Canadian Sponsored Plug-in Hybrids and Their Impact

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Abstract:
Specific plug-in hybrids sponsored by Canadian governments and companies are described, including a metal-air hybrid, two natural gas hybrid vans, a gasoline hybrid van and a natural gas hybrid shuttle bus. The gasoline hybrid van was shown in Los Angeles and the shuttle bus was trialed in New York. They can be linked to subsequent developments. The applicability of hybrids to the commercial vehicle sector is discussed.

Introduction
The plug-in hybrid electric vehicle (PHEV) was a step to the commercially viable “unplugged” hybrids of today and may now be a step again to a more efficient future. We will explore here Canada’s role in its development and how the PHEV can fit in the commercial vehicle field vis-à-vis conventional hybrid vehicles.

The Canadian automotive industry mirrors that in the United States. Only in the heavy bus field was there a move towards the production of hybrids[1] before Toyota had launched the *Prius* in Tokyo in December 1997. This is despite Toyota’s direction on hybrids being well known in the early 90’s, (Geddes (1994).[2]

The Honda *Insight* hybrid was delivered both in the US and Canada just ahead of the *Prius,* with the first being delivered in the US in December 1999, just as Canada’s Federal government was concluding a two year, country wide process to determine low cost options to tackle climate change. The “Transportation Table” was part of this study and had input from the energy and automotive industries and other stakeholders as well as the provinces of Canada. A specific study for the Table (Levelton et al, (1999))[3] actually showed that *both* hybrid light and heavy duty vehicles were low cost options to tackle greenhouse gas emissions. However, the final climate change mitigation options that came out of the Table for action did not include hybrids.[4] At the time, there were not only already tens of thousands of light hybrid vehicles on the road in Japan, but the Canadian led Orion IV hybrid transit bus was *already* being offered commercially and five were in service with the New York City Transit Authority.

Early vehicle engineers had been undeterred by the large size of electric motors or the low energy density of batteries. Not only were pure electric vehicles produced but Ferdinand Porsche’s patent on the “Mixte” transmission, filed in 1897 (Wakefield, (1998)) [5], led to a successful “series hybrid” while Pieper (1905)[6] described a parallel hybrid with the electric motor coaxial with the engine. These vehicles continued to have the ability for their batteries to be externally charged and were PHEVs.

Wakefield (1998) describes early projects in other countries, and the first he mentions in Canada is a parallel hybrid built by a team led by the University of Toronto’s F.C. Hooper .This was usable as a pure electric vehicle and entered in the Clean Air Race of 1970. The PHEV had a 10 kWh battery.

In 1976 the US Congress passed Public Law 94-413 calling for the development of Electric and Hybrid Vehicles, Kurtz (1983)[7]. In 1982 the Office of Technology Assessment of the US Congress received a report (Carriere et al. (1982))[8] which describes a number of hybrid personal and commercial vehicles equipped with a range of battery technologies where the "battery fraction" (the battery weight fraction of the vehicle's loaded weight) is 13% to 19% and there is discussion of a range of battery fractions of 10% to 32%. The report discusses hybrid vehicle fuel costs and it was assumed that part of the fuel came from the grid.

The 9th International Electric Vehicle symposium (EVS 9) was held in Toronto in 1988. Victor Wouk (1988), a leader in US hybrid vehicle thinking from the 70's, reviewed the status of hybrids [9] and, for example, included a British Lucas-Chloride parallel plug-in hybrid described in more detail by Harding et al[10] (1983). It had a "pure electric" vehicle range and an onboard charger is shown in a schematic in both papers.

At the same conference Adams and Morgan (1988) [11] gave a review of battery activities across Canada. They predicted that new developments in advanced magnets and materials would usher in a new age for electric and hybrid vehicles. They reported on three lithium battery initiatives in Canada: two decades later two of the companies continue as Electrovaya and E-One Moli.

This paper discusses a sample of four pre-1997 PHEV projects that were funded by Canada, Ontario, Saskatchewan, BC and Canadian companies, joined by US agencies and companies, and a British company.

1 Semi Fuel Cell hybrids 1984-1992

Sponsors

Alcan, NRC, TDC, Unique Mobility (now UQM Technologies, Inc.) and the Ontario Ministry of Energy.

Outline

In 1981 Alcan became aware of work at the Lawrence Livermore National Laboratory on the aluminum-air battery or semi fuel cell for vehicle applications. The company was convinced that the automotive industry would link a need for lighter aluminum vehicle structures with heavy batteries and put together an international effort to take a lead in the area. The technology was featured on the Alcan stand at the 1983 Society of Automotive Engineers (SAE) conference in Detroit. [12] Aluminum-air semi fuel cells or batteries can have neutral or alkaline electrolytes and practical power densities are very low to maintain efficiency. Power densities range from only 5 to 20W/kg and Alcan rapidly moved to hybridizing Al-air with lead–acid batteries.

The late Jack Morgan, at the Transport Development Centre (TDC) in Montreal, had recently supported the development of both a pure electric and a hybrid delivery van, the Marathon *C360*[13], and was impressed by the improvement that hybridization made to battery life. Discussions led in 1984 to a saline aluminum-air hybrid “off road” vehicle project supported not only by TDC but also the National Research Council of Canada under DSS project 15SD.T8200-4-4530. Results were presented in 1988 at EVS 9[14]. This co-funded project concluded in 1986 and Alcan then internally funded the demonstration of an alkaline telecom unit vehicle range extender in a plug-in hybrid version of the UQM *Electrek*.

The hybrid *Electrek* was displayed at EVS 9 and the results were reported in Vancouver at a 1989 SAE meeting[15]. Toyota and Nissan engineers had attended EVS 9 and Nissan purchased an aluminum-air system from Alcan for trial in their laboratory while another was purchased on behalf of Toyota by Aisin-Seki.

The Ontario Ministry of Energy then supported the demonstration of the aluminum-air hybrid in a UQM converted Chrysler Minivan (below). The results of this work were reported at EVS 10 in Hong Kong by Lapp et al. (1990)[16] and at EVS 11 in Florence by Lapp and Dawson (1992)[17]. The minivan was test driven by Renault engineers in Kingston ON, and an aluminum-air system was purchased for the Renault laboratory in Paris.

Gelled batteries were discussed (Anderson (1990a)[18] and Anderson(1990b) [19]), but experience may have been mixed as the battery system used on the Alcan vehicle, the last of three hybrid *Electreks*, was a 22 kWh battery made up of 18, six- volt, 205 Ah, Chloride 3ET 205 wet batteries common to the Lucas-Chloride Griffon that was built on a Bedford platform. These batteries were also used on the Magna G-van.

Lapp and Dawson (1992) give the total vehicle weight of the Alcan vehicle as 2649 kg and assign 630 kg to the Chloride batteries and their “mounting” structure which, by comparison with the later BCR hybrid G-van we will estimate here as 50 kg. This yields an active battery weight as 580 kg. (See Table 1)

2 Gasoline/natural gas plug-in hybrid minivans 1988-1990

Sponsors

Alcan, UQM Technologies and San Diego Gas and Electric

Outline

A series hybrid Chrysler minivan T115 was modified and developed in response to the Los Angeles Initiative was described by UQM’s Anderson, 1990a at the SAE meeting and a two motor version described later that year Anderson, 1990b.

The gasoline hybrid was designed for a range of 56-64 km on its battery and was equipped with a 5 kW “range extender”. The minivan was one of three vehicles featured in November 1989 at a press conference[20] at which Councilman Braude, Mayor Tom Bradley and senior executives from California Agencies announced the successful completion of Phase 1 of the Initiative.

San Diego Gas and Electric sponsored a natural gas version of the same vehicle, and it was also the base vehicle that Alcan used in the project mentioned above.

3 A natural gas plug-in hybrid shuttle bus 1992-1996
Sponsors
Alcan, UQM Technologies, Ontario Bus Industries (now Orion), Ontario's Ministries of Energy and Transportation, NYSERDA, the Canadian Gas Association and San Diego Gas and Electric

Outline
Gilbert and Rehn (1992)[21] describe the drivetrain design of a modified Orion II transit shuttle bus. The bus was powered by two UQM SR218 60 kW traction motors. The hybrid engine was a natural gas fueled Chevrolet 4.3 liter V6 coupled to a third SR218 motor operating as a generator. Rehn and Gilbert (1992)[22] describe the sealed battery pack as being 30, twelve volt 160 A-hr modules in two 180 volt strings wired in parallel, i.e. it had a 57.6 kWh capacity.

At a curb weight of 9,779 kg [23]vehicle performance exceeded industry White Book specifications and was designed to a loaded weight of 10,700 kg. In October 1994, UQM were contracted by NYSERDA to upgrade vehicle electronics and to prepare the bus for leased transit service in the state of New York. From June to December 1995, the bus was made available to seven New York State transit operators.

4 A natural gas plug-in hybrid delivery van 1995-1996
Sponsors
BC Research Inc. (BCRI), NRCan, the Science Council of BC, BC Gas Utility ltd. (now Terasen), the Saskatchewan Research Council (SRC), Lordco Auto Parts Ltd and Hawker Batteries Ltd,.

Outline
BCRI leased a GM/Vehma electric G-Van that Magna had donated to the University of Ottawa. The wet Chloride batteries were removed and replaced with low impedance Hawker Genesis lead acid batteries. There were 36, twelve volt, 38 Ah modules divided in two strings of 216 V. The capacity of the battery was 16.4 kWh and it could be charged with an onboard 10 kW charger developed for the project. The engine was a 1.3 litre fuel injected Suzuki engine converted by SRC and similar to one that used in a concurrent NRCan supported Geo Metro project.

The curb weight of the final hybrid vehicle[24] was 3000 kg and the battery weight (excluding the battery tray) was 580 kg. The "battery fraction" was reduced from 35% to 19 %. A zero emission range of 40 km was reported in a BC Research literature sheet.[25]

The hybrid project focused on the control strategies for a fleet vehicle in urban use to maximize engine efficiency. Results were reported by Drozdz et al (1996)[26]. The vehicle is used as an example by Drozdz and Yip (1996)[27] in a patent application. The grant of this patent led BC Research Inc. to form Azure Dynamics.

Commercial Vehicles

Conventional hybrid technology is successfully penetrating the delivery vehicle and shuttle bus markets because there is a pay-back to the fleet manager. Delivery vehicles with a loaded weight of 5380 kg and a shuttle bus (10 passengers + driver) of 6550 kg have a battery fraction as low as 1.84% and shuttle buses as low as 1.51% (Oversby and Botting)(2007)[28]. The low battery fraction being used today is driven by cost, space and payload demands.

Cairns (1981)[29] analyzed a large number of vehicles with a "battery fraction" from 25% to 30% and showed, on an urban cycle, the SAE J227a "C" cycle, that 0.15 Wh/kg.km was a practical number for "wall electricity". Recent work sponsored by Transport Canada has shown (Overland (2004))[30] that a modern bus driveline need only draw .074 Wh/kg.km. With low impedance batteries and more efficient battery charging it is reasonable to use 0.1 Wh/kg.km for "wall electricity" for modern estimates of urban zero emission range.

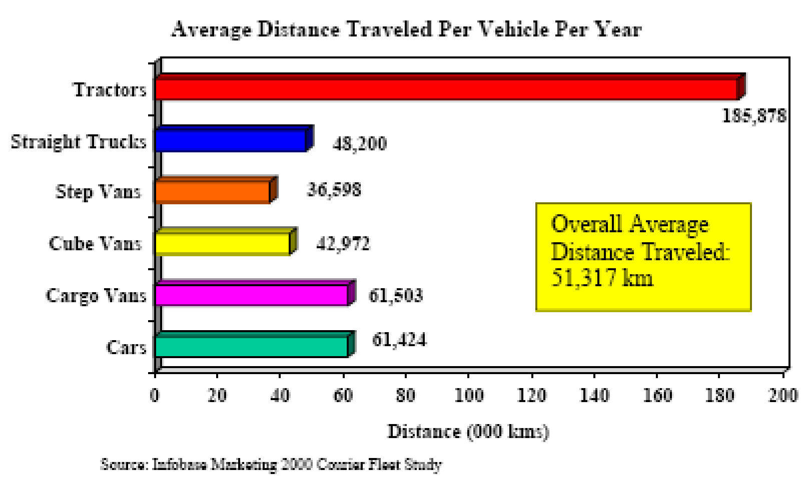
The plug-in hybrid vehicles discussed above can be summarized with Table 1. Their zero emission vehicle (ZEV) range is normalized using the Overland (2004) figure which would apply to a modern drivetrain and which gives a higher range than was actually achieved during these projects. For courier vehicles Transport Canada have provided the data in Fig 1.

Table 1 Three Vehicles Discussed

Vehicle	approx test weight	battery weight	Battery fraction of Curb Weight	kWh	Wh/kg	Range km at 0.074 Wh/kg.km
UQM Chrysler T115	2949	580	21.9%	22	38	101
Orion II Shuttle Bus*	10779	2,037	20.8%	57.6	28	72
BCR Hybrid G-van	3300	580	19.3%	16.4	28	67

* deduced battery weight for "gel cell" using Genesis figure

Figure 1: Annual distance traveled by vehicles in the Courier business in Canada



We again make use of the Overland (2007) figure 0.074 Wh/kg.km for battery energy use. Taking step vans with a loaded weight of 5,380 kg (Oversby (2007))[31]as a target, and for a 250 day operating year we can see that a daily range of 146 km is needed. A 58 kWh battery capable of 250 full annual discharge cycles would be needed to explore full electric vehicle delivery.

This would convert to a 12 kWh battery need for 20% EV range. This figure is not unreasonable for a large truck but, since currently Toyota warrants their *Prius* battery for 10 years, a warranty requirement might need a battery capable of 2,500 full DOD cycles for a PHEV. Transit shuttle buses, though, can exceed 100,000 km per year in operation and with Azure's having a test weight of 6,550 kg (Oversby (2007), would place almost triple the demands on the battery life cycle.

The liquid cooled NiMH batteries that Azure use weigh in at 99 kg and have a capacity of 2.8 kWh (Oversby and Botting (2007)). Their costs are on track to be recovered from savings. We can deduce that, even with only 12 kWh capacity batteries that if "plug-in" hybrids are to enter the commercial vehicle area they will be in niches where, like the passenger market in which it originates, that long hours of use are rare.

School buses, for example, are a relatively easy technical target but the incremental cost will be hard to match with fuel savings alone. With the shorter annual range, relative to regular hybrids, for market penetration to occur there need to be additional factors in the business case for the fleet manager.

Possible PHEV commercial fleet candidates might include vehicles that can use batteries to generate clean silent power. Examples where there are potential business cases include utility line trucks, city service vehicles, and emergency services vehicles.

Benefits of these vehicles might include revenue from vehicle to grid operations and one should note that advances in battery management have led to the current successful operation of pure electric vehicles in the US Post Office fleet in New York. Some of the benefits of vehicle to grid connections may accrue to pure electric vehicles in the commercial sector and it may be that vehicle to grid experiments can be implemented in fleets with these pure electric vehicles while battery technology develops.

There will be benefits of "plug-in" technology in the commercial sectors that differ from those in the passenger vehicle sector. Currently WestStart-CALSTART has a task force studying business cases in the commercial sector for plug-in hybrids. Quantification of the benefits will follow.

Discussion of Impacts of the Projects Described

The projects discussed provide examples of Canadian government support and show that small focused efforts have led to change and specifically to Canada's lead in the large commercial hybrid vehicle niche. Not only was Canada key in helping projects start but so were the governments of Ontario, Sakatchewan and British Columbia. More than one of the projects engaged agencies and team members on both sides of the international border.

Lessons learned by the Alcan team from the aluminum-air work included the following:

- The prime mover, fuel cell or engine, will be more efficient and need have only a low power density if hybridized
- The generator or fuel cell voltage, i.e. the number of cells, could be much reduced by using an efficient DC-DC inverter to charge the battery
- It was found that the power battery returned to base fully charged on typical urban trips
- The vehicle could start before the fuel cell came up to power
- Highway driving requirements specified the power of the prime mover
- Urban delivery is simpler hybrid target than a passenger vehicle with mixed use.

At EVS 9, the late councilman Marvin Braude, keen to reduce ground level emissions, spoke of an announcement he had already made in May and challenged participants to deliver electric vehicles in Los Angeles. Two Canadian companies were to participate in the response in 1989. Magna developed and delivered the electric G-van and Alcan funded the plug- in hybrid delivered by Unique Mobility (now UQM) in which Alcan had bought an interest that was only sold in 1997 when former Chrysler Chairman Lee Iacocca's new company, EV Global Motors (EVG), formed a strategic partnership with Unique (now UQM Technologies). EVG purchased a million plus shares of UQM stock from Alcan Aluminium Limited in a private transaction.[32]

Range limitations hampered Marvin Braude's thrust with electric vehicles and for clean air the hydrogen fuel cell attracted much interest and government support.

The Orion II natural gas bus project could not lead to commercial success as the system packaging lost 40% of the passenger seats. The Transport Development Centre in Montreal followed the project with interest and with Ontario Bus (now Orion) supported Ortech (now Bodycote Testing Canada Inc. (Mississauga)) to analyze possible components for the larger Orion VI. This process used MatLab Simulink to model the vehicle, a technique now used by the National Renewable Energy Laboratory in Colorado; Drozdz et al. (1994)[33].

The natural gas hybrid G-van project at BC Research resulted in the formation of Azure Dynamics which is currently delivering production hybrid trucks and shuttle buses and has a working relationship with Ford.

Alcan's interest in hybrids and electric vehicles stemmed from an interest in introducing aluminum into the vehicle structure. It is generally less expensive to lighten a vehicle than to add battery. One can suggest that the more expensive the battery becomes the greater the interest in light vehicle structures for regular vehicles which will become.

We can see that improvements in electric driveline efficiency, compounded with progress in batteries, opens up the potential niches where larger battery fractions can be used.

The jump in driveline efficiency in the commercial vehicle section is greater than the jump in energy density between the wet lead acid battery of 38 Wh/kg and the air cooled NiMH batteries in the Toyota *Prius* of 46 Wh/kg.[34]

Conclusions

It can be seen that it's not only important to develop batteries but to have high driveline efficiency.

While "plug-in" hybrid projects have led to viable courier hybrid delivery vehicles and shuttle buses, battery cycle requirements in particular suggest that future commercial "plug in" or "battery dominant" hybrid projects must be picked carefully if they are to lead to commercial success. Examples given include utility trucks and emergency service vehicles, while noting that there are pure electric vehicles in the commercial sector that offer the opportunity to examine vehicle to grid benefits.

Canadian governments supported metal-air, natural gas vehicles and hybrid electric vehicles. This led to change in Canada and the US.

Recommendation

Canadian governments should continue to support and encourage work on *both* the drivelines and batteries for hybrid vehicles.

Besides the direct benefits, work on battery intensive vehicles may lead to spin-off fuel savings across the full market from the lighter vehicle structures needed, as a low cost way to increase "battery mass fraction" is to reduce the weight of a vehicle structure. In this respect it may be worth engaging the attention of the light vehicle structures industry which played a role in bringing hybrids into play in the 1980's and 1990's.

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I would like to thank those I came with into contact in the vehicle and battery field from 1979 onwards and also to thank my family for supporting my "hybrid journey". I particularly credit a 1984 meeting at the offices of the Japanese Electric Vehicle Association in Tokyo leading me to visit UQM, then Unique Mobility. I was told by JEVA that "Denver" was where "Toyota had bought an electric vehicle"; it was one of 50 *Electreks* that had been built and Toyota was pleased with it. I learned on arrival at UQM that they had built, in only six weeks the hybrid, used to carry a TV camera ahead of the marathon runners in the 1984 Olympics in Los Angeles. I had seen a hybrid in 1982 in Birmingham, but 1984 was when I was convinced.

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