First Mover Advantages in a Costly and Disruptive Technology
The high-stakes fuel cell game

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1. **Introduction**

This paper explores the issue of first mover advantages and their sustainability in emerging, knowledge-intensive industries. Its focus is on the hydrogen and fuel cell (HFC) industry and Canadian firms within it.

In a speech in September 2004, Arthur Carty, then Canada's National Science Advisor, noted that "Canada is fortunate to be early out of the gate on hydrogen and fuel cells. Companies like Ballard, Hydrogenics and Stuart are global leaders in the search for new energy solutions. And there are a growing number of small and mid-sized firms behind them, poised to take the world by storm in various niches of the hydrogen and fuel cell business". Less than a page later Carty added "But Canada will have to work hard if it is to maintain this [leadership] position" (Carty 2004: 2, 3).

As the literature on industrial leadership (Mowery & Nelson1999) and first mover advantages (Agarwal and Gort 2001; Kerin et al 1992) both illustrate, being first in the market, whether country or company, is no guarantee of longer term success. Canada is no exception to this generalization as its position in the forefront of new technologies in the past– digital switching in telecommunications [Northern Telecom], portable computers [Hyperion] and fighter aircraft [Avro Arrow] reveals. Indeed, as this paper was being written, Nortel entered bankruptcy protection, with the likely sale of many of its core components and intellectual property to companies outside Canada. Are we looking at more of the same with respect to hydrogen fuel cells?

Section two of the paper sets out a number of hypotheses drawn from the literature on first mover advantages and industrial leadership. It pays particular attention to sector characteristics, competitive practices and policy dynamics at both global and national levels. Section three reviews the development of the hydrogen fuel cell sector in Canada and the strategies of its leading firms, notably with respect to research, partnerships, and access to finance. This segment of the paper also considers the initial choice of these firms to work with the auto industry as a main partner. Choices made at the level of the global auto industry thus would have an important impact on the HFC sector. The concluding section assesses the challenges that Canadian 'first mover' firms face in sustaining their leadership position in a research intensive, emerging industry. It also examines the role that the state might yet play in strengthening the industry's ability to deal with these challenges.

Data for this paper has been gathered by developing profiles on companies located in the hydrogen and fuel cell sector in Vancouver and Toronto, interviews with executives in key enterprises, reviews of federal and provincial government documents and interviews with officials in British Columbia and Ontario.

2. Can First Movers in Small Market Economies Remain Front Runners in an Emerging Industry?

The advent of digitalized information and communication technologies (ICTs) in the 1970 and 1980s marked the beginning of a new wave of disruptive technologies which by definition would have a significant impact on a wide range of different industries and on the way we live and work. ICTs were followed by biotechnology, nanotechnology and hydrogen and fuel cell technologies.

'New wave' technologies (Mytelka 2004, 2008:6-12) share a number of characteristics that differentiate them from earlier 'technological revolutions' such as those in the textile and automobile industries that were based on mechanical technologies. They are anchored in the sciences, are research and patent intensive and systems embedded. In the emergence and development of ICTs and biotechnology, linkages to universities and public sector research institutes have been important. The combinatorial nature of the knowledge base in these industries was a stimulus to the early formation of strategic partnerships with firms in upstream and downstream industries as they emerged.

The products of new wave technologies are also combinatorial. On the input side, the ability to develop such products has depended upon innovations from across a wide range of scientific and industrial domains. On the output side, these are rarely stand-alone products. Systems integration is thus a common feature of new wave technologies and moving an innovation from laboratory to the market has required partners, strategic alliances or joint ventures in research, product development and standard setting.

These characteristics suggest that the nature of the technology, notably its research intensity and the kinds of alliances that are formed will have major consequences for the speed with which initial technological innovations can be turned into products and commercialized. As we saw in the emergence of biotechnology, waves of optimism were succeed by investment droughts as the time horizon to commercialization was pushed further into the future[1]. This places a considerable burden on firms in emerging knowledge-intensive industries to secure financing when they are in the final stages of research and product development –a moment in the development of a new industry that is rarely the focus of existing financial institutions such as banks or venture capital firms. This gap, however, opens space for creative policymaking by governments. Strategies of firms and policies of governments are thus key to the growth of industries based on new wave technologies.

The business literature on first mover advantages and the innovation systems literature on the interactive nature of innovation processes and the policies of states in supporting innovation and sustaining industrial leadership, provide two points of entry for an analysis of front runner firms in the emerging hydrogen fuel cell industry. The literature on first mover advantages focuses on the individual firm and on the national and global environment in which it is embedded. The term refers to the presumed market advantage ascribed to first entrant into a

[1] Less than 15 years ago small biotech firms in the United States, strapped for cash to carry out further research, with products not yet ready for the market and unable to find partners were selling the rights to their most promising product and exiting the industry (Katterman:1995)

market for a specific product or service. Much of this literature addresses the sale or marketing of consumer or industrial products and the competition for market advantage as potential markets increase due to globalization, new communications technology and rising consumer income (Agarwal and Gort 2001:162-3). In this paper we are examining first mover advantage with respect to an intermediate product rather than a consumer good. Like the chip in relation to computers, machine tools or digital phones, hydrogen fuel cells are a component in a final product across a wide range of industries.

Lieberman and Montgomery (1988) suggest that environmental changes, "changes in technology and/or customer needs" may provide the opportunity for a firm to become a first mover. In the case under discussion in this paper, the "environment" is taken literally as an enabler; concerns about energy consumption and energy security as well as about climate change are a critical factor in the interest in HFCs. However, far more is required than simply a favourable environment for a firm to benefit from its first mover status. A range of skills and resources are required, human and financial. Also critical is the capacity of the first mover to retain its technological advantage. As Porter (1983) notes lowering the cost of a new product as well as continuing product improvement are critical to maintaining FMA. In emerging knowledge intensive industries research leading to a continuous stream of new innovative products is also required[2]. What is also critical to a front runner producing an intermediate product, and something over which it may have limited control but to which it will have to adapt, are the technological choices of potential end users of its product. As we will see in the case of the auto industry, assembler investment choices with respect to fuel efficiency and alternative fuels – a focus on hybrid vehicles for example – reduced the research dollars and attention to HFC vehicles (HFCVs) and required some HFC firms to adjust accordingly.

A firm can attain first mover status in different ways; it could be the first to develop and market a new product, to use a new process, or simply to enter a previously closed or un-serviced market (Kerin et al 1992:33). A first mover may come to "define" the product category" and be seen as the touchstone or model against which later entrants are assessed (Alpert 1987; Howard 1989, cited in Kerin et al).[3] A firm may sustain first mover advantage as a result of its technological leadership and the costs to users of switching suppliers (Liberman and Montgomery 1988). This explains the effort first mover firms make to create strong ties between themselves and buyers/end users of their product. Agarwal and Gort (2001) demonstrate the quickening erosion of FMA over time, in other words, the speed with which imitators/competitors enter a market. Their research determined that is was the case with a range of diverse products, including more technologically sophisticated ones (Agarwal and Gort 2001:164, 173). Foreign competition is part of the explanation for the increasing rapidity of the challenge to first movers, as are the speed with which information is disseminated as well as the capacity for reverse engineering (Agarwal and Gort 2001:173) . A firm may lose its FMA and monopoly position with the entry of competitors; however, first movers are frequently able to retain considerable market share for their product (Agarwal and Gort 2001: 173) as Nokia has done, for example.

[2] The shortened product life cycles of chip generations and drugs are illustrative.

[3] Arguably Ballard has played this role in the HFC sector.

The literature on industrial leadership, in contrast, emphasizes the country level and within it the competitive advantages of institutions, innovation processes and markets for inputs and outputs. (Mowery & Nelson 1999; Lundvall 1992). This approach goes beyond the individual firm to include geographical clusters of producers and users along with ancillary support services such as banking and finance that enable lead firms to remain at the forefront as competitive and technological conditions change. In the case of new wave technologies, the speed of technological change, the entry of new competitors and the availability of financial resources are particularly important.

These two bodies of literature have highlighted a number of factors that are thought to explain the difficulties front runners have in emerging industries based on new wave technologies. We will build on these in our analysis of the experiences of a number of firms in Canada's two HFC clusters, Vancouver and the Greater Toronto Area and the role that the Federal Government has played in supporting the emerging hydrogen fuel cell (HFC) industry in Canada.

One of these is the problem of being located in a small open economy. Canada faces this problem. But, if the size of the domestic market is a factor, it can be overcome, as the examples of Nokia (Finland) in cell phones and Research in Motion (RIM) (Canada) with its Blackberry demonstrate. The former has succeeded in remaining at the forefront of the cell phone industry though it does not shape the technological direction of that industry. It has done so by investing heavily in new product development and pursuing export markets (Mullins 2006). More recently, RIM has set the standards for electronic personal diaries and telephones with its Blackberry, which is marketed around the world. Despite stiff competition from considerably larger American firms, some years after its launch, it remains a world leader in this technology (Beamish et.al. 2008). In digital switching, on the other hand, major manufacturers such as Siemens (Germany) and Ericsson (Sweden)) have been hard put to do the same, as the telecommunications industry itself underwent major transformations (internet, data transmission, wireless networking), even though, in the case of Siemens, the domestic market was important and the firm large, multidivisional, and internationalized. As we will argue in this paper, the outward looking strategy of Canada's leading firms in the hydrogen fuel cell industry, Ballard and Hydrogenics, has to some extent compensated for the very limited locally generated demand for hydrogen fuel cells (HFCs) in one of its principal downstream potential user industries – automobiles and their linkages though alliances, mergers and acquisition abroad in the energy sector (generating hydrogen through electrolysis and producing HFCs) has played a similar role as a point of entry into the stationary power sector abroad. Research, however, is by definition costly. As we will argue, unlike other sectors, notably biopharmaceuticals (Mytelka 2004) leading firms in the emerging hydrogen fuel cell industry had a strong preference for in-house research and alliances with downstream user firms to provide research funding. For much of its history HFC firms thus had few alliances with local universities (Molot & Mytelka:2007).

A second lies in the long time horizon from research to market, the difficulties of predicting accurately what the time frame may be, and the challenge of securing financing to keep the company afloat in the absence of revenue from sales or what is known as the "valley of death" problem (World Economic Forum 2008:22). Some of the "valley of death" literature argues that once the high risk, basic scientific research on new technologies is completed in

universities or other publicly supported institutions and potentially profitably uses have been identified, government support diminishes. This results from a reluctance to 'pick winners' or introduce distortions in the market by subsidizing selected activities. However, the private sector may well still see too much uncertainty to undertake product development. The funding gap can seriously delay commercialization (Avato and Coony 2008:14-5) and, given the competition among firms and countries in new wave technologies, result in competitors moving ahead in the race to commercialization.

To this must be added the disruptive nature of HFC which new wave technologies such as HFCs would likely result in the decline of some existing industries, need major investments in new infrastructure and require changes in existing habits and practices of potential users. As we will argue in this paper, this added to the pressure on governments in Canada and abroad, now facing the challenge of climate change, to search for more immediate and incremental solutions from among a range of alternatives in energy and transport. Uncertainties about the future of a hydrogen economy were thus reinforced and the time horizon for a possible hydrogen economy was shifted forward. As a result, although governments in Canada have provided and continue to provide some funding, this was and remains inconsistent and insufficient. Memories of the difficulties encountered by biopharmaceutical firms in the mid-1990s also marked the practices of venture capital (VC) firms which have been cautious in investing in this emerging industry as we will argue. The greater emphasis by governments on a wider range of eco-technologies has also intensified competition for capital among firms in the wider 'clean technology' industry, thus crowding out riskier, newer technologies.[4]

Lastly, the literature tends to emphasize that first movers generally are producing end products. As noted above, however, hydrogen fuel cells are an intermediate product. Most early adopters of HFCs come from either the downstream transport or the energy sectors. As we will argue with respect to the changing competitive practices that took place in the global automobile industry, the way competition is shaped in these end product industries has a powerful influence on the speed and direction of technological change in intermediate goods producers in emerging industries based on new wave technologies.

3 .The Canadian Fuel Cell Industry

Hydrogen and Fuel Cells constitutes a relatively new economic sector. Few of its products are as yet commercialised and the boundaries of the sector are not well established., In its surveys of the 'worldwide fuel cell industry' PriceWaterhouseCoopers (PWC) (2004, 2005, 2006, 2007), defines this emerging sector narrowly to include only firms that design and manufacture fuel cells, produce hydrogen or hydrogen fuelling or storage systems. They reduce the scope of their survey still further by including only publicly traded companies. These are estimated to represent less than a third of the industry. Private firms and operating divisions or subsidiaries of larger diversified firms account for the rest but are not included in the early versions of the PWC survey (PWC 2006).

[4] Competition for capital in the area of clean technology is intense and availability fell fallen in the last quarter of 2008 and first quarter of 2009. Cleantech Press Release April 1, 2009.

Over the five years for which data were available, the total number of firms in the survey of public fuel cell companies rose from 18 to 26. Data on gross revenues and R&D expenditures for these firms support the emergent nature of this sector. While total revenues excluding investment or other income have risen between 2002 and 2006, they barely exceed R&D expenditures and net losses are substantial (Table 1). This also demonstrates that the sector remains highly research intensive and suggests that its technology is far from mature and its future technological trajectory uncertain.

Table 1

Company Financial Information for 23 Firms in the PWC Fuel Cell List

(US$ thousands)

Year	Gross Revenues	Net Loss	R&D Expenditures	Number of Firms	Number of Canadian firms
2006	415,162	(644,303)	212,728	26	6
2005	261,215	(370,950)	199,175	23	7
2004	233,554	(469,028)	220,540	20	8
2003	244,119	(387296)	216,388	18	9
2002	203,110	(383,588)	229,264	18	9

Source: PWC: 2007, 4 (For the years 2005 & 2006), PWC: 2005:2 (For the years 2004 & 2003), PWC: 2004, 4 (For the year 2002).

Canada was a pioneer in the global FC industry. Despite the narrow definition adopted by PWC for inclusion in its Hydrogen Fuel Cell industry surveys, of the 18 firms listed in 2002, half were Canadian, US firms accounted for the other half. By 2004 the survey included 23 firms of which 7 were Canadian, 10 American 4 from the UK and one each from Australia and Italy. Two years later, there were 26 firms in the survey. Ten of these were American, 6 from the UK, 2 from Germany and one each from Australia and Italy. Mergers and acquisitions within the Canadian industry, bankruptcies and the difficulty of initiating IPOs had led to a decline in the number of publicly listed Canadian firms, which in 2006 accounted for only 6 in the firms in the PwC global survey.

While this reflects the number of publicly held companies, it seriously underestimates the growth and diversification of the sector in Canada where a large percentage of the firms are privately owned. The Canadian Hydrogen and Fuel Cell Profile of 2004, for example, reporting data for 2002 and 2003 noted that "[t]he number of companies involved in the sector had doubled within the past five years" of these 61 companies, 38 were private companies and 23 public companies (Canada 2004:2). In their 2006 survey the number of private companies remained high (40) while public companies, now including divisions/subsidiaries had fallen to

12. Among the areas of expertise listed in the survey instrument, the area of fuel cell developer or manufacturer was chosen 17 times in 2004. In 2006 and 2007 the category of systems integrator was added. The number of times a firm selected fuel cell developer or manufactuer in the latter two years was 15 while systems integrator was selected 5 times. Nevertheless, there are indications that the industry is increasingly under pressure.

A 2008 report, Canadian Fuel Cell Commercialization Roadmap Update (Government of Canada 2008)[5] adopts a hopeful, but simultaneously tough, tone in its assessment of the situation of Canadian fuel cell companies in the global context. There were 80 companies active in all segments of the FC industry in Canada in 2006; most were small or medium-sized enterprises. Increasing international competition and, the difficulties of raising capital have required many Canadian firms to restructure and virtually all to focus on "near-term market opportunities" (Government of Canada 2008:35). Although automotive applications – fuel cell vehicles – remain the dream, HFCVs are, according to the Roadmap Update, anticipated in the 2015-2025 time frame (Government of Canada 2008:71). Even this may be optimistic unless there are significant and fairly early breakthroughs. Recognizing the importance of focusing on segments of the HFC with reasonable potential for sales and therefore revenue generation, Canadian HFC firms are currently active in five segments of the FC sector: portable power for electronic devices, materials handling (FC lift trucks), backup and stationary power, residential cogeneration (primarily in Japan) and fuel cell buses.

Ballard Power, started by Geoffrey Ballad in Vancouver in 1979, was Canada's first FC firm. It gained considerable prominence in the mid-1990s when it demonstrated the world's first fuel cell bus in Vancouver. In 1993 Ballard formed an alliance with Daimler and Ford to develop HFCs for automobiles. Much of Ballard's early funding came from Canada's Department of National Defence which was interested in the energy potential of FCs for its equipment (Koppel 1999). Other HFC firms followed in the Vancouver area, Palcan Power in 1987, Cellex and General Hydrogen in the late 1990s and many firms in the first decade of this century. Nine HFC firms in the Vancouver area can be seen as spinoffs in one way or another from Ballard since Ballard "alumni", in other words, former Ballard employees, were involved in the creation of these companies. Former Ballard employees were also critical in the establishment of venture capital firms in Vancouver (Hamilton 2007).

Some of the firms in the Greater Toronto Area (GTA) also have a long history: Stuart Energy was created in 1948, Astris Energi in 1983,[6] and Hydrogenics in 1998.

The Vancouver cluster, with more than 40 firms is nearly three times larger than its Toronto counterpart. It also has a broader and deeper structure. Firms in Vancouver cover much of the supply chain around HFCs. There are multiple FC and FC stack producers, components manufacturers, firms making control systems and fuel and fueling systems as well as testing equipment and services. In addition, the Vancouver area includes a number of engineering and consulting firms, a university and public sector research laboratory and, of particular importance,

[5] Report is based on a literature review as well as 28 interviews with CEO's and key technical players of Canadian companies across the spectrum of fuel cell activities (Government of Canada 2008:13).

[6] Stuart Energy was taken over by Hydrogenics in 2005, Astris by MKU of India in 2007.

a number of venture capital firms which have supported some local HFC firms. Companies in the GTA are more focused around fuel, fuelling and control systems. Some of the GTA firms are Canadian subsidiaries of multinationals, such as Dana, which makes auto parts. There are also in the Toronto area a couple of firms producing FCs and stacks and one producing hydrogen fuel injection systems. Although Hydrogenics is the largest firm in the GTA, it has not played the role of an anchor firm, one which has spun off start-ups, as Ballard has in Vancouver.[7]

The FC product orientation of the two clusters is different. The major focus of firms in the Vancouver cluster is primarily on transport uses of HFCs, forklifts, HFC buses and cars, even though none of these vehicles is assembled in the Vancouver area whereas the GTA cluster is oriented primarily to stationary uses of fuel cells (despite its proximity to the auto industry).

Because HFCs are an intermediate product, from the outset, firms in this sector have needed to build relationships with potential end users, designing products to meet the needs of these downstream users and facilitating the integration HFCs into downstream products. Ballard Power decided early to link with the auto industry.[8] Although there were some early successes – the first FC powered bus and then a car – the realistic time horizon to commercialization was much longer than first anticipated. There was the need for continuous research to solve a myriad of problems, among them the cost and size of the FC stack, cold weather starts, etc. Moreover, Ballard had no influence over the technology priorities and alternative energy choices of the vehicle assemblers. The implications of this choice for Ballard's research trajectory and its other alliances will be discussed below.

Although some of the R&D in the Canadian HFC clusters has been done in publicly supported institutions, universities and the NRC's Institute for Fuel Cell Innovation, most of R&D in this new wave technology has been done by private firms. Financial support for this research has come from investors/venture capital, government funding, and revenue from other sources, including stock market listings for a few firms, and product sales. With a few exceptions [companies that sell hydrogen for industrial uses for example, or Enbridge for which the HFC segment is only a small part of the company's activities] HFC companies have very limited revenue and most do not have positive balance sheets. The challenges in Canada of securing funding for the commercialization of innovation were underlined in the Science and Technology Innovation Council's 2008 report.

3.1 Experiences of Selected Canadian HFC companies

This section of the paper examines the experience of a number of firms in Canada's two HFC clusters with respect to the realities of and constraints on front runner in a new wave technology drawn from the literature: linkages with downstream users; time frame to market, revenue and funding challenges and avoidance of the valley of death; and the ramifications of

[7] For a more detailed analysis of the two clusters see Molot and Mytelka (2007).

[8] As noted, the link in 1993 was originally with Daimler; in 1998 it began to work with Ford (Koppel 1999:213, 230-1).

end user choices. In order to keep the analysis manageable and to provide some detail on corporate activities, we will use as examples 4 of the 6 Canadian companies that are part of the 2006 PriceWaterhouseCoopers survey of the global fuel cell sector. Two are in the Vancouver cluster, Ballard and QuestAir Technologies, and two, Hydrogenics and Astris Energi are in the GTA. Two, Ballard and Hydrogenics, manufacture HFC stacks. QuestAir produces purification systems for hydrogen, and Astris worked on Alkaline FCs.

(i)Linkages with downstream users: Firms can have upstream as well as downstream linkages. The former are important in revenue terms as well as in strengthening the interaction among firms in a cluster. In the Vancouver area, for example, Ballard Power has supply agreements to provide fuel cell stacks to a number of companies located nearby; for example, Cellex and General Hydrogen, both use Ballard stacks to produce hydrogen power units for sale to potential downstream customers. These sales are a source of revenue for the company making them, but are relatively insignificant in terms of Ballard Powers' overall revenue stream and its total number of linkages.

Linkages with downstream users can be examined in a number of ways: the number of firms in each of the clusters with linkages outside the area; the total number of linkages a firm has; the sector/activity of the downstream user; the character of the linkage – is it an off the shelf sale or is the relationship more long-term, such as a strategic alliance or a joint venture; does the linkage include research; the location of the downstream user; and whether the linkage relationship is the recipient of any government funding. The Canadian Fuel Cell Commercialization Roadmap Update notes that Canadian HFC companies reported 124 strategic alliances reported in 2006 and 221 research partnerships (Government of Canada 2008: 36). Since we are looking at the evolution of the sector historically, we have tracked corporate alliances since the inception of our firms.

Given the larger size of the Vancouver cluster it is hardly surprising that far more firms have linkages than firms in the GTA. What is far more significant is that only one firm in the GTA, Hydrogenics, has more than 5 downstream relationships.[9] More than a dozen Vancouver firms have 5 or more downstream linkages; the vast majority of these are outside the Vancouver cluster and most are outside Canada. The United States is the most important foreign location of these linkages; Japan and Germany are also critical. Connections to China are becoming more important for a number of Canadian HFC firms. Linkages within Canada can be to downstream users; often they involve connections with other companies and actors to secure government funding. Looking at some of these connections in more detail for our four companies, we see the following:

(a) Ballard Power Systems: Ballard Power Systems produces HFC stacks for transport uses. It also assembles stacks for back- up and stationary power purposes. From its first connection with Daimler in 1993 to its last linkage in 2007 (a sale of stacks for delivery to London Transit in 2009 for FC buses) we could find 112 linkages for Ballard. Some of the sales or research agreements involve more than one partner. Of these 112

[9] The only other GTA firm with more than 5 linkages was Stuart Energy, which was purchased by Hydrogenics in 2005.

connections, the largest number (36) were with companies or research consortia in the United States; 31 were with companies or consortia in Japan, 19 in Germany (almost all with firms in the transport sector) and 15 in other countries. Thirteen of the linkages were in Canada, among them, as noted above, with companies in the Vancouver cluster to which it supplied its FC stacks. Ballard has sold FC stacks to a range a number of auto assemblers (Chrysler, GM, Honda, Nissan and Hyundai), though its only alliance relationship in the auto sector is with Daimler and Ford.[10] Ballard is also a substantial, if not the most important, provider of FC stacks for HFC buses. It has worked with Daimler in the production of the Citaro bus, more than 30 of which were used in an EU multi-city trial of HFC buses in recent years. Citaro buses with Ballard stacks have also been purchased by cities in Australia and China. Ballard stacks powered the first FC buses on trial in Vancouver and Ballard FC stacks will be in the New Flyer buses that will be part of the BC Hydrogen Highway starting in 2010.[11] Ballard stacks have also been in FC buses in trials in Chicago and Washington DC.

In addition to stacks for transport uses, Ballard is involved in building stacks to generate backup or stationary power, what is termed in Japan "co-generation". Ballard is participating in a number of alliances and joint ventures with Japanese and European power supplies and oil companies in this side of its operations. Ballard's gross revenue in 2006 was close to $50 million and for the previous year slightly over $42 million (PWC 2007:4).

(b) QuestAir Technologies: Created in 1996, QuestAir Technologies is a much smaller company than Ballard. It is a developer and supplier of advanced purification systems for hydrogen, methane and helium fuels. Ballard acquired a 10 percent interest in QuestAir in 2000. Seven of its 16 linkages are with US companies, including two with a leading oil company; one is with an oil company in the Netherlands, three with firms in Japan and Korea, and five with Canadian actors in the sector, including demonstration projects. The company's gross revenue in 2006 was slightly over $6.6 million; in 2005 it was $5.1 million (PWC 2007:4).

(c) Hydrogenics: Hydrogenics, created in 1998, has grown through acquisitions in Canada (of Greenlight Power and Stuart Energy) and abroad. The company produces FC stacks, designs and manufactures testing and sensor equipment as well as hydrogen production equipment for on-site power generation. Thus, its range of activities in the HFC sector is the broadest of any of the firms in the two clusters we are examining. We could identify 96 linkages Hydrogenics had with companies, research institutes and governments in Canada and abroad from 2000 to the end of 2006, though in six instances the nature of the relationship and/or its location were not clear. By far the largest number of Hydrogenics' linkages were in the U.S (40); 14 were in Asia, of which 9 were with actors

[10] The current character of this relationship will be discussed below.

[11] The H2H is a key component of British Columbia's effort to become, the in words of the Premier's Technology Council Report "to have the world's pre-eminent hydrogen economy by 2020" (2004:3). The H2H is a project to demonstrate HFCVs, primarily buses, refueling stations, and stationary power organized in anticipation of, and with the intention of being ready for, the 2010 Vancouver Olympic games.

in Japan, 10 were in Germany and another eight were in other countries. Close to 20 percent of Hydrogenics' connections were in Canada; some of these were sales of stacks or testing equipment, some for the development of HFC stacks for forklift vehicles and refueling technology and others related to demonstration projects. Perhaps reflecting its range of activities, Hydrogenics had far fewer linkages with auto assemblers (13), most of them with GM, which, as the result of a strategic alliance in October 2001, acquired about 24% of Hydrogenics.[12] The company has sold its control and test systems to a European auto company as well as to Japanese auto assemblers and to the Japanese Automobile Research Association to assist the latter in fulfilling its mandate to establish standards for FC power module testing and supplied a hydrogen station to Ford. Hydrogenics has become increasingly involved in supplying HFC stacks for materials handling vehicles (forklifts) and has sold some stacks to assemblers of minibuses for use in Europe and California. Hydrogenics has sold generators for back-up power to customers in Asia, Eastern Europe, Latin America and the Middle East and has worked with energy companies in the US and China. In 2006 sales of Hydrogenics's products led to gross revenues of $30 million; gross revenue in 2005 was $37.1 million (PWC 2007:4).

(d) Astris Energi*:* Created in 1983 Astris Energi started with the manufacture of alkaline fuel cells aimed at small engine applications, for example, portable and stationary generators, forklifts, and golf carts. The company engaged in a few joint development projects in Canada, and the US but we could find no evidence of sales of products (although the company reported gross revenue for 2006 of $74,000 (PWC 2007:4)[13]. The proposed joint ventures did not materialize or last.

The experiences of our two largest HFC companies demonstrate the importance of connections outside Canada, both for sales of HFC stacks as well as for research and development purposes. The number of linkages relating to research underlines our point that HFC firms that do research tend to do it in-house (often with partners), with financing from the partners. HFC companies in Canada do almost no research with each other or with local research institutes and universities as partners.[14] This means they were and remain dependent on raising funds for research when the commercialization time horizon was often far in the future. This, in turn, became a limiting factor on how quickly they could overcome cost and technological challenges.

(ii) Financial Stability: Research costs in a new wave technology are high and continuing as companies work to develop new iterations of their technologies. Companies can generate revenue through the sale of products – if the company is at a point where it has products to sell, through research and development funding from governments and public sector research institutes, and by raising capital through joint ventures, from VC firms or via public offerings.

[12] By 2007 GM's share of Hydrogenics had decreased to approximately 12.4 percent.

[13] Its revenue in 2005 was $241,000 (PWC 2007:4)

[14] A few firms in the Vancouver area are located at NRC's Institute for Fuel Cell Innovation; however, NRC's role is a support one.

Many of the companies the HFC sector in Canada, thus making financial information difficult, if not impossible to obtain. What sometimes is in the public domain are successful efforts to raise capital from private venture capital funds, a point to which we will return shortly.

Although all four of the Canadian firms in the 2007 PWC study we are looking at revenue generated through sales and consulting services, all have consistently lost money.[15] All spend more on R&D than they bring in through sales.[16] Product costs and the uncertainty of major and sustained product sales make it difficult for firms in the HFC which are publicly traded to garner revenue through the regular trading of stock. Although some years ago, when there was excitement about anticipated – though ultimately unsuccessful commercialization – Ballard's stock traded as high as $159 a share in 1998 and $210 in 2000; the stock began to fall in mid-2000 (Nuttall-Smith 2003: 50, 52) and in mid-May 2009 was trading at just over $2 a share. Hydrogenics, which trades on the Toronto Stock Exchange as well as on the Nasdaq, ran afoul of the latter exchange's minimum corporate stock value requirements for inclusion on the exchange in November 2007 because the price of its common stock had closed below the minimum of $1 per share for the previous 30 business days. By July 2008 Hydrogenics had met Nasdaq regulations for continued trading (http://www.hydrogenics.com/ir_news.asp).

Government funding for research and development as well as for the early stages of commercialization is critical. All of Ballard Power's early funding came from the government of Canada, first through the National Research Council and then through the Department of National Defence (Koppel 1999:64). Ballard has received other Canadian government funding, for example in 2004 from the Hydrogen Early Adapters (h2EA) program and for the development of emergency power back up from both Ottawa and the Government of British Columbia. These were small sums relatively speaking. Although the Canadian government has created a range of programs over the last decade to promote clean energy, emission reductions, and the development of new technologies,[17] only two directly relate to HFCs, the Canadian Transport Fuel Cell Alliance,[18] replaced by the eco-Energy Technology Initiative[19] and the Hydrogen Early Adapters Program (h2EA).[20] Of the six governments, including Canada, that

[15] None of the firms in the PWC 2007 survey made money in either 2006 or 2005.

[16] Interestingly, Ballard and Hydrogenics spent the largest amounts on R&D – and Ballard more than Hydrogenics – of the companies on the PWC FC list. The Canadian Fuel Cell Commercialization Roadmap Update reported HFC company revenue at $133 million in 2006 (not much different from 2005 at $133 million). Product sales constituted the largest component of revenue ($89 million), though down 8 percent from 2005. Industry R&D and demonstration budgets declined by 11 percent in 2006 - $193 million compared to $215 million in 2005 (Government of Canada 2008: 36).

[17] Among the programs are the Climate Change Action Fund, (with four different blocks of activity),Sustainable Development Technology Canada, and Program on Energy R&D (PERD.

[18] A seven year program (2001-08), $23 million initiative, which showcased refueling projects, light, medium and heavy duty FC vehicles, etc. The governments of Ontario and BC also support activities in the HFC sector, including demonstration projects, but, with the exception of BC's commitment to fuel cell buses for the Hydrogen Highway their support is very limited.

[19] An $8.8 million fund to support HFC demonstration projects in Canada.

[20] This program expired on March 31, 2008.

support fuel cell technology – in the context or addressing environmental and energy concerns – Canada ranks last, proving average funding of about $30 million annually.[21]

Overall government policy choices have a huge impact on potential downstream users of new wave technologies and, therefore, by implication on the firms developing these new technologies. Two recent policy decisions by the Obama Administration illustrate this. The first, captured in an announcement, made in early May 2009 by US Department of Energy (DOE) Secretary Chu, revealed that the Secretary anticipated that the hydrogen car economy would not occur for close to 20 years, and that the Administration would be supporting advanced batteries and biofuels rather than HFCVs; as a result DOE would cut funding to its hydrogen program and eliminate light duty vehicle funding (Fuel Cell Today 2009).[22] The second is President Obama's of new fuel efficiency standards. Corporate decisions about R&D investments have long time horizons and reveal the company's best estimate about what it can produce and what will sell. Particularly now the Detroit assemblers do not have unlimited R&D dollars. The anticipated raise in fuel efficiency standards will require changes in the research priorities of vehicle and parts producers. It will also likely mean reductions in financing of research into HFCVs. Both policy choices may have an impact on front runner firms in the HFC sector.

(a) Ballard Power has received considerable funding from the US Department of Defence (for work with Plug Power, a US company, as well as on its own) and from the US Federal Transit Administration as part of a consortium to make HFC buses commercially viable. Government support pales in contrast to financing Ballard has obtained through selling shares or creating joint ventures for R&D and potentially commercialization with firms around the world. Mention has already been made of its early relationship with Daimler-Benz and Ford. In April 1997 Daimler acquired 25 percent of Ballard's shares. It also invested large sums and its FC system technology with Ballard in the creation of an engine company (DBB Fuel Cell Engines). Other companies with which Ballard created joint ventures include Ebara and Tokyo Gas of Japan, and Alstom of France. In addition, Ballard has development agreements with firms around the world, in which it as well as its partnering company invest in product development.

(b) QuestAir Technologies has been able to generate revenue through sales (they supply hydrogen) and development agreements. Ballard purchased 10 percent of its stock in 2000 and Shell Oil made an equity investment of $11 million in 2002.

(c) Hydrogenics, as mentioned above, formed a strategic alliance with GM in 2001, as a result of which it received an infusion of capital. For its investment GM received

[21] Close to one-third of this funding supports programs at government labs and universities, with the rest split between firms and end-users to support product development and demonstration projects (Government of Canada 2008:22).

[22] After the Secretary's announcement, GM, Toyota and Honda were all quoted in the press confirming their commitment to HFCVs. Other governments, those of the EU, Germany, Japan, and South Korea, are still supporting HFCVs (FCT 2009).

approximately 24 percent of Hydrogenics' common stock and a seat on its bd. By 2007 GM's share had been reduced to 12.4 percent. Like Ballard, Hydrogenics has historically generated some revenue through sales of its products. Government funding has also been an important component of the company's revenue. Hydrogenics has received funding from federal government departments (DND and NRCan) to design, develop and integrate its technology into end-use products. The company's activities, including demonstration projects, have also been funded under various federal government programs (The Canadian Technology Fuel Cell Alliances, Sustainable Development Technology Canada, and h2EA). Hydrogenics has also received financial support from the US Army and Navy as well as from subnational governments in Canada, the US and Germany. It has also been funded by a couple of US VC firms.

(d) Astris Energi was listed on the Nasdaq. It raised some funds through a share offering in March 2007 (Acme Global bought the shares). This share offering was cancelled on July 2007 when Astris sold its fuel cell technology and related assets to MKU Canada, which is in effect owned by a private firm in India. Astris generated some revenue through product sales (of small fuel cell stacks). The only government funding it received was through its Czech subsidiary from the Czech government to subsidize work in that country on its fuel cells. The total sum was less than $US1 million over 2 years.

As the data from the PWC 2007 survey of public companies in the fuel cell sector as well as the Canadian Fuel Cell Commercialization Roadmap (Government of Canada 2008) and the short corporate histories demonstrate, revenue generation of firms in the HFC sector is problematic. This is not surprising for front runners. At the same time they have to take decisions that management hopes will allow them to continue operations. One way companies can cope with financial pressures is the narrowing of research and product focus. Hydrogenics, for example, closed its test equipment business (located in Vancouver) in November 2007, reducing its full time staff by 40 percent. This leaves the company freer to focus on refueling and systems integration and materials handling vehicles.[23]

Ballard sold its automotive fuel cell assets to Daimler and Ford in November 2007, although the new company (Automotive Fuel Cell Cooperation) in which Ballard will have a 20 percent share, is operating on Ballard's premises in Vancouver.[24] Ballard expected to generate close to $100 million as a result of the transaction. A statement by Ballard's president and CEO captures the challenges front runners face in terms of the pressing need to generate revenue versus the uncertain time horizons of some applications of new wave technologies:

> This transaction will enable Ballad to concentrate on growth in fuel cell applications which provide clean energy solutions in commercial markets….It also lowers Ballard's

[23] Hydrogenics also continues to provide stacks to some HFC bus trials.

[24] The sale included Ballard's automotive fuel cell intellectual property and $6 million of test equipment.

risk profile by addressing the realities of the high cost and long timeline for automotive fuel cell commercialization. At the same time the new private company will be established and will be positioned for success in automotive fuel cell technology over the longer term, with management and funding provided by Daimler and Ford (News Release Ballard website).

There are always front runners that succumb to the valley of death and either cease operations or are taken over. Fuel Cell Technologies, a maker of solid oxide fuel cells that emerged from Alcan and traded for a few years on the Toronto Stock Exchange, closed in October 2006 because it ran out of money. The company's assets were bought in 2007 by Acumentrics, a US power generation firm. Its website that the employees and assets of Fuel Cell Technologies "their balance of plant expertise enhances our systems design" (http://www.acumentrics.com/about-company.htm). Two Vancouver firms, Cellex and General Hydrogen, both privately held companies and both manufacturers of fuel cell packs for use in materials handling vehicles, were bought by a US firm with deeper pockets, Plug Power, just after these two companies started testing their products in forklifts at a number of US companies.

Some companies in the HFC have been successful in raising funds from venture capital (VC) firms, though there is huge competition for such funding and companies need products close to commercialization to be attractive to venture capitalists. Canada's venture capital market is proportionately smaller than that of the US; venture capital companies in Canada historically had difficulty raising capital domestically and abroad. According to the president of the Canadian Venture Capital and Private Equity Association, "[a] typical company …[in Canada] gets 40% what a company gets in the United States (Lam 2009: FP11).

There are a number of VC firms in Vancouver – Chrysalix Energy Limited Partnership, Ventures West, Yaletown Venture Partners,[25] and Growthworks – which have invested/continue to invest in HFC companies. Ballard received funding from Ventures West in 1988; Ventures West also invested in Cellex. A review of investments made by Chrysalix in 2006 and 2007 indicates that recipients of their funding operate in a number of energy-related sectors (eg. solar) in addition to HFCs. Recipient firms were in the US as well as Canada; although a few firms, among them Angstrom Power of Vancouver, received more than $10 million, most investments were in the $1-$10 million dollar range.

In sum, financial sustainability is a serious problem facing front runners in the HFC sector in Canada. Unless there are dramatic break-throughs in technology, which lead to commercialization possibilities, Canadian HFC firms are likely to struggle financially for the short to medium terms.

(iii) New Wave Technologies and the Ramifications of Choices of Potential End-Users: New wave technologies face uncertain futures. New products can easily become more attractive than those developed by first movers and trump them. Front runners in intermediate technologies are

[25] As noted earlier (Hamilton 2007) Ballard alumni were involved in establishing these three VC firms. Westcoast Energy, another Vancouver area HFC firm, has also invested in Chrysalix.

dependent on the decisions with respect to potential utilization of their product by potential end users and have limited capacity to influence the choices that directly affect their viability. One factor in this is the ease/difficulty of overcoming technical challenges. A second is the availability of competing and perhaps less expensive technologies.

A case of relevance to the HFC sector relates to HFCVs. We noted above that one of Ballard's early visions for HFCs was in HFCVs. To this end it made an alliance with Daimler and then Ford. Expectations were high – a HFCV by 2005. By the end of the 20th century the market debut had been pushed back several times, with a negative impact on Ballard's stocks as well as the ability of other firms focusing on mobile uses of HFCs to secure funding.[26] One reason for the longer anticipated time to commercialization were the problems associated with putting HFCs into vehicles, among them the costs of these vehicles, their reliability in different weather environments, the lack of infrastructure and uncertainties about consumer responses. More significant were two other factors: the decisions made by vehicle assemblers about the privileging of alternative propulsion systems which were seen as less costly to develop – hybrid vehicles for example – as well as the pressures put on governments, particularly on the US government, by the auto and petroleum industries to slow the pace of change at the global level and to continue to search for ways to continue to use petroleum based fuels – and therefore the internal combustion engine – but to make them cleaner. Although Ballard and Hydrogenics had alliances with a number of the vehicle assemblers, they could have little or no impact over corporate decisions that affected their futures. This reality also helps to explain Ballard's decision to focus for the immediate future on surer short to medium term uses of HFCs – on stationary power or power co-generation and on mobile uses which have already demonstrated some successes, materials handling vehicles and HFC buses.

4. Conclusions

This paper is a preliminary examination of the challenges Canadian "first mover" or front runner firms face in sustaining a leadership position in a research intensive, and therefore costly, new technology. We have demonstrated in particular the difficulties of financial sustainability when there is enormous competition for venture capital and returns on that capital are uncertain in the medium term. We have also explained, using Ballard as an example, the costs of an error in identifying the potential end use of a new wave technology in which it had no competence and its inability to influence the research and technology choices of its partners. At the same time, the range of its downstream partners and its capacity to refocus are why Ballard is still alive.

We are cautious about the future of the HFC sector in Canada. On the positive side, Canadian firms have reputations for innovation and excellence and continue to set the standard for HFCs in a number of areas of potential end use of this intermediate technology, among them fuel cell buses, stationary power, and portable power. Although the number of Canadian companies appearing in the PWC report on the industry globally has fallen over this decade, many Canadian firms continue to be active along the value chain in the sector and are heavily

[29] Some of our interviewees referred to the anticipation and then inability to deliver on promises as the "Ballard effect".

engaged in research. Many have a significant numbers of downstream linkages with end users and some have created joint ventures and subsidiaries abroad. Among the more significant linkages and Canadian research connections are those between Ballard and its partners in automotive research, Daimler and Ford. Ballard may have had no choice but to sell its automotive fuel cell assets to Daimler and Ford; nonetheless, the new company is located at the Ballard facility in Vancouver, a recognition of the value of a location in which there is a critical mass of firms in the HFC industry.

At the same time, we front runner firms face huge financial constraints. Very few of the firms in our study have positive balance sheets. Most spend far more on R&D and commercialization efforts than they generate in sales. A number have fallen victim to the valley of death scenario. Some Canadian HFC firms have been purchased by competitors with deeper pockets who saw the Canadian companies and their products as a valuable source of intellectual property as well as upstream and downstream linkages critical to potential commercialization. Although VC firms in Canada are growing, the network is younger and less well developed in Canada than in the US (CVCA 2009:26) and receive far more financing proposals than they can possibly support. HFC firms have received some VC finding but they have to compete for these infusions with firms much closer to product commercialization and export than they are.

Government support can be critical in assisting firms in new wave technologies with research as well as some of the costs of commercialization. This is particularly true when firms cannot generate their own revenue and are not yet at a point in their research-development-commercialization trajectory to be attractive to venture capital. The formulation and implementation of targeted programs allow firms to compete for/access government monies; it also signals the importance governments attach to R&D efforts with respect to the technology in question. However, to make a difference, government funding needs a multi-year time horizon and sufficient to make a difference. As noted earlier, Canada is not spending large sums on HFC development and commercialization (Government of Canada 2008: 21-2). Some sub-national governments in federations also provide support, eg., British Columbia and Ontario in Canada and Germany in the EU, but in Canada sub-national funding is limited. Policy in Canada will be affected by choices made elsewhere, particularly in the US. Still, if Canadian firms are going to continue to be players in the HFC sector in the areas identified by the Canadian Fuel Cell Commercialization Roadmap Update (Government of Canada 2008), the Canadian government will need to develop a position paper articulating the importance to Canada of the hydrogen economy[27] and the funding programs to support its implementation.

[27]In 2005 the Government of Canada issued a paper entitled *Toward a National Hydrogen and Fuel Cell Strategy*. The paper outlined the issues involved in developing hydrogen capacity and a number of steps, the last of which would be a statement outlining Canada's Hydrogen and Fuel Cell Strategy. The step that followed the issuance of the paper was consultation with stakeholders across the country. This was done in 2005. However, no strategy was approved by the Martin government before the January 2006 election. The Harper government has not, at least thus far, evinced any interest in national strategy on HFCs (Fitzgibbons 2008).

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