From the Internal Combustion Engine to Hybrids and Beyond: 
The Canadian Auto Industry and Disruptive Technologies

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“Ballard fuel cells set for U.S. program (Globe and Mail 2005a: B17)

“Hybrids put Toyota ahead of the pack” (National Post 2005: FP6)

Canada is fortunate to be early out of the gate on hydrogen and fuel cells. Canadian companies like Ballard, Hydrogenics and Stuart are global leaders in the search for new energy solutions” (Office of the National Science Advisor 2004: 2).

The auto industry, defined in terms of vehicle assembly and parts production, is Canada’s most significant manufacturing industry. A range of statistics attest to its importance: the industry accounts for 12 percent of Canada’s gross domestic product, 28 percent of its exports (finished vehicles and parts), approximately 20 percent of new manufacturing capital expenditures, and it powers the economy of the country’s largest province. It is also an industry in which the assembly sector is totally foreign owned, which means that critical decisions about production and research and development (R&D) are made elsewhere (in the United States, Japan and Germany). Some auto industry R&D is done in Canada, but it is generally not in leading edge areas of technology.

The global automotive industry is in a state of flux as assemblers compete in the search for, and commercialization of, technologies that will make vehicles less dependent on petroleum products. The internal combustion engine (ICE) has powered vehicles since 1885, when Karl Benz and Gottlieb Daimler produced their first car. By the beginning of the 20th century the ICE had become “the dominant design” (Mytelka 2003:15). Although this technology has been modified over the years, as has the fuel (diesel, unleaded gasoline), the ICE and the systems “within which it…[is] embedded” (Mytelka 2003:16) remain the defining characteristics of this mode of transportation.

Concerns about the vehicle emissions and air quality, the long-term availability of petroleum, and the rising costs of fossil fuels are pushing the auto industry as well as firms in other sectors (for example the petroleum industry), to search for new technologies to power vehicles. Fuel cells seem to be the technology of choice. Huge sums are being invested in the U.S., Japan and Germany to develop this revolutionary

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1 These include fuel refining technology and the infrastructure on which the automobile depended, roads, highways and gas stations (Mytelka 2003:16-17).
and disruptive technology. Canadian companies are active in fuel cell research and development (R&D) and a couple, Ballard being the most prominent, have been working with the assemblers to develop fuel cell vehicles (FCVs). FCVs are being tested in a number of North American cities, among them Vancouver, Sacramento, Orlando, Taylor and Ann Arbor (Ford Press Releases 2005; http://media.ford.com); these tests will provide the companies and participating governments with information that will facilitate refinement of the technology.

But we are not close to FCVs for mass consumption, or even for fleet use. Cost and infrastructure issues, among others, remain to be addressed. The date at which FCVs may be available for purchase at anything approaching reasonable prices has been pushed forward on a number of occasions by the assemblers as well as by firms in the fuel cell sector. In October 2005, GM’s chief engineer of fuel cell systems spoke of the “need to solve issues in performance, cost and durability….We have to see all these [solved] before we can pull the trigger and start commercial production.” He anticipated a “viable fuel cell powered call by 2010 with volume production possible two to three years later (National Post 2005c: FP 20). Ballard, the premier Canadian developer of proton exchange membrane (PEM) fuel cells anticipates a time frame that is at least as long, if not longer.  

The pressures promoting the race to develop fuel cell vehicles are also pushing the auto industry to innovate more narrowly. The intermediate technology on which most assemblers are focusing is the hybrid, a car that uses both an ICE and a battery for propulsion. From a vehicle that aroused mild interest when it was first demonstrated some years ago but which was not seen as a significant innovation, hybrids have become a model around which there is intense competition. Toyota, which sold its first hybrid vehicle in 1997 is now producing a third generation Prius and anticipates that in a few years all its vehicle models will be hybrids. By 2010 Toyota anticipates selling one million hybrid vehicles annually (Katz and Inque 2005: D3), including 600,000 in the US (Brooke 2005). Ford, which currently makes its Escape SUV as a hybrid, wants to position itself as a major player in the hybrid vehicle market (Ottawa Citizen 2005: C3). In September 2005, General Motors (GM) and BMW, both of which had focused on FCVs, announced they had negotiated an alliance with DaimlerChrysler to develop new hybrid vehicle technology.

A BMW executive explained his company’s decision in language that captures the challenges all assemblers face as a result of the first mover advantage Toyota and, to a lesser degree, Honda share with respect to hybrid vehicles: “The creation of a shared technology platform for hybrid drives will allow us to more quickly integrate the best technologies on the market and will therefore exploit and strengthen the innovative

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2 A disruptive technology is a new technological innovation, product, or service that eventually overruns the existing dominant technology in the market, despite the fact that the disruptive technology is both radically different than the leading technology and that it often initially performs worse than the leading technology according to existing measures of performance (Wikipedia. Accessed October 9, 2005). The ICE was a disruptive technology in its day.

3 See discussion in Bourgeois and Mima (2003: 81-87) of the challenges of commercializing fuel cells.

4 There are two kinds of hybrid cars available,…
potential of all participating companies” (Shields 2005: FP 11). In other words, vehicle assemblers and their suppliers are not going to move from ICEs to FCVs in one step. Many intermediate steps are required, of which the hybrid is a significant one.

This paper explores the position of the Canadian auto industry in the global competition around new automobile propulsion systems. It does so by examining the position of the Canadian assembly and parts sectors in the North American and global auto industry, including in the intensifying rivalry around hybrids, and the status and forward linkages of the Canadian fuel cell sector. Thus the paper brings together two important sectors of the Canadian economy, which, are largely unconnected. The paper argues that despite the capacity of the assembly and parts sectors and the innovative character of Canadian FC companies, Canada is likely to be a very minor player in this global competition. There are a number of reasons for this situation, which the paper will examine. Most important are:

(a) Foreign ownership of the Canadian auto assembly sector;
(b) Limited R&D in the Canadian assembly sector and the character of that R&D;
(c) Leading edge research, on hybrids and fuel cells, is held close by the assemblers, and is taking place at corporate headquarters;
(d) Canadian fuel sector firms partnering in R&D with the assemblers, are working with these head offices;
(e) Canadian governments (federal and Ontario) have been slow to promote connections between the two sectors;
(f) Provincial government priorities for the hydrogen economy are broad and while Ontario’s includes the auto industry, this is not the sole focus;
(g) North American assemblers were caught off-guard by the emergence and popularity of hybrid vehicles and are playing catch up with their Japanese competitors around this transition technology;
(h) The Canadian parts sector is heavily dependent on the so-called ‘traditional North American assemblers – Ford, General Motors (GM) and Chrysler, now Daimler/Chrysler and generally has short time horizons;
(i) Vehicle specific parts for hybrid vehicles are currently available only in Japan;
(j) Canadian parts firms have little comparative advantage in those parts which are unique to and important for hybrid vehicles;

The paper begins with an examination of the structure of the U.S. and Canadian assembly sectors and continues with a review of the Canadian parts sector. The second section will examine auto industry R&D on new propulsion technologies, fuel cells and hybrid vehicles. The third section examines the Canadian fuel cell sector, the fourth, Canadian government priorities around and support for the hydrogen economy. The paper concludes with questions about the promotion of connections between these two important sectors and the future of Canadian auto industry competitiveness without more attention to the development of capacity with respect to disruptive technologies.
I. Vehicle assembly in the United States and Canada

North America remains the world’s largest vehicle market, but its auto industry, once dominated by the ‘traditional’ Big Three – Chrysler (now DaimlerChrysler or DCX), Ford, and GM – is now facing aggressive competition from what DesRosiers calls the “New North American Assemblers” (NNAA), the Asian and European transplants. This competition is of three kinds, sales, profitability, and R&D.

Ford, GM and DCX’s market share for passenger cars has fallen steadily over the last decade or so and their pride of place in the light truck segment of the market is also under attack as the NNAA increase their truck assembly capacity. Ford and General Motors held 75.8 percent of market share in 1997 as compared with 52.9 percent in 2004 (DesRosiers 2005b: ). In 1997 the production-to-sales ratio in North America was 92.2 percent, meaning that more than 90 percent of vehicles bought in North America were made on the continent; in 2004 this ratio was 81.2 percent (DesRosiers 2005a: 5). All of the new vehicle assembly plants opened in the United States and Canada since 1990 have been built by the European and Asian transplants, all with financial incentives offered by job-hungry US states (Molot 2005: 297-324). Toyota has replaced Ford as the second largest seller of vehicles worldwide and anticipates overtaking first place GM by the end of this decade, if not sooner.5

There is considerable excess assembly capacity in North America. Assembly plants have the capacity to produce 25 million vehicles annually, yet sales across the three countries are closer to 20 million (DesRosiers 2005c: 22). The ‘traditional’ Big Three have closed a number of assembly plants in recent years, including three in Canada, and may well be forced to close more if they continue to lose market share.6

Ford, GM and DaimlerChrysler are also struggling with serious financial situations. Stock values are falling and corporate bonds of GM and Ford now have ‘junk’ status. As a result of enormous ‘legacy’ costs – the pension and health care benefits of retired workers – GM lost about US$1200 per vehicle in the first half of 2005 in North America, while Ford lost US$139.7 DaimlerChrysler made US$186 per vehicle. In contrast the major Japanese assemblers all earned over US$1000 per vehicle (Globe and Mail 2005b: B10). GM and its formerly owned auto parts firm Delphi, which is now under Chapter 11 (U.S. bankruptcy legislation) protection are renegotiating their pension and health care benefits in an effort to reduce costs.

Vehicle assembly in Canada is fully integrated with that in the United States and Mexico. This is the result of three agreements, two bilateral and the last, trilateral. The first was the Canada-US Auto Pact signed in late 1964, which promoted rationalization of vehicle assembly between Canada and the United States. This was followed by the Canada-US

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5 An article in the Daily Telegraph (Litterick 2005) suggests that this will happen in 2006. In that year Toyota (with its two subsidiaries) will produce 9.2 million vehicles; FM is not likely to top its 2005 production of 9.12 million vehicles.

6 See article by Brent (2005: FP6) in which the Chair and CEO of Ford indicates the need to consider plant closures in light of weakening sales (SUVs among others as a result of higher fuel costs). See also McKenna 2005: B10).

7 GM has two to three people sitting at home for every person working (Globe and Mail 2005b: B10).
Free Trade Agreement implemented on January 1, 1989 and then the North American Free Trade Agreement, which came into effect on January 1, 1994. Vehicles and parts move tariff-free across borders as long as the North American content requirements are met.\(^8\)

The vehicle assembly sector in Canada is wholly foreign owned and has been since the second decade of the 20\(^{th}\) century. Ford, DaimlerChrysler, General Motors, Honda, Toyota and CAMI (a GM-Suzuki joint venture) all assemble vehicles in Canada. This means that decisions on production – vehicles and platforms allocated to plants, length and size of production runs, and plant closures – as well as on research and development are made outside Canada. The first three companies have a long history in Canada; Honda and Toyota established assembly facilities in Canada in the mid-1980s, shortly after they had done the same in the United States.\(^9\) All vehicle assembly in Canada takes place in Ontario, which is now the largest vehicle-producing jurisdiction in North America.\(^10\)

The auto industry is Canada’s largest and most important manufacturing industry, contributing close to 12 percent of Canadian gross domestic product. The industry is also Canada’s largest manufactured export, accounting for 28 percent of Canadian exports. Approximately 85 percent of vehicles assembled in Canada are exported (almost solely to the United States) as are two-third of Canadian-made parts.\(^11\) In 2003-4 Canada produced 16.6 percent of vehicles assembled in North America, approximately twice the number bought by Canadians (DesRosiers 2005a: 2). In other words, Canadians purchase only about half as many vehicles as the country produces. The industry accounts for 9 percent of total manufacturing employment in Canada and 1 in 6 in Ontario jobs is connected to the auto industry. The industry is a big consumer of steel, rubber and processed aluminum as well as other commodities.

The Canadian assembly sector receives about 20 percent of annual Canada-US new capital expenditures in the assembly sector (DesRosiers 2002: 2) and in overall manufacturing (Jackman and Lambert 2005). In 2004-5 Ford, GM and Toyota announced major investments in assembly capacity, the first two to upgrade their existing facilities and the latter a new assembly plant. Vehicle assembly plants in Canada are, on average, more productive than their US counterparts by about 10 percent and there is higher utilization of assembly plant capacity in Canada. Two GM plants in Oshawa topped the 2005 J.D. Power and Associates annual ranking of vehicle quality (Keenan 2005b: B9; 2005c: B1, B8).

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\(^8\) NAFTA rules of origin require 62.5 percent North American content for vehicles to move duty free among the three countries. Each maintains its own tariffs on vehicles and parts imported from non-NAFTA members. Canada-US trade in vehicles and parts has been integrated since the late 1960s.

\(^9\) CAMI began operation in 1989.

\(^10\) Assembly in Ontario surpassed that of Michigan in 2004 by about 100,000 vehicles. By 2008 the difference is projected at 600,000 (Durbin 2005a: B4).

\(^11\) 90 percent of the vehicles purchased in Canada are imported, 65 to 70 percent of these from the US, the remainder from offshore. 70 to 75 percent of parts used in vehicle assembly in Canada are imported.
This relatively positive portrait of Canadian vehicle assembly capacity has to be seen in the context of the highly competitive North American assembly sector described above. No Canadian assembly plants are slated to close in the immediate future, although as a result of the 2005 negotiations between the Canadian Auto Workers and the traditional Big Three the number of assembly jobs will fall through attrition. Ford will close its casting plant in Windsor, Ontario in 2007 and, this will lead to a loss jobs at a nearby engine plant (Keenan 2005d: B1, B9).

The auto parts sector is an essential segment of the Canadian auto industry and, like the assembler sector, is integrated into the North American vehicle production system. Two-thirds of vehicle components made in Canada are exported directly (almost solely to the U.S.) and many others exported indirectly, in finished vehicles. The Canadian parts sector is very heavily dependent on sales the traditional Big Three. Close to 85 percent of components made in Canada are sold to these three assemblers; GM alone purchases almost half of the output of the Canadian parts sector. Some Canadian-owned parts firms sell components to Toyota and Honda, but relatively few have cracked this market given the length of time these two companies have been operating in Canada and the number of vehicles they assemble. Nor have Canadian parts producers been successful in selling components to the NNAA that do not have assembly facilities in Canada, Nissan, Hyundai, or BMW for examples.

Ownership of parts firms in Canada is mixed. Approximately half the parts companies are Canadian owned. Of the remainder, the largest number are subsidiaries of U.S. parts firms, a small, but growing number are subsidiaries of Japanese companies lured to Canada by the NNAA, and a still smaller number owned by European parts firms such as Bosch.

The parts sector in Canada is comprised primarily of medium and small sized firms. There are some very large parts producers – Magna, which is now the 5th largest parts producer globally being the best known. There are a few other Tier I companies in Canada, but not many. There are a number of important parts categories in which Canada has little capability – electronics, drive train, and steering suspension, for example (DesRosiers 2002:4). Canada has considerable capacity in engine production, but very little with respect to batteries.

Parts producers in the U.S. and Canada are under considerable pressure from the assemblers. All assemblers, but particularly the traditional Big Three, are putting enormous pressure on their parts suppliers, particularly on Tier I firms and system

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12 Canada was the largest supplier of vehicle parts to the U.S. until three years ago, when it was replaced by Mexico.

13 A survey of North American parts suppliers suggests declining confidence in the traditional Big Three and a preference for working with the Japanese assemblers. Parts makers indicated their intention to raise R&D budgets and capital expenditures for Toyota, Honda and Nissan, while reducing them for the Big Three (Durbin 2005b: B12; Sherefkin 2005: 1.55). These reports do not indicate whether any Canadian-based parts producers were included in the survey. However, the survey results are in accord with interview comments about the difficult relationships between Canadian suppliers and the traditional North American assemblers.
integrators, in terms of their engineering and design contributions to new vehicles as well as with respect to prices. Assemblers see cost reductions from parts suppliers as one way to keep vehicles costs down. Assemblers want to reduce the number of parts suppliers with whom they work and are putting pressure on some suppliers to become system integrators (assembling components into vehicles segments). Canadian parts producers are also facing competition from Asian and some Mexican suppliers.

Because of their dependence on the traditional Big Three and the continuing demands for price reductions on parts, most Canadian parts firms have tight profit margins and short time horizons. Their ability to remain solvent depends on fulfilling current sourcing agreements, anticipating the next opportunity to bid on parts, and hoping they can meet the competition. The declining market share of the traditional Big Three, plus the considerable rise in value of the Canadian dollar since 2003, are adding to the challenges faced by Canadian parts firms. A number have requested assistance from the Canadian government, while others have closed (Keenan 2005a: B1, B2).

Canadian parts producers do some R&D, but, because of the character of the sector, R&D tends to be focused on activities with an immediate payoff, in other words much of the attention is on process technologies that will help the firm meet assembler demands on price, delivery times, or engineering and design. The one exception is Magna, which because of its size and diversity of activities can afford to invest in R&D with a longer-term payoff. Again, with the exception of Magna, Canadian parts suppliers are not involved in any work around alternative fuels. The R&D focus of the Canadian parts sector will be discussed again below.

2. Auto Industry R&D on Alternative Fuels

2.1 Fuel Cell Vehicles

Inter-firm competition in research and development in the auto industry is intense. As noted above the major R&D competition is over fuel cell technology as well as, increasingly, around hybrids. This is not the place to describe in detail the range of US federal and state governments programs supporting assembler R&D on fuel cells.\(^{14}\) This support is a function of concerns about auto emissions, air quality (particularly California\(^ {15}\), and long-term availability of hydrocarbons as well as the recognition of the economic importance of the auto industry and the challenge to national competitiveness of these disruptive technologies. The creation of the Partnership for a New Generation of Vehicles (PNGV) in 1993, which was “a multi-technology private-public partnership” gave the Big Three “the opportunity to create a Fuel Cell Alliance with the [U.S.] Department of Energy (DoE)” (Avadikyan and Larue 2003: 134). The PNGV was a purposive arrangement that can be understood as one of a number of joint government-auto industry efforts to create a common framework to take advantage of the R&D activities of government departments which could contribute to technological advances in the auto industry (Avadikyan and Larue 2003: 141). Although research consortia are

\(^{14}\) See for example Avadikyan and Larue (2003: 133-58) who discuss the “Partnership for a New Generation of Vehicles” (PNGV) and the US Department of Energy’s Transportation Fuel Cells Program, and then the Freedom Car program.

\(^{15}\) California created its Fuel Cell Partnership in 1999.
Important in the initial stages of research on new and costly technologies, inter-firm competition for first-mover advantages imposes limits on the extent of corporate cooperation around R&D. The PNGV was replaced in 2002 by the Freedom Car program, which will last until 2010 and which places priority on FC and hydrogen technologies.

Most of the major auto assemblers are working to produce FCVs and are doing so in their home countries, generally at sites close to head offices. DaimlerChrysler’s fuel cell R&D is based in Germany, that of Ford and GM in the U.S., and Toyota in Japan. GM, which began cooperation with the U.S. Department of Energy on alternative fuels in 1989-90, was the first assembler to begin research on hydrogen vehicles. GM has invested considerable resources over a long period of time in the search for a viable FC vehicle and has R&D alliances with a number of companies, Dow Chemical among them, to improve on fuel cells not only for vehicles but also for the stationary power market (Fletcher 2004: DO 14). GM also invested very heavily in trying to produce an electric car, without success, although some of the lessons learned in this effort are useful in R&D on FCVs. In March 2005 GM signed an US$88 million deal with U.S. Department of Energy to build a fleet of 40 hydrogen FCVs and to further develop the technology. Under the 5 year program GM will spend US$44 million to deploy FC demonstration vehicles in Washington, NY, California and Michigan and the DoE will contribute the other half. In a separate deal Shell Hydrogen LLC will support GM by setting up 5 hydrogen refueling stations in Washington, and New York, between these 2 cities and in California (National Post 2005: FP 12). DaimlerChrysler is participating in this project with GM. DCX will invest US$70 million and will place FC vehicles with consumers who will provide feedback on the vehicles’ performance. DCX already testing 100 FC vehicles in various locations (G&M March 31/05:B17 FIND CITATION). DCX has also been active in the production of fuel cell buses. Ford’s distribution of FCVs for trials in U.S. and Canadian cities, mentioned above, is evidence of that firm’s R&D on this new technology. Toyota and Honda are also investing heavily in R&D around FCVs.16

Because of the very significant first mover advantage that will accrue to the assembler that is the first to produce a reliable and reasonably priced fuel cell vehicle it is not surprising that assemblers undertake this kind of leading edge research in-house. In describing the “strict partitioning” between research undertaken in-house and that conducted under the auspices of the PNGV, one expert used the term “firewall” (Avadikyan and Larrue 2003: 152). A critical issue around this R&D, with obvious implications for the Canadian auto industry, is the identity of the parts producers with whom the assemblers are working. Evidence suggested that, at least in the late 1990s and very early 2000s, the traditional Big Three were engaging with their most trusted suppliers on FC R&D - various subsidiaries of Delphi for GM and a range of other firms for Ford and DXC, among them Allied Signal, Chrysler Liberty, McDermott Technologies, and 3M (Avadikyan and Larrue 2003: 146-9). (The current financial difficulties of Delphi raises some questions about its continuing participation in this R&D.)

16 See Automotive News (2005a: 26B) interview with Takeo Fukui in which the Honda president indicated his company was for the immediate future at least, working on its own on fuel cell vehicles.
The costs of FC R&D and the search for competitive advantage have pushed vehicle assemblers into strategic alliances with each other as well as with firms in the energy sector. These alliances keep changing, as a result of financial exigencies as well as corporate assessments of the value of these relationships.

A number of Canadian fuel cell companies are participating in strategic alliances with assemblers. Ballard Power Systems of Vancouver, a very early mover in fuel cell technology, has for many years been part of an alliance with Ford and DaimlerChrysler to develop a FCV.\textsuperscript{17} The three formed a joint venture, called Xcellsis in 1998 (Avadikyan and Larrue 2003:134). For financial reasons in mid-2005, Ballard sold its stake in its German fuel cell development subsidiary to its assembler partners; Ballard will, however, continue to be responsible for the design, development and manufacture of vehicular FCs for its alliance partners, while DCX and Ford will jointly undertake the design, development and manufacture of the vehicular fuel cell support system (Wong 2005: B7).

Ballard Power Systems is the unquestioned technical leader with respect to PEM fuel cells, supplying the technology to six of the largest assemblers; Ballard expects to supply more than half the fuel cells used in the previously mentioned tests of FCVs in different locations in the U.S. and Canada (Globe and Mail: 2005a: B17). In addition to Ford and DCX, Ballard has also supplied fuel cells to other assemblers, including GM, Honda, and Nissan, but not Toyota (Bourgeois and Mima 2003: 91). A second Canadian FC company in an alliance with one of the major assemblers is Hydrogenics (based outside Toronto), which has an alliance with GM to produce its in-house FC system ((Avadikyan and Larrue 2003:134).

Disruptive technologies are by definition uncertain. Despite the huge amounts invested in R&D to develop fuel cell vehicles, a number of uncertainties around cost, infrastructure, hydrogen production and storage remain. Some analysts have queried the commitment of assemblers to fuel cell vehicles “as the future car solution” (Mima and Criqui 2003: 54; interviews). Is it possible that at least the U.S.-based assemblers are participating in FCV consortia as a kind of insurance, particularly since a substantial portion of the consortia costs are covered by government funds? Whatever the depth of their dedication to FCVs, the assemblers are undertaking their R&D at their home office locations and working with suppliers with whom they have longstanding relationships. What this means for Canadian capacity in FCVs will be discussed below.

2.2 Hybrid Vehicles
Assembler R&D over the short and medium terms does not focus solely on FCVs. There are other alternative propulsion systems in play, diesel, which currently is much more popular in Europe than in North America (though it is likely that more diesel vehicles will be available in the U.S. and Canada in the near future)\textsuperscript{18} and hybrid vehicles. Because of the innovative nature of latter and the current competition to produce and sell

\textsuperscript{17} Because of other joint ventures, this strategic alliance is part of a much larger network which includes Mazda, Shell Hydrogen, Mitsubishi Oil, etc (Avadikyan and Larrue 2003: 151).

\textsuperscript{18} See DesRosiers (2005b) for a discussion on why diesel powered vehicles should be produced for sale in Canada.
hybrid vehicles in North America, attention in this paper is focused on hybrids rather than diesel.

In the competition around hybrid vehicles, Toyota is the technological leaders. The company has a virtual monopoly on patents for hybrids. Other assemblers producing hybrids – Ford and Honda for example - are licensing Toyota technology. The number of Toyota patents on hybrids has generated a “patent minefield” which will be very expensive to review and move beyond.

Toyota’s success with hybrid technology is forcing other assemblers to invest in this area. And Toyota has far deeper pockets than its competitors. As noted in the introduction, Ford produces one hybrid, with others anticipated. It will be some years before Ford makes a profit on its hybrid Escape. The other major assemblers are playing catch-up. In 2005 none of the assemblers is making a profit on its hybrids, even if the vehicles are more expensive too consumers than regular cars. But with experience and growing sales, Toyota can anticipate reducing its own losses on each hybrid car, if not breaking even. GM’s CEO, Rick Wagoner, acknowledged “our hybrids will lose money…It is early stage technology and the volume is low” (Macintosh 2005:FP20). Anticipating its first hybrids in late 2007 GM would appear to have misjudged the trajectory of new automotive technologies by concentrating first on electric and then on fuel cell vehicles until 2005.

The battery is a critical part of a hybrid car. This is where a significant part of the Japanese comparative advantage lies. The company that, thus far, is the major supplier of batteries for hybrid vehicles, Panasonic EV Energy, was a joint venture between Toyota and Matshushita Electronic Industrial Co. In early October 2005, Toyota increased its stake in Panasonic to 60 percent from 40 percent, effectively making its joint venture into a Toyota subsidiary (Sapsford 2005: B15). At about the same time, GM, desperate for cash, sold its stake in Subaru, a subsidiary of Fuji Heavy Industries Ltd. The latter is also a producer of hybrid batteries, which it has been selling to a number of U.S., European and Japanese automakers (Yamaguchi 2005: 6). Almost simultaneously, Toyota purchased almost 9 percent of Fuji Heavy, with access to its lithium ion battery capacity a major factor (Inque and Green 2005:B14).

At the end of 2005, all of the critical hybrid technology is sourced in Japan. Although Toyota will import some, if not most, of the significant hybrid components from Japan, for example the battery, electrical technology and the power train, when it starts to

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19 Toyota has been able to reduce some of its hybrid production costs by integrating the alternative technology into its traditional assembly line process. All Toyota hybrids are now built alongside conventionally powered models instead of the dedicated plant that previously built the Prius (www.theautochannel.com/news/2004/08/03/207164.html).

20 Ford does not expect that its Escape hybrid will be profitable for “at least a couple of years” said president Jim Padilla. “The costs are pretty high…our supply base needs to become more efficient. The car has a complicated electronic control system. I don’t think there’s a chance with the first generation of product” for it to be profitable (National Post 2005a: FP3).

21 Lithium ion batteries are smaller and lighter and are seen as critical to future of hybrid cars (Brooke 2005b: FP 6).
assemble hybrid vehicles in North America\textsuperscript{22}, it will have to develop North American suppliers over the medium and longer terms. This is one of the reasons the Asian assemblers are now investing heavily in R&D centres in the United States. Although R&D on power trains, electronics, and vehicle architecture is, and will likely continue to be, done in Japan (and Korea), the North America centres will be responsible for sourcing parts from North American suppliers and for working with these suppliers to create components and adapt technology developed abroad for vehicles assembled and sold in North America (Truett 2005: 1, 49). Given the close relationships between assemblers and their suppliers it is likely that Toyota start its North American sourcing by recruiting its major Japanese hybrid component suppliers to establish North American facilities. Concomitantly, or subsequently, it will start to work with existing North American parts producers. Reliable supplies of the necessary components will be the real constraint on the number of hybrid vehicles Toyota will be able to produce in North America (Chappell and Yamaguchi 2005: 8).\textsuperscript{21}

Johnson Controls, a U.S. company and the world’s largest producer of lead-acid batteries as well as a manufacturer of batteries for hybrid buses in use in Europe is actively positioning itself (through research and acquisition-based investments) to supply batteries for hybrid vehicles (Automotive News 2005b: 24A). In October 2005 the company announced that it reached an agreement with battery maker Saft Groupe SA for a joint venture to produce batteries for hybrid vehicles and that it expected to complete the agreement in early 2006 (Globe and Mail 2005c: B19)\textsuperscript{24}.

Honda is working with Sanyo Electric to make the batteries for its hybrid cars and Ford is procuring batteries for its hybrids from Sanyo. Because, as noted above, Toyota controls critical hybrid technology, other assemblers have little alternative but to source parts from suppliers with which Toyota does business. Toyota has established strong relationships with its suppliers. This means that companies like Ford, which are producing hybrids to compete with Toyota, and are sourcing from firms which supply Toyota, find themselves in a cue behind the Japanese assembler when it comes to receiving shipments of parts. Although Ford acknowledges the importance of developing partnerships with U.S.-based suppliers (Brooke 2005b: FP6), this will take time and will be hindered by Toyota’s hold on hybrid-related patents and its long standing connections with its key suppliers.\textsuperscript{25} As noted in the introduction, GM, DaimlerChrysler and BMW

\textsuperscript{22} Toyota’s Georgetown, KY facility is the one mentioned most often as the likely first location for assembly of a Toyota hybrid (the Camry) in North America. Although, in mid-2005 Toyota announced that it would build a new assembly facility in Woodstock, ON, it has made no announcement with respect to the production of hybrid vehicles in Canada.

\textsuperscript{23} Assembly in North America of 100,000 vehicles per year of one model would lead Toyota to start discussions about a local supply base in the view of Toyota general manager of the hybrid vehicle systems engineering division in Japan (Chappel and Yamaguichi 2005: 8).

\textsuperscript{24} Johnson Controls relatively positive financial picture contrast with that of some of its rivals, Delphi Corp, which filed for bankruptcy protection in early October and Dana Corp, which is also facing financial difficulties (Globe and Mail 2005c: B19).

\textsuperscript{25} Ford acknowledges that its plans to increase production of hybrids are dependent on its ability to find suppliers to produce key parts. In September 2005 Ford CEO Jim Padilla complained that Japanese assemblers have been “grabbing” most of the key parts, which he described as a “predatory approach” (Jewett 2005: 46).
have formed an alliance to develop hybrids.\textsuperscript{26} This follows on an earlier agreement between the first two firms to work on these vehicles. Their comparative advantage, which will result in better highway mileage (the current hybrid is more gas-efficient in city, rather than highway driving), will derive from the location of the electric motor; rather than situating the electric motor between the transmission and the gasoline engine, the electric motor in the GM and Chrysler hybrid systems will be an integral part of the transmission (Vander Doelen 2005:C3).

Although first seen as a short-term technology on the quick route to fuel cell vehicles, the challenges of the latter, underestimated by many in their enthusiasm for a technology seen as an answer to many dreams, it is clear that hybrids are an important transition step of indefinite duration on the path to FCVs. Toyota is developing FCVs based in part on what it has learned from hybrids; its test FCVs use the same battery as the Prius. Toyota believes that the assembler that has mastered hybrids will, whenever fuel cells become commercializable, will have a significant cost and learning advantage over its competitors that have been working fuel cells only (Hermance Automotive New June 27, 2005: 4).

2.3 Auto Industry R&D in Canada and Canadian auto industry capacity with respect to “disruptive technologies”

The analysis of assembler R&D on fuel cell and hybrid vehicles demonstrates that whatever the new technology, it is being developed by vehicle producers in their home markets. The traditional North American assemblers have invested heavily in fuel cell research and are playing catch-up with respect to hybrid technology. A statement by GM Canada’s President, Michael Grimaldi, indicates that corporate awareness of the technological churning in the auto sector:

\begin{quote}
Over the next several decades we will face an absolute revolution in the development and manufacture of the automobile... For a capital-intensive industry built around the internal combustion engine, this may be one of the most disruptive innovations of all (Keenan 2004: B3).
\end{quote}

At the end of 2005 there appears to be little hybrid capacity in North America. There is virtually none in Canada. The connection between Canadian firms active in the fuel cell sector, whether the FCs themselves or hydrogen infrastructure, and the vehicle assemblers is mediated through corporate head offices.

Canadian assembly plants have traditionally done very little R&D. Industry focus has been largely on vehicle assembly and the maintenance of jobs that assembly generates directly and indirectly. This lack of attention to R&D was noted in the October 2004 report of the Canadian Automotive Partnership Council (CAPC), an industry stakeholder-government partnership created in 2002 to ensure the long-term sustainability of the Canadian auto sector. CAPC’s “A Call for Action: A Canadian Auto Strategy” stated baldly that “[e]ven though Canada has an infrastructure, workforce and tax system

\textsuperscript{26} Bosch, an important German parts producer, is working the DCX and GM on hybrid vehicle technology (Floerecke 2005:22F).
supportive of R&D, the simple fact is that Cda is home to few head offices. Although some R&D is done in the country, Canada does not come to mind first and its advantages and capabilities are not well understood…” (CAPC 2004: 8-9). Although the CAPC strategic plan identified the twin goals of expanding investment and innovation, the bulk of its recommendations focused on topics other than alternative propulsion technologies. To the extent that it addressed alternative fuels, CAPC placed more emphasis on hydrogen infrastructure than on FC R&D (CAPC 2004:21-2). This focus may reflect what some industry stakeholders see as Canadian comparative advantage in R&D around hydrogen infrastructure, rather than direct work on FCVs, which thus far has bypassed Canadian assemblers and parts producers.

In recent years the three traditional North American assemblers have begun to invest in R&D in Canada. DaimlerChrysler has expanded its Canadian Automotive Research and Development Centre at the University of Windsor. GM is investing Cdn$135 million in R&D that will be conducted at various Ontario universities;\(^{27}\) this commitment to promoting industry-relevant education is part of a Cdn $2.5 billion investment in GM’s Canadian operations which will facilitate flexible manufacturing at its two Oshawa ON plants (Tuck and Howlett 2005: B8). And Ford, which also announced an investment to promote flexible manufacturing in its Canadian operations in 2005, is doing research at its paint shop on the feasibility of using paint fumes to power fuel cells; the project is in its initial stages. These latter two corporate investments are supported by national and Ontario government funding programs created to ensure the continuing strength of the Canadian auto industry. These efforts are significant and a recognition of the importance of a knowledge-based auto industry. But serious R&D capacity takes a long time to develop; for the short and medium terms at least Canada is on the periphery. R&D done in Canada tends to be an offshoot of that done at corporate headquarters. Although the federal and BC governments are both participating in the testing of Ford’s FCVs in Vancouver, there appears to be no involvement of Ford of Canada in this project.

If the assemblers in Canada are not involved in R&D relating to disruptive technologies it would be unrealistic to expect the parts sector to present a different profile. This is not to suggest that parts sector firms are not cognizant of the changing technology in the industry – they are. But the character of the parts sector is shaped by its historic relationship with the assembly segment of the industry and the overall industry’s North American character. Three points made above warrant repetition here. First, the Canadian parts sector, as robust as it is, has limited capacity in those parts unique to hybrid and fuel cell vehicles. While 80 percent of a hybrid or FCV is or will be comprised of components standard on current vehicles, and Canadian parts firms do very well providing these parts to assemblers on both sides of the Canada-U.S. border, the Canadian parts sector does not manufacture batteries or electronics, and although it makes motors, these are for ICEs. Second, with perhaps one or two exception (a Tier I firm or system integrator with global reach and significant R&D capability, research and development undertaken by Canadian parts firms relates directly to the components supplied to the assemblers. And third, Canadian parts producers depend overwhelmingly for their business on the traditional

\(^{27}\) The increase in Canadian automotive engineering capacity is intended to facilitate the engineering and design of more vehicle systems in Canada (Kennan 2004: B3).
Big Three. Some Canadian parts companies of longstanding sell to Toyota and Honda, as do subsidiaries of Japanese parts firms that followed the two assemblers to Canada. But, thus far, none of these suppliers has parts production capacity that differentiates it from the Canadian parts sector overall.

To recap this lengthy section briefly, the assembly sector is investing heavily in R&D around fuel cell vehicles. This work is being done at, or close to, corporate headquarters. Although FCVs are currently being tested in a number of locations (and fuel cell buses are being tested more widely), viable production of these vehicles for even limited consumption is a long way off. Second, hybrid vehicles have emerged as an important interim technology, one in which Toyota has a clear first mover advantage. All of relevant hybrid vehicle components are being producers in Japan. The North American auto sector, both the traditional assemblers and components suppliers, are playing catch up. Third, while the Canadian assembly and parts sectors recognize the potential of these disruptive technologies, no R&D relating to either hybrid or FCVs is being done in Canada.

3. Canada’s Fuel Cell Sector
Canadian companies were early movers in research on, and commercialization of, capacity in fuel cells and related technologies. Ballard Power Systems, located on the Canadian west coast, is recognized as a world leader in the development, manufacturing and marketing of zero-emission proton exchange membrane (PEM) fuel cells. As noted above, Ballard has strategic alliances with companies around the world, including some of the auto assemblers, and has supplied fuel cells for bus and vehicle trials. Although Canada ranks 5th in the number of fuel cell patents by country (Liston-Hayes and Pilkington 2004), the Canadian fuel cell industry ranks highly when measured in terms of the number of firms in the sector producing patents and the range of technologies covered. Kevin Fitzgibbons’ paper for this conference (2005) describes Canada’s fuel cell sector in some detail and there is no reason to replicate that information here. Suffice it to say that there are two major fuel cell clusters in Canada, the largest one in the Vancouver, BC area around Ballard Power Systems, and a second in the Toronto area, centred in what is known as Hydrogen Village. There is a growing cluster in Calgary, Alberta.

Canadian FC firms are working in a number of areas relevant to the hydrogen economy – the two kinds of fuel cells (PEM and the solid oxide fuel cell, SOFC); hydrogen infrastructure issues such as hydrogen delivery, refueling equipment and storage; hydrogen production; and stationary applications of FC technology, among others. As noted above, major FC sector players such as Ballard Power Systems and Hydrogenics are working directly with vehicle assemblers on FCVs. Other Canadian FC firms also have connections with assemblers, for example, Dynetek Industries with Ford, DCX and Nissan, or Praxair with Mercedes. In addition to the longstanding Ford and DCX investment in Ballard Power Systems, other assemblers have provided Canadian FC firms with capital. The Canadian FC sector has wide international connections; firms in this sector have research, marketing, and financial relationships with similar and complementary companies in Europe and Asia. To provide but one example, as a result of its acquisition of Stuart Energy, Hydrogenics has linkages in Europe and Asia. It has a
subsidiary in Europe that produces hydrogen using electrolysis; it also relationships with companies in Europe and elsewhere working on a variety of issues related to the generation and storage of hydrogen.

The importance of these strategic alliances and partnerships for Canadian FC sector is evident by looking at their growth. Their number of these relationships grew from 135 in 2002 to 256 in 2003; the largest number of alliances were with vehicle assemblers (33 percent), those with other hydrogen and fuel cell developers and public-private partnerships ranked second (at 20 percent each) (Government of Canada et al 2004: 7).

Although the Canadian FC sector is active in R&D, it is a sector, which is financially somewhat precarious. Many of the firms are small, dependent on government support and have difficult raising the venture capital required for commercialization. Fitzgibbons identifies a range of financial issues facing the sector (2005: 22). The CEO of one of the larger companies, Pierre Rivard of Hydrogenics, suggested that the FC sector is composed of too many small players, which are not financially sustainability and that, as a result there is a need for some consolidation (Anwar 2005: B7). The something on the financial precariousness of the sector, fact that most firms are

4. Government Support for Disruptive Technologies
Fitzgibbons (2005: 8-11) details the breadth of federal Canadian government support for fuel cell research and development and commercialization. As he notes, this support involves several government departments and the National Research Council (the government’s primary institution for R&D in the fields of science and engineering), as well as a couple of important funding programs, which provide financial support for high-risk, pre-commercialization research.

Although the Canadian government has been a strong proponent of FC technology and has created programs to support FC R&D, the government does not appear to be promoting linkages between the FC and automotive sectors.

Canada has been an active participant in the International Partnership for the Hydrogen Economy (IPHE) since its creation in November 2003. IPHE’s purpose is to facilitate and coordinate research and commercial utilization of emerging hydrogen technologies. It also serves as a forum for advancing policies and common codes, standards and regulations to advance the cost-effective transition to a global hydrogen economy. As an international agency in an area where there is enormous national and corporate competition for first move advantage in the various segments that will comprise the hydrogen economy, the IPHE can have little impact on the R&D around, and commercialization of, specific components of that economy. It might raise the profile of the potential for a hydrogen economy or promote the sharing of knowledge around some of the challenges of this new economy, around hydrogen storage and materials, for example. The IPHE might also strive to coordinate its activities with existing relevant international agencies, such as the International Energy Agency and the International

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28 Canada is a vice chair of the Steering Committee (together with India, Italy and Japan) and has agreed to host the Spring 2006 meeting of the Committee in Vancouver.
Standards Organization. Thus far its meetings have largely focused on the sharing of information that is already in the public domain.

Finally there are the efforts by the Canadian provinces to promote fuel cell and hydrogen technologies. The two most important are those of British Columbia and Ontario. Each has a different focus. BC’s hydrogen strategy is shaped by two key factors – the presence in the province of Canada’s largest fuel cell cluster, and the province’s success in winning the 2010 Winter Olympic and Paralympic Games. As Fitzgibbons (2005: 12, 18) notes, the “centerpiece” of the BC strategy is the Hydrogen Highway to be constructed in time for the 2010 Olympics. Other areas of focus include the development of a leading Energy Technology Cluster and the revitalization of the resource heartlands of the province to supply the fuel and know-how for hydrogen-based communities and industries and clean hydrogen production and distribution (www.fuelcellscanada.ca/BC%20Hydrogen%20Strategy.pdf).

The Ontario government announced its Fuel Cell Innovation program early in 2005. The program provides Cdn$3 million in annual funding over the next three years with a focus on commercialization and moving products to the manufacturing stage. The funds are designed to nurture the development of small and medium-sized Ontario companies working on FC technology development and FC compatible strategies (http://www.fuelcells.2ontario.com). The Ontario program is focusing on stationary applications of fuel cells, rather than portable applications or those related to the vehicle industry (cars, buses, trucks).

5. Conclusion
The purpose of this paper was to look at where the Canadian auto industry stands with respect to the R&D on and commercialization of alternative vehicle propulsion technology. The analysis demonstrated that the two sectors – automobiles and auto parts on the one hand, and fuel cells are the other – are strong, if not very strong (the case of autos). Both, however face challenges that are not unusual for small open economies. Decisions on auto assembly are made outside Canada; critical R&D and certainly that with respect to disruptive technologies is done at head offices; the Canadian parts sector has short time horizons and its R&D is largely focused on immediate component improvements, not longer-term component development. Although Canada was an early mover with respect to fuel cells and has FC companies with connections to the auto assemblers and firms in other related sectors outside Canada, firms in the sector struggle financially. It is too early to anticipate whether Canadian FC companies will continue to be significant players in the race to produce commercializable fuel cell technology.

Perhaps most significant is the finding that these two important sectors are not linked in any significant way inside Canada and that there seems to be little attention in government to this. Canadian governments are both levels are supporting FC R&D; whether they are doing so sufficiently is another question. What is not clear is whether governments (Ottawa and Ontario) appreciate the situation of the auto industry in Canada relative to disruptive technologies and whether both segments of the Canadian auto will
be able to adjust competitively to technologies that are changing the character of vehicle propulsion systems.
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