. (2005). New Product Portfolio Planning and Management. *The PDMA Handbook of New Product Development*. New Jersey: John Wiley and Sons.

Price Waterhouse Coopers (2003). *2003 Fuel Cell Industry Survey*, Vancouver Retrieved June 15, 2005, from http://www.pwc.com/extweb/ncsurvres.nsf/0cc1191c627d157d8525650600609c03/0156308d26dd0f3e85256da9005897c2/$FILE/fcis_03.pdf

Price Waterhouse Coopers & Fuel Cells Canada (2004). *Canadian Fuel Cell Sector Profile 2004*, Vancouver ISBN 0-662-37228-X

Price Waterhouse Coopers (2005). *2005 Fuel Cell Industry Survey: a survey of 2004 financial results of public fuel cell companies*, Vancouver Retrieved October 17, 2005, from http://www.pwc.com/extweb/ncsurvres.nsf/0cc1191c627d157d8525650600609c03/0156308d26dd0f3e85256da9005897c2/$FILE/fcis-05.pdf

Probert, D. R., Farrukh, C. J. P., & Phaal, R. (2003). Technology roadmapping – developing a practical approach for linking resources to strategic goals. *Procedures Institute of Mechanical Engineers, Part B: Journal Engineering Manufacture*, *217*, 1183-1195.

Probert, D., & Radnor, M. (2003). Technology roadmapping: Frontier experiences from industry-academia consortia. *Research Technology Management*, *46 (2),* 27-30.

Quenneville, Y. (2005). Personal communication: telephone interview, August 4 2005, NCR Biotechnology Research Institute, yves.quenneville@cnrc-nrc.gc.ca.

Rush, H., Hobday, M., Bessant, J., Arnold, E., & Murray, R. (1996). *Technology institutes: strategies for best practice*. London: International Thomson Publishing Inc.

Strauss, J.D., & Radnor, M. (2004). Roadmapping for dynamic and uncertain environments. *Research Technology Management*, *March-April 2004,* 51-57.