Understanding the British Columbia Hydrogen and Fuel Cells Cluster: A case study of public laboratories and private research

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June 2007

Abstract

In 2005 the National Research Council of Canada commissioned a study of the hydrogen and fuels cells cluster in Vancouver as part of a larger project sponsored by NRC (reported by Arthurs *et.al*., 2007, in a special issue of *International Journal of Technology Management*). This study looks at the cluster using a structured approach that tests clusters against indicators of current conditions and current performance. It includes the results of an extensive interview program and survey of professionals in the field, both within the cluster and elsewhere. The results give a clear picture of a cluster that has two major components – hydrogen based industries and fuel cell technologies, which are both global in reach and potential.

Keywords

Clusters, innovation, indicators, policy, fuel cells, strategic planning, competitiveness, hydrogen, British Columbia

Biographical Notes

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Disclaimer*: *The opinions expressed in this paper are purely those of the authors and do not reflect the views of their employers.

An earlier version of this paper was presented at the Hydrogen and Fuel Cells 2007 International Conference and Trade Show, Vancouver, BC, April 29th – May 2nd, 2007

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Introduction – Fuel Cells

A fuel cell is an electro-chemical device that produces low-voltage direct current electricity from a continuous flow of fuel, usually hydrogen, and an oxidizer. From an applications point of view, fuel cells are simply an energy-efficient source of DC power. They are then coupled with electrical systems (either propulsion systems or applications that require electrical power to operate). AC-power applications (which include putting energy into the electrical power grid) require DC-AC converters, which introduce power losses and other inefficiencies.

Fuel cell technologies have been available for over a century, but were inefficient and expensive. They first became widely known during the Apollo program when fuel cells were used to provide power for the spacecraft, an application where cost was not important, but reliability and minimal moving parts were crucial. In practice there are a number of fuel cell variations that are of commercial and military interest (see Table 1).

Table 1: Common types of fuel cells

Type of fuel cell	Fuel required	Operating temp. (°C) / catalyst	Application
Alkaline	Pure H_2 and O_2	50 – 200 / Ni or Ru	Military and space
Direct Liquid	Liquid hydrocarbons, particularly methanol	80 – 120 / Pt or Pt/Ru	Battery replacements
Molten Carbonate	Hydrocarbons and air	630- 650 / Ni	Large utilities
Phosphoric Acid	Hydrocarbons and air	190 – 210 / Pt	Stationary applications
Proton/Polymer Exchange Membrane (PEM)	Purified hydrocarbons and air	50 – 80 / Pt or Pt/Ru	Vehicular applications
Solid Oxide	Hydrocarbons and air	850 – 1000 / Ni	Large utilities

Markets for Fuel Cells

Table 2 is a summary of the potential markets for fuel cells and hydrogen fuels that forms the end points of the value chains.

Table 2: Fuel Cell and H_2 Market Matrix

	Consumer Markets	Public Sector	Military
Battery replacement	Computers and other low voltage, low power applications		Computers and other low voltage, low power applications
Electric hybrid vehicles	Automobiles	Buses, rail	Vehicles
H_2 powered vehicles	Automobiles	Buses, rail	Vehicles
Small scale distributed power systems	Home generators	Utility site electrical power (*e.g.* microwave stations)	Site electrical power
Large scale power generation		Large, series parallel fuel cells feeding the electrical grid	
H_2 energy storage		Energy storage from intermittent sources (wind) for input to electrical grid	
H_2 power production; Stationary diesels and turbines; mobile diesels and turbines	Vehicles; off-grid electricity	Vehicles (particularly in pollution sensitive markets); inputs to electrical grid	Vehicles; off-grid electricity

The BC Hydrogen and Fuel Cell Cluster in the World

The fuel cell industry is global and growing. According to PricewaterhouseCoopers (PwC), (PwC, 2005) new firms are emerging in Europe, Australia and Asia, and industry consolidation is on the rise. Major established corporations are now involved in fuel cells, including Dupont, 3M, and Johnson Matthey, as well as most of the world's largest automotive manufacturers, including General Motors, DaimlerChrysler, Nissan, Honda, Toyota, Ford and Hyundai. While Canada is recognized as a world leader in fuel cell and H_2 technologies, it is increasingly competing for global technological leadership with the US, Japan, and Europe (see Figure 1).

Figure 1: Worldwide distribution of manufacturing and R&D functions of fuel cell firms

Source: *2004 Worldwide Fuel Cell Industry Survey* (PricewaterhouseCoopers)

It is difficult to estimate the size of the world fuel cell industry for two reasons: what should be included in the definition of "fuel cell industry" and the magnitude of fuel cell operations in privately held companies. In addition, because of the research-intensive nature of the industry, the definition of industry does not usually include expenditures by universities and government laboratories, nor any of the research, development and prototype manufacturing carried out for military purposes. In 2005 PwC carried out a fuel cell industry survey. The BC cluster, based on their estimates, accounted for most of Canada's efforts (Figure 2); Ballard was the largest single player. However it is certain that these data understate "other" for the reasons given above, and because PwC's survey is restricted to those companies where data are readily available, in industrialized countries. For example, the magnitude of efforts in China, Russia and other non-OECD nations is unknown.

Figure 2: BC Fuel Cell Cluster as a percent of world fuel cell industry

Source: PricewaterhouseCoopers 2005 Fuel Cell Industry Survey (2004 data)

Hydrogen and Fuel Cells Canada (H2FCC) recently participated in a worldwide survey of the fuel cells industry with other fuel cell promotion organizations around the world (PwC, 2004). These findings are likely to be more comprehensive than those of the PwC annual survey, but as with any such comparisons there are wide margins for error. Table 3 summarizes the differences between the studies.

Table 3: Comparison of indicators of fuel cell activity in Canada and worldwide

Worldwide
PWC2342212789Worldwide H2FCC 3388507748Canada PWC1351151496Canada
H2FCC701572654

Cluster Theory

The interest in innovation clusters emerges out of a growing recognition that the sources of firm competitiveness and economic dynamics rest upon a mix of firm-based capabilities, as well as the broader industrial structure within which the firm operates. A key element of these competitive environments are clusters of firms engaged in traded and untraded relationships with each other, with public and private suppliers of specialized services, knowledge inputs and infrastructure, and with governments and customers. Significant scholarly, business, and policy literatures now exist on innovation clusters and the basic drivers of clustering, localization and urbanization economies are known. Geographical proximity yields benefits through a variety of localization and urbanization economic effects. According to Michael Porter, clustering "is so pervasive that it appears to be a central feature of advanced industrial economies" (Porter 1990). In fact, most industries exhibit clustering behaviour (Krugman 1994).

A standard definition of clusters adopted by many researchers and policy analysts, including members of the Innovation Systems Research Network (ISRN) – see Holbrook and Wolfe (2005) - is that provided by Porter:

"Geographic concentrations of interconnected companies, specialised suppliers, service providers, firms in related industries, and associated institutions (for example, universities, standards agencies, and trade associations) in particular fields that compete but also co-operate" (Porter,1998).

The key challenge for cluster analysis is to identify and characterize firms and their linkages with each other and with other innovation system actors, such as R&D institutions or educational institutions, within some geographically bounded area.

The study of clusters is not a purely academic enterprise. Indeed, much of the academic work is driven by the need for a systematic understanding of the factors that contribute to the creation and development of clusters, and their inter-relationships over time for the very real objective of improving economic and social development.

Research in Canada to date has confirmed that firms do cluster in specific geographic areas and that by doing so achieve greater competitive advantage. These results have been summarized by Holbrook and Wolfe (2005). These studies also underline the importance of the presence and participation of public sector institutions, both public sector laboratories (such as NRC institutes) and university facilities. Furthermore, the studies suggest that there may be one set of environmental conditions supporting the creation of a cluster; while a different set may be required for its ongoing development.

The Role of Public Sector Research Organizations in Cluster Development

The past decade has seen a growing reliance on public sector research in innovation policy in many OECD countries. Public research institutions, such as NRC, and institutions of higher education have become centerpieces of innovation policies.

Public research institutions appear to be increasingly important actors in cluster development. ISRN has produced two-dozen case studies of Canadian clusters, and public research institutions are seen to play a role in almost all of them. However, the literature on clusters has relatively little to say on this topic. These institutions are generally regarded as one part of the regional innovation support infrastructure – part of the organizational environment through which government can exercise policy (see for example OECD 1999 and 2001).

Increasingly, public research institutions are expected to generate more applied knowledge of greater relevance to industry, to diffuse knowledge, provide technical support to industry, and actively participate in the fostering of new commercial activity. This ever more complex innovation system has been described as the triple helix of university-industry-government relations (Leydesdorff & Etzkowitz, 1996).

Cluster Framework

The NRC framework for an innovation cluster has been described in detail by Arthurs *et.al.* (2007) in a special issue of the *International Journal of Technology Management.* It has two parts, *Current Conditions* and *Current Performance*. *Current Conditions* consists of the actors in the cluster – cluster firms, supporting organizations (including NRC and development agencies such as Western Economic Diversification Canada (WD), and the market context of customers and competitors – and the factors in the environment of the cluster that influence these actors (e.g. availability of skilled labour, business climate, etc.). *Current Performance* consists of the concepts that indicate how well the cluster is doing – its significance in terms of critical mass, breadth of responsibilities, and reach; its interactions internally and externally to the rest of the world; and its dynamism in terms of innovativeness and growth.

Arthurs *et.al*. showed these concepts by breaking down cluster conditions and cluster performance into a hierarchy of constructs, sub-constructs, and indicators as shown in Table 4. These are drawn these from the broad range of characteristics considered important to clustering in the literature. The indicators include the cluster's business characteristics, internal and external linkages, use of public innovation infrastructure, innovative behaviour, and market orientation. NRC's influence on a cluster is in the areas indicated by shaded boxes in Table 4 – human resources, innovation support, and community support.

Table 4: NRC Cluster Development Constructs and Indicators

(adapted from Arthurs *et.al*., 2007)

Concepts	Constructs	Sub-Constructs	Indicators
Current Conditions	Factors	Human Resources	Access to qualified personnel
			Local sourcing of personnel
		Transportation	Quality of local transportation
			Quality of distant transportation

	Business Climate / Community Support	Government policies and / Quality of local lifestyle
		Relative costs
		Relative regulations and barriers
Supporting Organizations	Innovation Support	Contribution of NRC
		Contribution of other research organizations

	Community Support	Business Government policies and programs
		Community support organizations
		Community champions
	Suppliers	Local availability of materials and equipment
		Local availability of business services
		Local availability of capital
	Firm Capabilities	
Competitive Environment	Local Activity	Distance of competitors
		Distance of customers

Firm Capabilities	Business development capabilities
	Product development capabilities

Current Performance	Significance	Critical Mass	Number of cluster firms
			Number of spin-off firms
			Size of cluster firms
		Responsibility	Firm structure
			Firm responsibilities
		Reach	Export orientation
	Interaction	Identity	Internal awareness
			External recognition
		Linkages	Local involvement
			Internal linkages
	Dynamism	Innovation	R&D spending
			Relative innovativeness
			New product revenue
		Growth	Number of new firms
			Firm growth

Analysis of the Vancouver Hydrogen and Fuel Cells Cluster: Methodolgy

NRC has launched a number of initiatives intended to make their research institutes the central hubs for technology clusters. These initiatives are in direct response to the federal government's vision for innovation, commercialization and economic development. A study (HAL, 2005) commissioned by NRC developed a framework, methodology, and execution plan to undertake studies of NRC's investment in technology clusters.

The scope of the cluster was defined in consultation with the IFCI, and selected cluster stakeholders. The definition of the cluster scope was influenced by considerations of the cluster's self-awareness (how do members of the cluster view themselves?), external recognition (how do others view the cluster?), and comparison (what definition will permit comparisons with similar clusters?). Based on this cluster scope, stakeholders were identified using lists obtained from the institutes, local economic development organizations, and other sources.

Sixty-two organizations were identified in the cluster by comparing lists of organizations from H2FCC and the 2005 PwC Fuel Cell Industry Survey, and the attendance list for the "*Towards a National Hydrogen and Fuel Cell Strategy*" stakeholder consultation workshop" held on December 15th 2005 in Vancouver. Of these 62 organizations, 32 were core cluster firms, 5 were research organizations, 10 were support organizations, 5 were user organizations, and 10 were service providers.

Detailed interviews were conducted with 15 stakeholders representing each of the cluster sub-sectors: core cluster firms, research organizations, support organizations, users, and service providers. These provided insight into the internal dynamics and workings of the cluster. In addition a shorter telephone survey was carried out with all the firms in the cluster. Of the 32 firms contacted for the survey, 23 responses were obtained for a response rate of 72%. The survey had two parts: the first concerned different aspects of cluster conditions and performance; the second posed questions for the social network analysis. This survey provided the quantitative data quoted below.

The NRC Cluster Development Constructs: Results

Current Conditions and Factors

Human capital: Vancouver is well supplied with human capital for the fuel cells cluster. All of the local post-secondary institutions have programs that train professionals for the fuel cell and H_2 industry. The survey results show that the majority of firms recruit between 80 and 100% of their employees locally. Some industry interviewees reported a shortage of skilled technicians and other trades people.

Transportation: The Lower Mainland of BC, which is where most of the cluster firms are located, has an excellent transportation infrastructure. Vancouver enjoys excellent international connections both by air and by sea, as well as being the Pacific terminus of national rail and roads links. These collectively provide an infrastructure that is second to none in Canada, and a competitive advantage that, in no small part, overcomes the relatively distant location of Vancouver from other major economic centres. Cluster firms were almost equally divided on the quality of the local transportation system: almost 45% of survey respondents considered it poor to fair, while 49% considered it good to excellent.

Business Climate: The business climate is perceived as average. In spite of high land costs, and inflated construction costs due to the Olympics, Vancouver is, according to the survey, perceived as being a slightly more expensive place for doing business compared to other competing regions. This is supported by KPMG's 2006 Competitive Alternatives Study which indicates that while Vancouver's costs are lower that the US average, they are the highest for Canadian cities. Interviewees commented that wages are competitive with other parts of North America, but housing prices and personal taxes are higher. Off-setting this is the social safety net accorded all Canadians, which makes Canada an attractive location for mobile labour in the North American context.

Vancouver has a history of entrepreneurship as a result of the presence of the former Vancouver Stock exchange, which provided a venue for risk-taking entrepreneurs. This has assisted in the establishment of new enterprises and the spinning-off of new firms from existing institutions.

There are some contrasting views among interviewees about the availability of venture financing. There has been a strong stream of capital into the region, as Asian and American investment in real estate, some of which has been channelled into venture capital. Interviewees observed that international investors (particularly those from China) see Vancouver technology start-ups as a financial vehicle to get a foothold in North America (and indeed also as a means of accessing North American IP for exploitation in Asian markets). Interviewees also noted that risk capital was abundant until the technology bust, and investors are now focused on seeing returns. Unlike most regional centres in Canada (i.e., outside Toronto) the major banks in Canada have divisions in Vancouver headed by senior VPs, so that major investment decisions can be made locally.

The local lifestyle is an important competitive advantage. Of all of the items examined in the survey, lifestyle has the highest mean value (4.59 out of 5). BC has a high level of social capital. It is very progressive in many social areas and is often at the forefront of Canadian social change. This attitude is reflected in mainstream life – there is a strong sense of community.

Supporting Organizations

Innovation Support: The key institutions for supporting the cluster are IFCI and the three large Lower Mainland universities. The university system has been an important source of basic science and more importantly, human capital for the industry. As noted above, the University of Victoria (UVic) was the original "supporting organization' when it started performing research under contract to Ballard. Subsequently SFU developed a competency in fuel cell chemistry, while the University of British Columbia (UBC) has now developed a competency both in H_2 fuelled devices as well as fuel cells.

IFCI is a fairly recent supporting organization, but appears nonetheless to be important to the cluster – over half of survey respondents consider IFCI's R&D to be important or very important to their business. As well, NRC support for innovation through the Industrial research Assistance program (IRAP) is perceived as a strong asset. Currently, there is an even split between those who consider testing and validation as important, and those for whom it is unimportant, and IFCI's technology transfer is not considered important. Interviews also revealed mixed perspectives. Many are supportive of NRC-IRAP and the Institute - *"NRC is clearly the centre of this cluster"* – however others noted that NRC-IFCI resources are spread too thin, and felt that they haven't fully articulated their value-added to the cluster.

While interviewees were positive about the contributions of the federal government as a whole to the cluster (including Natural Resources Canada, NRC, and WD) there is some concern that these efforts are not well co-ordinated: *"focus, focus, focus"* is what is needed, according to interviewees.

Community Support: Community support is perceived, according to the survey, as average to good by 73% of respondents. The industry association, Hydrogen and Fuel Cells Canada (H2FCC) is active and supported by cluster members. As one interviewee stated: "*H2FCC is a unified voice for the industry*". There is active support from technology promotion organizations at both the provincial and municipal level (such as the BC Innovation Council and the Vancouver Economic Development Council). Nonetheless, many interviewees felt the province should be doing more to support the cluster.

Suppliers: Access to materials and suppliers is perceived as average, according to the survey. According to interviewees, virtually all raw materials and specialized manufactured inputs are imported into the Vancouver region. Interviewees noted that many specialized subassemblies and machined parts have to be sourced from regions where there is a strong competency in this type of production (such as Seattle, where the aerospace sector has fostered the development of specialized precision machining capabilities). But given that these inputs are physically small and the transportation facilities are good, this need to import inputs is not seen as a problem.

Competitive Advantage: BC's competitive advantages include a sticky labour market and a strong human capital base for research and skilled manufacturing fed mainly by the quality of life in the Lower Mainland of BC. However, it is not an ideal location for manufacturing-based clusters. Land and labour costs are high, and it is not centrally located with major North American markets. BC's competitive advantages are unlikely, in the long term, to overcome the lure of far cheaper manufacturing costs overseas and the incremental costs of importing raw materials and exporting finished manufactured products to world markets.

As well, BC is not necessarily an ideal market for alternative sources of energy because BC has a large and efficient hydroelectric grid in place with many generating sites available for development. Unconventional sources of electrical power must therefore compete with the low marginal cost of hydroelectric energy. That said, BC has the potential to convert existing energy resources, both renewable and non-renewable, into H_2 and therefore has a competitive advantage as a source of H_2 fuels.

In terms of the global economy, BC is Canada's gateway to Asia, and has an enviable position on the Asia-Pacific rim as a dynamic, efficient and safe environment in which to do business. At the same time it is firmly part of the North American economy. Its links to Europe are more tenuous. Respondents to the survey perceived their main competition as coming from the US. A disadvantage is that both labour costs and personal taxes are high compared to most jurisdictions, as are land costs, with the result that large-scale manufacturing simply does not occur in the region. Most private sector people interviewed stated that large-scale production of their products would be carried out in more cost-efficient jurisdictions in Asia.

Local Activity: As noted in the annual reports by PwC, the BC region is probably the largest, in terms of numbers of enterprises, in which fuel cell activity takes place. Other regions in North America, Germany and Japan may have similar, or even larger, numbers of researchers and revenues, but BC maintains the lead in terms of entrepreneurship. There is neither strong competition among firms locally, nor are there strong local (or even regional or national) markets. Firms consider that their competitors and markets lie in the US and elsewhere internationally. Most firms occupy specific niches. Consequently very little of their revenues are generated locally (or regionally or nationally).

Firm Capabilities: Interestingly, for a cluster that is largely pre-revenue and R&D driven, only 66% of survey respondents felt they had excellent or very good product development capabilities while fully 75% of respondents consider that they have very good or excellent business development capabilities. An issue for the future is that larger multi-national firms may become interested in acquiring BC firms to obtain their intellectual property. As one interviewee noted: "Outsiders, upon seeing the BC cluster for the first time, say there is a lot more here than they thought."

Current Performance

Critical Mass and Responsibility: As noted above, there are effectively two sub-sectors within the cluster – hydrogen and fuel cells and the number of firms in the cluster is dependent on the extent to which the value chains of each subsector are included. For this study, 35 fuel cell firms were identified. An indicator that the cluster is evolving towards critical mass is that many interviewees were of the opinion that the cluster would continue to exist even if the anchor firm were to disappear.

Of the firms surveyed by HAL, there are a significant number with less than 10 employees, and a virtually level distribution of firms by size up to 100 employees. There has been a fairly constant rate of creation of new firms since 1995 - approximately two new firms are created every year. According to the survey, firms in the Vancouver fuel cells cluster are either independent firms (58%) or subsidiaries of larger enterprises (33%).

Reach: The fuel cell cluster has global reach. In the survey, 65% of firms responding reported that 80% or more of their revenues came from the US or other international destinations. Very few clients of the cluster firms are local, and to the extent that the cluster has sales, these are to international clients.

Interaction

Identity: Most firms consider themselves to be part of a cluster (83% of survey respondents), and consider that the rest of the world perceives them as a cluster (77% of survey respondents). However, there is a clear divergence between firms who believe themselves to part of a fuel cells cluster and those that believe themselves to be part of an H_2 cluster.

Linkages: There is a high degree of civic interaction in the cluster, however a number of interviewees noted that there are few direct exchanges and interactions between firms as they are concerned about sharing intellectual property. They pointed out that firms tend to meet through associations and on "neutral territory" such as at IFCI events. There appear to be numerous, regular meetings of stakeholders in this industry which contribute to increasing the number of linkages in the social network as well as the strengthening existing ties. The survey confirms the strength of local interactions, as the majority of firms (77%) responded positively to the question "are you involved in a local or regional association?" One interviewee captured the cluster dynamic as follows: "it is a strong associative cluster, a cluster of people more than companies."

This view is borne out by a social network analysis of the cluster's linkages. Both the number of linkages and the breadth of those linkages (i.e. the number of topics discussed) are high. Vancouver firms tend to interact mostly with other firms, followed by educational organizations and then research organizations. Most of the organizations they interact with are within the province. As for most clusters, the primary topic of discussion is R&D, but surprisingly, the next most common topic is local economic development (whereas it would be market development in most clusters) – this is expanded upon in the next section of this paper.

The thick social network among individuals in the cluster started in the early days when Ballard Power formed a research alliance with the UVic. Currently, many of the firms in the cluster have personnel whose careers either started at the UVic. or at Ballard. As noted above, the survey shows that most firms get 80% or more of their employees from the region.

The fact that the fuel cells cluster in Vancouver consists of two symbiotic subclusters –fuel cells hydrogen fuels - leads to a more complex network which can provide multiple, and technologically important, pathways for innovation.

Dynamism

Innovation: In general, respondents consider the degree of innovativeness in the cluster is good to excellent, compared to other regions (see Figure ***3***). The hydrogen and fuel cells cluster is almost unique among Canadian high-tech clusters in that the technology was developed in the private sector, and virtually all of the intellectual property used in the cluster has been generated by firms within the cluster.

Figure 3: Cluster Innovation (1 = low, 5 = high)

It should also be pointed out that there is a strong bipolar distribution of firms in terms of revenues and expenditures particularly on R&D (see Figure 4). Virtually all perform R&D, but many are "pre-revenue" where their R&D expenditures greatly exceed any revenues. A few of the larger firms enjoy revenues from the sale of their products – their R&D/sales ratios are consequently much lower.

Figure 4: R&D as a % of gross revenues

Current Conditions	Factors	Human Resources	**Access to qualified personnel**: Good,

Interviewees remarked that virtually all firms are engaged in R&D. However, the current focus is on applied R&D to ensure commercialization in the short term. This degree of R&D has had a positive impact on innovation, contributing to the critical mass of researchers employed in industry and available in the region, and contributing to the extent to which other firms seek to benefit from proximity to this firm.

According to the survey, at least 60% of the products from the cluster are from innovations that have taken place in the last three years (see Figure 5).

Figure 5: Innovation

Growth: Interviewees noted that the origins of the cluster can be traced back to the close working relationship between Ballard and UVic. Many of the smaller companies have started as spin-offs from either Ballard or the UVic. Historically, there has been a healthy rate of entrants: most firms were established after 1995 and there has been a relatively constant rate of company establishment (one or two firms per year, based on survey respondents) since 1995.

However, the outlook for growth going forward is not good, and interviewees pointed out the urgent need for the sector to commercialize products and generate revenues to survive. According to the survey, employment in firms is lower today than it was three years ago, and is likely to decline further. The mean number of employees per firm, three years ago, was 86. Today the level is only 70, while in three years time, most firms expect there to be a decrease to 59 per firm.

According to the interviews, demonstration projects are important for gaining public acceptance and generating markets and growth. Interviewees were supportive of the Hydrogen Highway initiative and the 2010 Olympics, which will provide excellent opportunities to demonstrate fuel cell technologies.

Summary

Table 5 summarizes the findings using the NRC cluster framework of Arthurs *et.al*, 2007:

Table 5: Vancouver Hydrogen and Fuel Cells Cluster Summary

Concepts	Constructs	Sub-Constructs	Indicators

Current Conditions	Factors	Human Resources	**Relative to qualified personnel**: Good, due to quality of life.
			Local sourcing of personnel: Excellent. Most personnel are local but professionals are global in origin. Some come from local universities (particularly U Vic) but many come from elsewhere in Canada and from abroad.
		Transportation	**Quality of local transportation**: Fair to good (depending on location);
			Quality of distant transportation: Good to excellent.
		Business Climate	**Quality of local lifestyle**: Excellent. Strong entrepreneurial tradition, multi-cultural, vibrant city, proximity to mountains, ocean, strong knowledge base.
			Relative costs: Fair. Higher than the rest of Canada but about on par with major US cities,

Relative Regulations and Barriers: Good.

Supporting Organizations	Suppliers	**Local availability of materials and equipment**: Fairly Specialized materials
	Innovation Support	**Contribution of NRC**: Good. NRC impacts are mainly felt in terms of cluster strategy and NRC-IRAP support.
		Contribution of other research organizations: Fair. Universities are important sources of basic ideas and human capital, but they do not contribute much IP. Public labs are less important sources of ideas and knowledge.
	Community Support	**Government policies and programs**: Good. Many feel the province should be doing more to support the cluster.
		Community support organizations: Good. Federal support strong but not coordinated, province's support weak.
		Community Champions: Fair

Competitive Environment	Local Activity Suppliers	**Distance of competitors**: Far. Most competition is U.S. and other **Local availability of materials and equipment**: Fair. Specialized materials and equipment are not available locally, but this is not perceived as a problem
		Local availability of business services: Good
		Local availability of capital: Fair. Much risk capital was available until the tech bubble burst; investors now want to see returns.

Current Performance	**Significance** Competitive Environment	Critical Mass Local Activity	**Number of cluster firms**: 34 or so. **Distance of competitors**: Fair. Most competition is U.S. and other international.
			Distance of customers: Poor. Virtually all markets are U.S. or international.
		Firm Capabilities	**Business development capabilities**: Good.
			Product development capabilities: Good.

Current Performance	Significance	Critical Mass	**Number of cluster firms**: 34 core cluster firms were identified.
			Number of spin-off firms: Fair.
			Size of cluster firms Good. Mostly small firms with a large anchor firm.
		Responsibility	**Firm Structure**: Fair.
			Firm responsibilities: Good. Most firms in the cluster are independent, some subsidiaries and very few HQ units
		Reach	**Export orientation:** Excellent. Virtually all firms look to export, though many are pre-revenue.
	Interaction	Identity	**Internal awareness**: Excellent. According to the survey they see themselves as members of a cluster.
			External recognition: Excellent. Most firms believe they are perceived as members of a cluster in BC.

	Linkages	**Relative involvement**: Excellent **Local innovativeness**: Good. But potentially waning; historically it is the **Internal linkages**: Excellent with many local linkages.
Dynamism	Innovation	**R&D spending:** Excellent. Most firms are doing R&D, but many firms have little revenue, and R&D levels are declining compared to other countries

		Relative innovativeness: Good. But potentially waning; historically it is the world leader in fuel cell R&D, but other countries are becoming competitive.
		New product revenue: Excellent. Most firms in the cluster, if they have any revenue at all, get their revenues from new products.
	Growth	**Number of new firms:** Excellent. Steady growth in the number of firms oer past decade. Most of firms are relatively new (founded in 1995 or later).
		Firm Growth: Poor. Prospects are for a decrease in employment.

The fuel cell cluster in BC is one of the major technology-based clusters in the province. It was initially was built around Ballard in the private sector and more recently around IFCI in the public sector. This cluster has all of the necessary attributes for the creation and maintenance of technology-based clusters – a strong private sector player, strong publicly funded research facilities, and active industry-based associations H2FCC. Each of the three major universities in the region, SFU, UBC and UVic., have research programs on fuel cells. H2FCC has provided strong networking and support facilities for the industry. Finally, based on our interviews, it is reasonable to conclude that the cluster is no longer dependent on a single anchor firm – the cluster will continue to exist even if one of its major organizations fails or leaves the region. Indeed, this cluster is a good case study of how initial, modest, investments by the public sector can be turned in to a knowledge-based cluster with a global reputation.

Of particular interest is that the Government of BC has declared the 2010 Olympics to be the "Hydrogen Olympics" and is considering funding the establishment of a number of hydrogen fuel stations on the Vancouver-Whistler corridor. This will provide a significant boost to firms making demonstration vehicles, as well as a significant operational test of the complete vehicle/fuel supply system. Association with the Olympic events will ensure worldwide coverage of BC's fuel cell capabilities.

In 2005, an IFCI foresight exercise made a preliminary examination of potential future scenarios for the fuel cell industry in BC. The results of that exercise tested the viability of the fuel cell cluster in BC against a number of variables, including oil prices. Most of the futures implied strong growth in the fuel cell sector, based on the volatility of oil prices and the associated political instability in most major oil producing nations. However, the extent to which fuel cell and H_2 technologies will penetrate mass markets hinges on their ability to become competitive with alternatives, through cost reduction and improvements in reliability, performance and durability.

The Hydrogen and Fuel Cell Value Chain in BC

One of the key lessons from the development of the BC fuel cell cluster has been the development of the chain of specialized firms required to supply the unique inputs to the fuel cell manufacturers, and the specialized downstream system integrators and users who take the prototype models of fuel cells and test them in a wide variety of applications.

The fuel cells cluster should be viewed in terms of a value chain (see the top half of Figure 6). There are firms that are specialty suppliers of the physical inputs to fuel cell manufacturers. There are also specialized manufacturing sub-contractors who make the subsystems required for the complete fuel cell systems. Similarly there are university and community college programs that feed skilled workers into the cluster. At the output end, there are firms that use fuel cells in a number of products, particularly those firms that produce platforms that use fuel cells for propulsion or energy generation. There are also service suppliers, ranging from venture capital firms to patent lawyers.

A similar value chain exists for the production of the H_2-based fuels that are used by fuel cells (see the bottom half of Figure 6). The H_2 based fuels that are used by fuel cells can also be used in many other applications, with similar efficiencies and reductions in pollution. For example, as demonstrated by Westport Industries in BC, H_2 can be used in specially adapted diesel engines with resulting gains in cycle efficiencies and reductions in greenhouse gas pollution (not to mention the complete elimination of particulate emissions). Production of H_2 from renewable sources of energy (such as electrolysis of water using wind or tidal power) is also a good method of storing energy for later use in a transportable form, and unlike the use of non-renewable feedstocks (usually hydrocarbons), there are no greenhouse gas emissions.

Figure 6: Fuel Cell and H_2 Value Chains

Thus it should be no surprise that the fuel cell cluster has spawned an H_2 fuel cluster. The two subclusters are often thought of as being one, but analysis must recognize the fundamental differences between the two.

Interviewees were not clear as to how governments, federal or provincial, can lead this, or any, cluster. Without a clear mandate to lead, they must develop strategies to support and follow industrial initiatives. IFCI's "value-added" could be a vehicle for strategic investments – it could act as a showcase and spokesman for the fuel cell cluster. This includes acting as an active supporter for demonstration projects. IFCI has already done so, with its support for fuel-cell automobiles; both the federal and provincial governments have provided support for fuel-cell powered buses for the 2010 Winter Olympic Games.

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Throughout this paper we try to use "hydrogen and fuel cells cluster". As will be seen there are differences between the two sub-clusters. Often though, for ease of writing, we will use "fuel cells" when we mean "hydrogen and fuel cells" cluster.

Although, in aerospace programs, they can be used as auxiliary power units, generating low voltage DC for avionics.

More recent studies both by PwC and others confirm this result

H2FCC was formerly known as Fuel Cells Canada

The Innovation Systems Research Network (ISRN) is a group of Canadian researchers funded by federal research granting councils and NRC to research and disseminate results on Canada's diverse regional systems of innovation and develop policy responses for the various levels of government. See Holbrook and Wolfe (2005)