Fuel Cell History, Part 2

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Horse power. Truly amazing amounts of organic horsepower. Available everywhere, in every village, in every town and city – a long time ago.

In New York City, during the late nineteenth century, between one hundred and fifty thousand and two hundred thousand horses where pulling wagons to transport everything the population consumed, and all the raw material needed for the products and the freight the inhabitants of New York produced. People were moving from the countryside to areas of commercial and industrial activity by the droves. Horses also pulled the trams that transported the populace between their newly constructed homes and their productive jobs in mushrooming factories. The industrial revolution was in full swing, and the same was happening in cities and towns all across the country, in America and in Europe.

Horses in such vast numbers left a lot of pollution in liquid and solid form on every street they worked and travelled on, potentially attracting rats and insects, and thus spreading diseases. Reports from America's largest city inform us that up to 2,000 tons of horse manure had to be removed from the city's streets on a daily basis. Yes, I searched for and read the reports, and I also checked the math.

Not the 1800s, and not a horse-less carriage, but a transportation method in a developing country.
Illustration courtesy of Auto Bild.

No wonder then, that one hundred years ago the world welcomed the automobile with open arms as its environmental saviour, when the news of their invention spread around the globe. Nevertheless, as we know now, a new type of pollution replaced the old type; we just did not recognize it until decades later.

Cars and trucks were a novelty at first, showing up in small clusters here and there. Then their numbers grew, they were faster than horses and became more reliable as time went on. Naturally, wagon builders, blacksmiths and veterinarians decried the lack of work, and warned that massive unemployment among their ranks would undoubtedly follow.

Does this sound familiar? Remember, all the workers who made radio and television tubes lost their jobs over time when electronic devices were developed. What's more, all the persons who built carburettors were displaced when fuel injection became the norm in the automotive world more recently. You can surely think of other examples; this is what we consider progress. However, life will always go on and get even better than before, for all those who have been affected. The population keeps increasing, and so will the number of available jobs. Jobs will differ, but they will be created as technology changes.

And many of the men and women working in the oil fields now, will become unemployed during the next generation, when the hydrogen economy takes hold. But who produces hydrogen? Education has, and will continue to ready us for the next step. And Mother Nature will provide us with another resource when the old one diminishes.

Now, let's catch up with fuel cell and hydrogen history.

As we know, one third of all automobiles in the first quarter of the twentieth century were battery powered electric vehicles (EV). The 'gas battery', now known as the fuel cell, had been invented, or more appropriately, discovered, a long time ago. However, not all the pieces of a puzzle do fit together all of the time. Collectively, humans are not really that smart, after all.

Sir William Robert Grove's 'innovation' of the "gas voltaic battery" in 1839 produced proof that electricity could be generated with hydrogen and oxygen. But when EVs were relatively plentiful during the first two decades of the twentieth century and well into the 1920s, nobody in the growing automobile industry seemed to remember this. Porsche and other automotive pioneers produced and sold hybrid electric vehicles (HEV) during the early years, but seemingly, nobody saw the potential of Grove's gadget for electric vehicles.

Grove's invention was left to linger as just another scientific curiosity, because Volt and Ampere meters to perform useful measurements were non-existent. Only now and then, a scientist would come across the idea, and carry on where Grove's experiments had left off.

Since hydrogen (H_2) is the fuel of fuel cells, we ought to look at some early uses of H_2 as a fuel in internal combustion engines as well as early applications of fuel cells. As you may be aware, H_2 can be extracted from many sources, from coal, petroleum or natural gas. Since the world must get away from the carbon emission of those base stocks, the goal is to produce H_2 from water by electrolysis. The substantial energy required for this process must come from renewable sources, like wind, wave or solar power. These are now being developed along with fuel cells at the beginning of the 'Hydrogen Age'.

In part one of this series, I listed the exploits of Rivaz, but skipped Lenoir. Etienne Lenoir patented his two-stoke engine in 1860, and he installed it in a three-wheel wagon, named the "Hippomobile", because its fuel -- hydrogen --, was electrolyzed from water. French humour, I guess. He later experimented by running his engine on different fuels, coal gas among them – the very first flex-fuel engine. (Is there absolutely nothing new under the sun?) Lenoir built and sold almost 400 of these engines, competing successfully with steam engines of the time.

A replica of Lenoir's "Hippomobile", the very first 'flex-fuel' pickup truck. Illustration courtesy of the Louvre, Paris.

In 1874 science fiction writer Jules Verne predicted that the world would use water as a fuel in the future – we are still working on that. And 'Dr. Mirabilis' had already foretold 'speeding wagons' in the middle ages. (other than on the Autobahn, we are being fined for doing that). I ask you; did these people in the old days have nothing else to worry about, but to imagine what might happen in the far future? I am struggling here just to get history into a meaningful sequence.

Fifty year after Grove's experiments, in 1889, Charles Langer and Ludwig Mond, tried to build an apparatus that would function to create electricity with air and coal gas. At about the same time, William White Jaques conducted similar research, using different materials. All three of these scientific experimenters have been credited with being the first to use the term "fuel cell". (I believe it was one of the bureaucrats in the patent office, who wanted to make a name for himself). Oh, the vagaries of history.

In addition, at about this time, the steam engine was occupying most inventors' minds, time and resources.

And then, suddenly, the newfangled internal combustion engine (ICE) was in the news; that is, it could be observed at many exhibitions and at World Fairs, and it fascinated the general public of the time. Converting horse carriages to 'horse-less' was the goal of inventors and entrepreneurs. Steam-vehicles, battery-electric cars and combustion-engine automobiles vied for domination well into the 1920s. We all know which one came out ahead; in large part, because the flourishing oil companies made it easy to obtain petroleum fuel.

As early as 1923, Scottish biochemist and geneticist John Burdon Sanderson Haldane presented a paper to Cambridge University about the advantages of hydrogen as a fuel. He had the foresight to warn that the plentiful deposits of coal and oil would come to an end, and that industry should prepare for the use of alternative fuels. J.B.S. Haldane suggested to make use of wind-power to electrolyze hydrogen and oxygen from water. In his opinion, Great Britain could satisfy its increasing energy demand with H_2 mixed with petroleum products as a fuel for transportation needs.

Is it not a strange, but reoccurring fact that society habitually disregards visionaries and innovators during their own time?

Remember, this was 1923, and J.S.B. was neither an automotive executive, an environmental advocate nor had he any direct interest in the industries affected by what he anticipated. Eighty-plus years later, we know how right he was, and how "not worth mentioning," Haldane's hypothesis was perceived by his contemporaries.

In the meantime, nevertheless, people in different places had not given up on hydrogen as a fuel. A great deal of H^2 research occurred during the 1930s. This proved to be the decade that really put hydrogen research into favour with the scientific community.

One attempt which received little publicity, was by the Norsk Hydro Company in 1933. The Norwegian power producer modified one of their small trucks to run on H^2 instead of gasoline. They installed an on-board reformer to extract hydrogen from ammonia. It was cumbersome, but it foretold the future.

Pickup truck of the Norsk Hydro Company, converted to run on hydrogen gas. Illustration courtesy of the Oslo Technical Museum.

Another almost forgotten fact is Sikorski's experimentation with hydrogen-powered engines in helicopters. After building fixed-wing and rotary-wing aircraft in Russia, he fled to the USA in 1917 during the Bolshevik Revolution. Other Russian immigrants helped him financially to organize the Sikorski Aviation Research firm in 1938. Igor Ivanovitch Sikorski was able to persuade the US government to front a two million dollar budget for further trials on vertical take-off and landing aircraft (VTOL). He also proposed using liquefied hydrogen as a fuel for aircraft.

By this time, one hundred years of research and experimentation had been applied to this infinitely abundant fuel. Scientist and industrialists had tried to find ways to utilize hydrogen's potential to propel machines on land, on water and in the air. Engineers and experimenters around the world did not let go of the idea that a way would be found soon to tame nature's gifts to humans.

Please, be aware that it is nearly impossible to draw a straight time-line through the infancy of two closely related activities of combining fuel and machine. Repeating and overlapping experiments, discouraging results and promising successes, different personalities in various countries doing similar tasks almost simultaneously, just as it happened with Daimler and Benz, make this a daunting assignment.

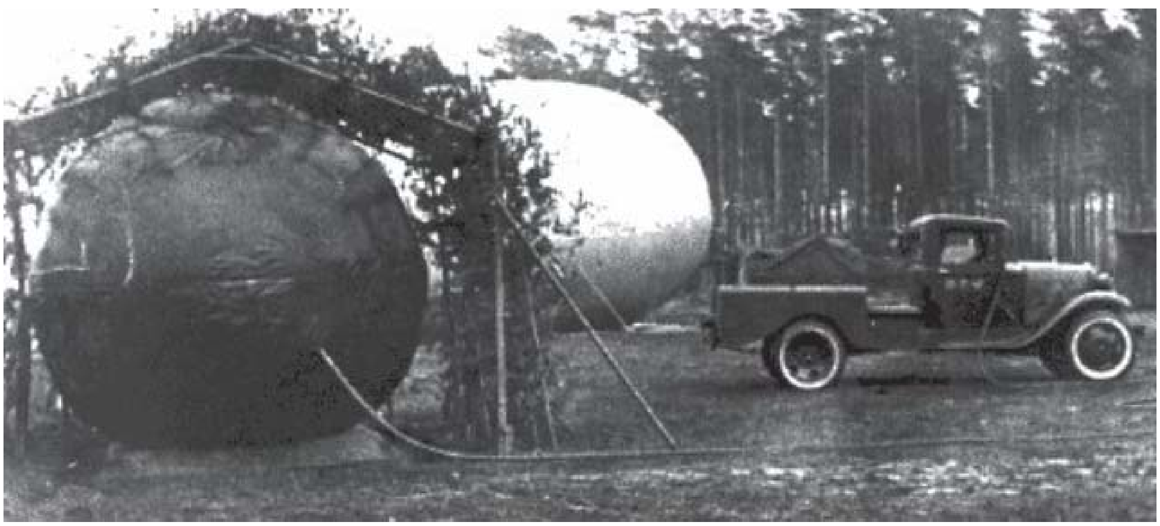
Who would have thought that it would require almost another century of research and development, before fuel cells and hydrogen would come close to being "ready for market"?

During the decade before World War II, Rudolph Erren and Franz Lawaczeck were very influential in hydrogen research in Germany. 'Frank L.' was a turbine designer, and he had been sketching and endorsing hydrogen fuelled turbine cars for more than ten years. He collaborated with the American J.E. Noegerath and the German Hermann Oberth on work leading to the use of liquefied H_2 as a rocket fuel.

With regard to Hermann Oberth: I do remember the excitement at my house as a youngster when my father had arranged a meeting between ‘Herr Oberth’ and other influential people soon after WW II, and Mr. Oberth gave a speech in our small town that evening. But that’s another story.

Meanwhile, Rudolph Erren had been researching internal combustion in Germany since the 1920s, much as Sir Harry Ricardo did in England. Erren experimented by adding hydrogen to common air-fuel mixtures to increase output. Before World War II, Erren converted vans, buses and railway engines to run with different combinations of hydrogen and regular fuels. He worked together with British and Australian groups, but the War put an end to this peaceful collaboration between nations.

In Russia, Boris Shelishch and the GAZ automobile manufacturer ran a truck with hydrogen as fuel in 1941. It was war time, though, and other priorities prevailed. The GAZ company is still in existence, and is producing contemporary vehicles in Gorky; that name has now been changed to Nizhny Novgorod.



Filling up the GAZ at the ‘gas’-station. Illustration courtesy of the GORKY Auto Plant.

Germany, lacking petroleum resources, experimented extensively with synthetic fuels (i.e. Leuna) and hydrogen as a petroleum replacement. A little known piece of information is that the Allied Forces captured a “trackless” (Under-sea) U-boat during the War. Conventional fuels leave a trail, or track, of exhaust bubbles, but in the engines of this ‘silent killer’ only hydrogen and oxygen were combusted, leaving no track of revealing bubbles. This combustion process left no other emission than water vapour, very difficult to detect in the ocean, indeed.

When running on the surface, the sub’s diesel engines powered an electrolyzer to generate H^2 for storage when running submersed. This eliminated the need for heavy batteries and the additional electric motor(s) of normal submarines of the time. The weight and space savings resulting from this gave an additional 15,000 miles of operating range and the possibility of faster and deeper dives.

What a waste of effort and money for a needles war; and we still have not learned the lessons from this, literally and figuratively.

Well known is the fact that, a few years earlier, in 1932, Dr. Francis Thomas Bacon, engineering professor at Cambridge University in England, undertook to modify the equipment as it had been used by Mond and Langer. Bacon used a less expensive material for the electrodes and a less corrosive electrolyte. He called this first alkaline fuel cell the “Bacon cell”.

During World War II Bacon was asked to work for the British military, and he continued his research on fuel cells under the Anti-submarine Experimental Establishment. But the war ended before any concrete results from his laboratory work could be obtained.

Never giving up on a promising concept, Bacon continued, and by 1959 had patented his device. He demonstrated a fuel cell unit that developed 6 kilo-Watt of power, enough to power an electric welder.

At about that same time, in America, Harry Karl Ihrig, his effort being in the fields of farmers rather than the scientific fields, had become very involved with fuel cells. He worked for the agricultural implement manufacturer Allis-Chalmers and modified one of his company’s farm tractors to run with an electric motor. To power this unusual contraption, he assembled 1008 cells to generate about 15 kW of electricity (20 HP, approximately). Karl Ihrig demonstrated the world’s first fuel cell vehicle at farm shows across the country. The tractor developed enough power to pull a 3000-pound weight.

Not for sale to any collector, the Allis Chalmers D-12. Weighing 1270 kg, it is equipped with an alkaline fuel cell (4 Stacks with 252 Cells each) delivering enough power to plough a field. The fuel was propane stored as compressed gas in a pressure vessel.
Illustration courtesy of the Cooper-Hewitt National Design Museum.

Allis-Chalmers continued to do fuel cell research for a few years with assistance from the US Air Force. They assembled a fuel cell powered forklift, a golf cart and –hard to believe from the fly-guys - a submersible.

In the meantime, the US air force itself experimented also with hydrogen as a fuel – once again. In 1956, they modified a B-57 bomber to burn H_2 in one of its engines. The pilot could switch the one jet engine to run on hydrogen during flight, instead of the normal kerosene jet fuel. The test was considered successful, but since petroleum fuel was less expensive, no further development took place.

At about the same time, Lockheed, together with Pratt & Whitney, developed a high-altitude reconnaissance plane to run on liquid hydrogen. The CL-400 aircraft got as far as wind-tunnel testing, but again, no additional development happened.

The one positive outcome of these tests by the military and the newly formed National Aeronautics and Space Administration (NASA) was the official determination, "that hydrogen did not require more safety precautions than that which were required for hydrocarbon fuels".

This was a significant step in dismissing the "Hindenburg myth."

NASA was now preparing for manned spaceflights. They were looking for a power source to provide spacecraft with electricity; batteries were too heavy, solar energy was still too expensive at that time (even for NASA) and nuclear energy was considered too risky. On what type of supply should they decide? Scientists and engineers believed fuel cells to have the best potential merits, and awarded several companies with research contracts to come up with a practical and reliable design solution.

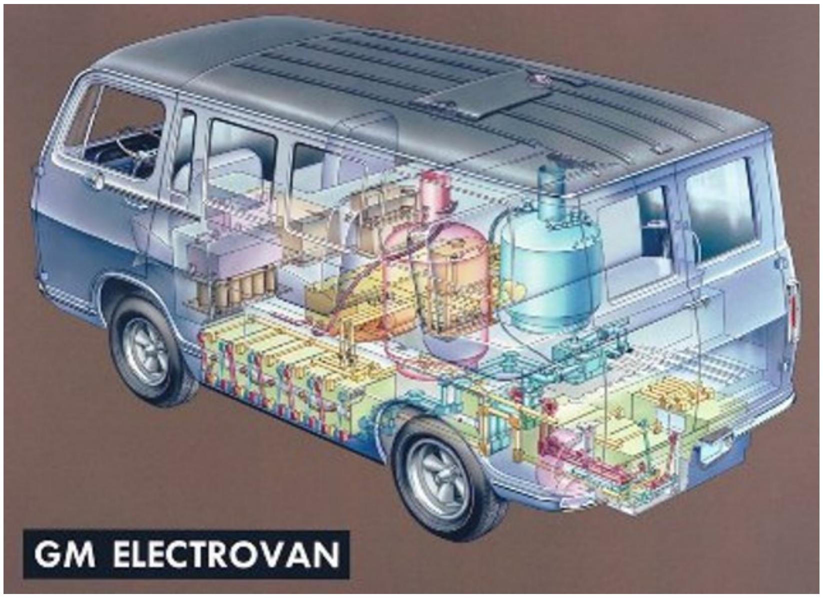
Between 1955 and 1958 several groups of chemical engineers and scientists at General Electric (GE) worked on a suitable design of a fuel cell to generate electricity for the spacecraft of the near future. The first Proton Exchange Membrane (PEM) unit was a result of this research, credited to Willard Thomas Grub. Over time, Leonard Niedrach refined the PEM-type fuel cell by using platinum as a catalyst on the membranes. The 'Grub-Niedrach' fuel cell was further developed in cooperation with NASA, and it became the first commercially used fuel cell in the Gemini space program.

The aircraft and engine manufacturer Pratt & Whitney took a different approach in the early 1960s in developing fuel cells. They obtained a license for the patented 'Bacon cell'. To reduce weight and complexity, P&W modified the original design and strived for a longer useful service life than the GE system had shown. Consequently, NASA has used the P&W alkali fuel cells on the Apollo Moon mission and on into the present time with the Space Shuttle flights.

In 1959 P&W also first built the hydrogen-fuelled RL10 turbo rocket, which proved so reliable that it was successfully used for more than forty years.

Even though this surge of fuel cell development and use of H^2 as a fuel brought excellent reliability to this new technology, development work for more 'down to earth' applications, and a wider field of function, took a backseat to the more "glamorous" exploits in the sky. What is happening in outer space seems to be more interesting, than what goes on in someone's backyard.

That is exactly where General Motors tested the first earthbound, - I better say "road-bound" – vehicle, remembering Allis-Chalmers' farm tractor. In 1966 General Motors, together with Union Carbide, experimented with a hydrogen-fuelled, fuel cell powered 'Electrovan', with the cells directly energizing the electric motor – batteries not included. (Is this where that started?) As many other 'firsts', it was rudimentary, unreliable, and the van was only tested on the back-roads of factory properties for safety reasons. From the few publicly available reports, we can read between the lines that the technology was not yet ready for the road. The project was soon abandoned, nevertheless, it was another "FIRST".



Phantom drawing of the 'Electrovan'. Early installation of fuel cell apparatus left room for only driver and one passenger. At a weight of 3400 kg the van's Union Carbide 5 kW cell was fuelled with liquid hydrogen. The Electrovan had a range of 200 km and a top speed of 105 km/h. Its operating time was sometimes prolonged to several hours, fuel cell life was only 1000 hours. Illustration courtesy of General Motors.

Forty years later, General Motors is now proudly presenting their 'Electrovan' together with its recent models of FCV prototypes at the show "Propulsion after Petroleum" in one of the better known automotive museum in the 'States, the 'Petersen'.

Back in the'60s, the Austrian-born Dr. Karl Kordesch, one of Union Carbide's researchers, was associated with constructing the Electrovan's power-plant. An eminent battery specialist with many, many patents to his name, he continued to refine the alkaline fuel cell. In 1967 he attached one to a moped, which he used to travel around town.

Dr. Kordesch on his way to work in Boston. Original Union Carbide caption: "It looks like an ordinary motorbike but there's no internal combustion engine and there's no noise. The machine, which is powered by a hydrazine-air fuel cell system, was built under the direction of Union Carbide's Dr. Karl Kordesch (pictured), a pioneer in fuel cell development. Dr. Kordesch has run up over 300 miles on the motorbike which can do 25 miles an hour and can travel 200 miles on a gallon of hydrazine." Illustration courtesy of the Union Carbide Corporation.

In 1970 Kordesch took his Austin A 40 and used it as an FCV "mule", today's term for experimental prototype vehicles. He sacrificed the Austin's trunk to hold the fuel cell, and six roof mounted tanks held the hydrogen at a much lower pressure than what can safely be used today. He installed a group of lead-acid batteries in the engine compartment, under the bonnet, as the British say. With that, the "Austin FCV" had a range of about 300 km (180 miles). Kordesch drove that Austin on a regular basis for three years, commuting to and from work, going shopping, being looked upon and tolerated by the public as just another 'mad scientist' in his home town of that time.

A battery of batteries under the bonnet (hood) of the Austin A40.
Illustration courtesy of the Union Carbide Corporation.

As an electro-chemist and physicist, Dr. Kordesch is as familiar with hydrogen and fuel cells as anybody could ever hope to be. He was the first person to drive an FCV on public roads – a generation ago. Such is the complex nature of the simple hydrogen element and the engine of the 21st century, that after all this time we still do not have hydrogen-powered fuel cell vehicles in our driveways.

Visible in the 'boot' (trunk) is the fuel cell installation and the six roof-mounted hydrogen tanks. Illustration courtesy of the Union Carbide Corporation.

A true 'citizen of the world', Kordesch is in high demand in his home country, where he leads University research teams. After working at Union Carbide in the United States, he founded Batteries Technologies Incorporated in Toronto, Canada, and later Kordesch & Associates, a consulting company. His expertise now benefits the Canadian Research Council, the European Space Agency, the Dornier aircraft company, Siemens electronic supply company, Austria's Graz Technical University and many more.

In 1973, the priorities of industrialized nations around the globe changed in a monumental way: How to live and work without precious petroleum.

The oil embargo, the second oil crisis, got the better part of the world to think about how to manage its affairs with less and less of this geologically and politically unpredictable resource. Governments, companies, researchers and environmentalists looked seriously for alternative solutions. Visionaries contemplated how to keep the world moving without oil.

The term "Alternative Fuels" was coined and made headlines. By this time, air pollution from ever increasing industrial and transportation sources had increased to such an extend, that it started to present health problems for humans, animals and for nature itself.

One 'voice in the desert' spoke out; actually, it was on an island, Iceland, where Dr. Bragi Arnason proposed in 1978 to make his country a society completely powered by hydrogen. “Professor Hydrogen” has been on a three-decade crusade to utilize Iceland’s natural power source, the geo-thermal, or hot springs, to produce hydrogen. Over time, he has been able to convince the Shell oil company and DaimlerChrysler to assist his small country to convert every car, bus and boat to be powered by hydrogen. Iceland seems well on its way to become the world’s first hydrogen economy.

Dr. Arnason claims that Iceland’s future will look much like its past: "When the Vikings settled in Iceland, they used only renewable energy like wind, sun and wood. The Icelanders were the 'first solar-energy civilization' -- and so was the whole world. Now we are finding our way out of the fossil-fuel era, back into the 'second solar-energy civilization.' And, in the end, the same will also be the case for the rest of the world."

A modern FCV prototype in front of one of Iceland’s geysers.
Illustration courtesy of the Reykjavik Tourism Information Office.

Kert Davies of Greenpeace responded: "If they can demonstrate that an economy run on renewable energy is viable, it will be an enormous precedent for the world to follow."

As we know at the end of 2006, Iceland has made huge progress to achieve that goal, and the rest of the world is trying to follow suit.

At long last, during the two decades of the 1970s and 1980s a huge research effort got underway to identify new materials and to find new fuel sources for the “Engine of the Future”, as the all but forgotten fuel cell is now being thought of.

Because of the after-effects of the oil embargo, researchers checked past records and remembered the potential that hydrogen and fuel cells seemed to have promised; the current predicament required immediate and drastic action.

We all are aware of the shortcomings of our present, internal combustion, engine. Pollution control systems on new cars are becoming more complex as time goes on. Regulations are becoming more stringent every year, as global warming has a noticeable effect on our climate, and pollution is affecting our health. And oil reserves are dwindling, due to the insatiable appetite of the omni-present “infernal consumption engine”.

As fast as it is possible to change the habits of society – and you know how fast government functions -- scientists and engineers around the world are now under pressure to find a remedy for our “oil addiction”. They remembered that hydrogen had already been used to fuel Lenoir’s engine in 1860.

At the time when Dr. Kordesch ran his fuel cell Austin, and Dr Arnason called for the use of hydrogen, a Canadian, Dr. Geoffrey Ballard, was working as the head of the United States Federal Energy Conversation Research office in Washington. In his youth, he had been exposed to chemistry and electricity; his father was an electro-chemist in Niagara Falls, Ontario, and Geoffrey had earned a Ph.D. in geophysics in the USA.

At the height of his carrier, he quit, when the US Congress disregarded the seriousness of finding ways to reducing oil consumption. In 1983, Ballard returned to Canada, formed Ballard Power Systems, and with two younger partners won a contract from the Canadian Military, to research new, exotic forms of power. With engineer Paul Howard and electro-chemist Keith Prater, the team worked to make fuel cells lighter, smaller and less expensive. Eventually, they realized that this technology could be used in earth-bound vehicles at a future date.

During the 1970s and 1980s many auto companies started to convert engines to burn hydrogen. They had been reassured by a second well-trusted official agency of the safety of hydrogen. The Los Alamos National Laboratory, under Walter Stewart, had concluded that “hydrogen storage and refuelling of a vehicle can be accomplished over an extended period of time without any major difficulty”. The laboratory had modified a 1979 Buick, and scores of people had refilled the car over a three-year period at a self-serve liquid hydrogen pump.

A very hectic period of trial and error had started, and we will look at various manufacturers and models in detail in the next part.

As you can gather from the foregoing, it is not just a simple matter of filling a tank with hydrogen to run an engine, or engineering a fuel cell stack and bolting it into a vehicle. In hindsight, it is astonishing how infinitely complex this very simple element, H_2, seems to be, requiring almost two hundred years of experimentation.

Surely, study and advancement will continue. Many branches of learning and diverse occupations must come together to shape an innovative industry, a new age and a unique new, ’green’ society.