FUEL CELL HISTORY, PART ONE

George Wand

Foreword

We all get the latest facts and figures about this phenomenon from around the world at “FUEL CELL TODAY”.

On the other hand, what about yesteryear’s information? When, where and why did it all start? Who was involved? What happened along the way?

First time visitors to this site, as well as those deeply involved in this new industry, may well discover historic facts or retrace the chain of events that paved the way to the present state. Apropos paved, the omnipresent automobile is the most likely “vehicle” to “drive” fuel cell development forward. But fuel cells can do so much more than power a vehicle, as we’ll encounter.

No need to know chemistry or engineering; young and old will gain clear insight into this fascinating new era of abundant, “green” energy with the potential of a future without pollution. We often hear the term ”Sustainable Mobility”; For the future hydrogen and fuel cells have the promise and possibility to succeed the horse and oxen of the past, which is the internal combustion engine of the present.

Fuel cells also have the potential to supply electricity to power a wristwatch or a large city, replacing a tiny battery or a power generating station.

In easy to understand language, this series intends to inform and entertain one and all about the surprisingly long history of fuel cells and hydrogen as a fuel.

Abbreviations:

CVT	= Continuously Variable Transmission
EV	= Electric Vehicle
FC	= Fuel Cell
FCT	= Fuel Cell Today, authoritative news website on the subject
FCV	= Fuel Cell Vehicle
HEV	= Hybrid Electric Vehicle
H2	= Hydrogen
ICE	= internal combustion engine
l/100km	= liters per 100 kilometers
Mpg	= miles per gallon
O2	= Oxygen
PEM	= Proton Exchange Membrane
PhD	= Doctor of … (engineering, chemistry, and so on)
SUV	= Sport Utility Vehicle

Fuel Cell History, Part 1

Turbulent Times

April 2006. I'm gettin' gas pains. This is no April fool's hoax. This is serious. Crude oil has topped seventy-five US Dollars ($ 75.00). "Gas" (petrol) causes financial pain at the pump. Fuel set a new record, but not one to commemorate.

Optional fuel gauge for SUV; No explanation needed. Source unknown

Regrettably, someone reading this a few years from now might wish for the good old days of cheap oil. Tensions between some oil producing countries and The West are at an all time high. The quest for alternative fuels is proceeding at less than cruising speed, and in different directions. Billions of dollars have been spent for this purpose so far, and some companies in the pursuit of new ways to power our transportation systems are running short of resources.

As demand for petroleum products rises and crude oil supplies diminish, Jane and John Motorist, representing all of us, cry out under the burden of ever increasing fuel cost. Your boss will not give you extra "petrol pennies" for driving to work. Big companies such as airlines, shipping companies and the like require a fuel surcharge to survive. Oil corporations make huge profits while car companies have record losses.

With all the progress and refinements made on internal combustion engines (ICE), it is hard to give good reason for the fact that a certain popular SUV (sport-utility vehicle) is less fuel efficient at 16 l/100km (16 mpg) then the Model T Ford, which achieved 10 l/100km (25 mpg) almost a century ago.

Poor motorist! Despite the certain fact that the world will “run out of gas”, fuel efficiency has not kept pace with other progress. Is it any wonder that we long for a new, better way to power our vehicles and heat or cool our homes? Alternative fuels as a group hold great promise for the future, but none more so than hydrogen as an energy carrier to power fuel cells of various types.

The decade old promises of hydrogen fuelled transportation, fuel cell powered appliances, homes, offices and factories, in short, the Hydrogen Economy, is taking a long time in coming. Nevertheless, progress is made on a daily basis and in every imaginable place.

Even though Detroit is “just down the road”, Canadians should be proud of their contribution to the advancement of fuel cells; After all, Geoffrey Ballard is the one who really “got things rolling”; others almost “missed the bus”. These quips will become clear as the story unfolds.

“Detroit” springs to mind when thinking “fuel cell”. The automotive industry is among the world’s biggest and the most visible. Their fuel cell powered concept cars are the most obvious expression of things to come, on display at auto shows everywhere on Earth.

We also have to look at hydrogen’s promise and potential from the view of other countries. Not only North America, Europe or Japan, the major auto producing countries, but also African nations will benefit, and all others countries around the world. Iceland is striving to become the world’s first full hydrogen economy. One of the smallest countries, it has progressed perhaps the most. Having written about the awakening auto industry in China and India, I understand their approach as well.

Canada has recently announced a partnership to promote public education of fuel cells and hydrogen matters by establishing “Hydrogen Villages” here and in Wales, UK, the place where it all started. A Hydrogen Village is a combination of related infrastructure and demonstration vehicles for educational purposes. More on that later.

Not a Hydrogen Village – but a Danish concept of a hydrogen city of the future. (source unknown)

Confusing Times

What makes a light bulb glow? Many people will answer that question with “Hydro”. “We are running out of gas”, laments the American motorist. Both statements are a gas, an idle talk.

We are in such a hurry that we abbreviate much of what we say. The true meaning of things gets twisted that way. For the moment we have forgotten the origin and the history of what came before. Has the pace of modern life accelerated so much that we have already lost sight of what we learned in earlier times?

“Gas”, short for gasoline of course, is a liquid in North America. It is petroleum or petrol in other countries and in the land of Karl Benz, it’s Benzin. Hydrogen (H_2) and Oxygen (O_2) are a true gas separately, but when united with other gases they are a liquid, -- water. Why is life so confusing?

The light-giving “hydro” is electricity, generated at hydro dams, at the front of the water-storing reservoirs. Like so many other terms its meaning has changed over time, already removed from common memory; out of sight – out of mind. Clearly, electricity is also generated in various ways other than from hydro power.

And the ‘newest’ automotive technology breakthrough, creating its own electricity onboard in hybrid electric vehicles (HEV), is not new at all, and neither are fuel cells. From the beginning of the twentieth century to the 1920s, electric automobiles counted for approximately one third of all vehicles, HEVs included. At that time the

majority of the population favored the non-polluting, almost silent running electric cars, but the favoritism had “batteries not included”.

Electric vehicles as a separate entity are pollution free. But they receive their electricity from generating stations during re-charging. Many of these plants, other than the water powered ones, are serious polluters, as we all know.

Many cities look similar to this (unknown source)

On top of this problem, and despite all the progress made during the last century, electric vehicles (EV) are limited by their short driving range of between 80 and 200 km and the long time needed for recharging. Both are considered barriers to the EV’s progress and are related to the type of batteries used, the weight or load of the vehicle and other factors. Cold weather will further limit the useful range of an EV. The heater and defroster needed just under these conditions render the “old style” lead-acid battery almost useless for half of the year in propelling electric cars, especially in very cold climates. EVs usually need 6-8 hours of recharging, perhaps acceptable for fleet- or commuter vehicles, but certainly not for general use.

Paradoxically, the advent of the electric starter in engine-powered vehicles caused the end of the electric cars. Cranking an already “cranky” engine was no longer necessary, and petroleum had become widely available.

Without a doubt, the battery bears the brunt of the blame for the lack of progress to this day that could have advanced EVs to the forefront of transportation. What if there was an easier way, a better battery, to power EVs, and to keep laptop

computers working longer, to enjoy more melodies on the move, or to light, heat or cool human surroundings? Perhaps a “gas battery”?

Confusion seems to run rampant in this introduction.

Is uncertainty not the order of our time? “We are running out of oil to sustain our industries and our way of life”. “There is enough ‘Black Gold’ in the ground for generations to come”. “Nuclear energy is the future”. “Clean coal will prevail”. “We have to go electric”. Solar power, thermal power, wind power, fusion, fission… “The hydrogen economy is the way of the future” energy experts assert. “China and India invests in Canadian oil sands to advance and secure their mushrooming economies” the business papers report.

Lack of confidence reigns supreme in nations around the world. Should the government go ‘right’, should it lean ‘left’, should it turn “green”? Which energy policy should be promoted? Nature itself seems uncertain of where to go. Observe a river turning left and right, snaking back and forth across a valley. Yet, Mother Nature perseveres and wins in the end.

Nature has provided us with all the potential energy known to us – and more soon to be discovered. We just have not yet sufficiently learned how to make it all work for us. “We get too soon old and too late smart” as individuals, but as a society we have the collective smarts, that anybody with a keyboard can tap into. The information age should give us the opportunity to sort out what is best for all the species that depend on the Earth for survival.

“We are addicted to oil”, a first-namesake leader now admits. Being addicted to anything is bad news. Sparingly used at first, petroleum products later became ‘a way of life’ and now almost dominate most industries. Habitual use has eventually become our ‘addiction’ to pollution-causing hydro-carbons. It has allowed the western world to climb out of the agricultural age, and allowed large companies to rise to riches. Any excess or addiction is abnormal; our dependency on oil has caused pollution, global warming, strife between nations and misery.

“You can’t change what you don’t acknowledge”, well known TV psychologist Dr. Phil proclaims. Of course, we all know this only too well: recognize the problem and seek a solution. But it should be helpful to reflect on all of this, before exploring in more detail the one combination we now think will eliminate many of our present problems, be they ecological, economical or even of a social character.

Let’s be optimistic and try hydrogen, the carbon-free energy carrier, as our next step in the evolution of society. Humanity has advanced from the stone-age to the next age not because of the lack of stones, but because a better way was discovered. We are now on the threshold of advancing to the hydrogen age, not because we are running out of specifics from the current information age; on the contrary, we have gained insight into a better future.

Should we blame the “infernal consumption engine” (ICE) for all of our present problems, because we changed its diet from hydrogen to petroleum as an infant, and it became gluttonous in adulthood? Or should we blame ourselves for another example of human ignorance and confusion?

It may have already come to light that this fuel cell history is written with a leaning towards motor vehicles, because that is my occupational background. Though officially retired, my passion for automobiles and my keen interest in the progress and future of all means of transportation compels me to keep up to date. Weekly automotive newspaper columns since 2002 have made it a routine for me to search out new technology and keep files of related material. Frequent e-mail up-dates from major manufacturers make that chore an easy task. My “Fuel for Thought” articles report on the future and connect with the past.

Before delving into the emergence of fuel cells and their diet, we should explore the history leading up to their surfacing. In this context the steam engine, and later the internal combustion engine with all its variations should not be forgotten. After all, it is the shortcoming of all heat engines that has led us (back) to the electric motor and its care and feeding.

The imaginative Roger Bacon (c.1214–1294), also known as Doctor Mirabilis, already wrote about “wagons which move with unbelievable speed without draught animals”. Of course, that was a long time coming.

For some years I have followed hydrogen related news in FUEL CELL TODAY, and at other sources since 1986. (not quite the middle-ages) This has kept me abreast of specific developments. Obviously, the reports in FCT cover the present; the emphasis is on news; for that reason I offered to ‘connect the new with the old’.

I recently had the good fortune of having been invited to a fuel cell seminar at the Hydrogenics Corporation in Toronto. This awarded me a first hand look at the emerging fuel cell industry and hydrogen economy. Hydrogenics is one of the major Canadian ‘all under one roof’ hydrogen research, production and testing firms; another one is Ballard Power Systems. Hydrogenics develops fuel cells for a variety of applications for General Motors and other companies. Having driven all manner of fuel cell vehicles (FCV) at Hydrogenics’ headquarters, I can say: “been there, done that, got the T-shirt”. In spite of my preoccupation with vehicles, I will try not to neglect historical information about the other types of fuel cells, where relevant; Hydrogenics offered a glimpse at them as well.

Much of the detailed information of the automotive pioneers’ daily progress, or struggles, even a scant one hundred years ago has been lost. Personal experience in researching the history of a rare 1902 ‘auto-buggy’ for a nearby museum has revealed this to be an extremely difficult undertaking. I advise the reader to be aware that some of what you may find here could differ from your own know-how. You will stumble across an example or two of this later on. I would be grateful for having my data enhanced with new pieces of evidence.

The information age has helped immeasurably to bring together bits of data from a diversity of resources. This in itself creates the possibility of obtaining conflicting results. You will find examples of this as we go on. Irregardless, it makes it infinitely more efficient to assemble a story such as this, without spending tedious days at the library.

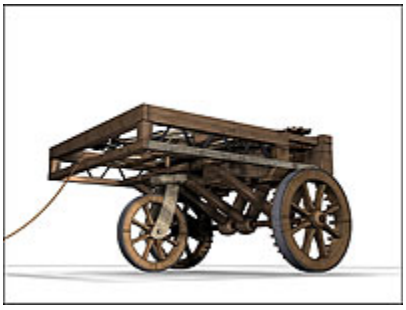
Most fuel cell information is less then one decade old. A seemingly new invention, the fuel cell in reality is older than the battery as we know it. And hydrogen as a fuel was used long before petroleum, at the time when pioneers experimented to harness the power of coal dust and other previously unknown forms of energy.

Early Times

Heat and light for human habitation has been available in various forms for quite some time, but the urge to have some-"thing" else do the heavy work for humans, other than animals, became a serious pursuit during the middle ages.

A brief foray into the early history of engines, motors and "autos mobilis" ("self moving" from Greek and Latin words) will suffice to refresh our memory. Let's skip steam power; engines and motors are of more concern at this time and for this sequence of articles. Also, a few dates important to this topic will follow to illustrate how slowly science and technology progressed in previous centuries, and how rapidly – comparatively - we advance as more basic knowledge is available in recent times.

It is now accepted that Leonardo da Vinci put together the first "automobile" in 1478 – as well as sketches for a continuously variable transmission (CTV). Steam and internal combustion engines were first tried in the 1600s.



A replica of da Vinci's vehicle with programmable steering; the rope acts as a remote control to release the brake, whereupon the wagon travels up to 40 meters. Illustration by the da Vinci Museum.

The early scientist Boyle (of late) published information in 1671 about "flammable air" [gas] that originates when metals are exposed to acid; that's high school "chemistry 101" in today's time.

Christian Huygens, a Dutch physicist, is credited with having the idea in 1673 of using the power of dilation (expanding gases by heat), thereby moving a piston in a cylinder. He sketched an internal combustion engine in 1680, but never built one.

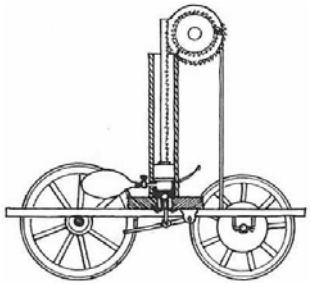
Henry Cavendish isolated and extensively studied hydrogen around 1766. About twenty years later Antoine Lavoisier split molecules of water into hydrogen and oxygen, and then recombined them to make water again. (Additional research into his method would go beyond the scope of this piece about the history.)

French-born officer Francois Isaac de Rivaz retired to Switzerland after his term of duty and at first experimented with steam powered vehicles. In 1807 he fashioned a combustion engine and mixed various gases to explore their combustibility. Rivaz used a mix of coal gas, air and hydrogen for his experiments.

Voila, the earliest use of hydrogen as a fuel.

The French Patent Number 731 gave Rivaz title to the use of combustible gases, instead of steam, in a piston type engine. The combustion pushed a heavy piston upward in a cylinder. Atop the piston is a toothed rod that engages with a gear wheel on its way down. In turn, the gear wheel uses a pulley and rope system to drive a vehicle's road wheels.

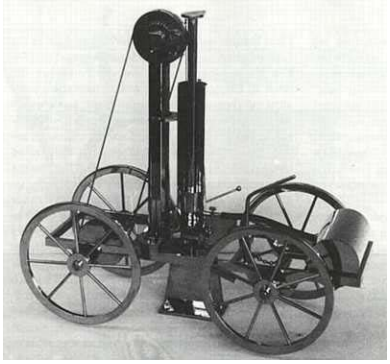
In 1813 Rivaz drove an "auto-mobile" with this engine, fueled by hydrogen gas from a balloon. He initiated 25 combustions with a hand-held igniter in succession and the wagon traveled a few hundred meters. This little know event was the first time in history that a vehicle was set in motion by an internal combustion engine, and the first time hydrogen alone was used as a fuel; The first H2-powered ICE vehicle on record. But clearly, this prototype needed a little more development before mass production could begin.



The sketch Rivaz included with his patent application, showing the H2 balloon.
(Wikipedia illustration)

The first time an ICE was used in an industrial application occurred in 1823. Samuel Brown, an English engineer, developed and patented a new version of combustion engine. He filled a closed chamber with a gas flame to expel the air; he then “condensed the flame by injecting water, and so operated an ‘air engine’ by exhausting into the partial vacuum obtained”. He got the idea from James Watt's condensing steam engine. Brown's engine was in use to pump water, propel a boat on the River Thames and also drive a road carriage. Ten years after Rivaz, Brown designed an engine that also used hydrogen as a fuel. In a test the engine pushed a vehicle up Shooter's Hill in London in the following year.

It is hard for us to comprehend how much trouble these pioneers went through to accomplish what we take for granted; no knowledge of which materials would stand up to the temperature and pressure of combustion; what fuel to use to allow controlled, rather than spontaneous, combustion; how to solve the lubrication requirements of high speed friction. (The 1902 auto-buggy mentioned above has leather wheel bearing lubricated by animal fat; normal for that time, but unimaginable by today’s young minds.)



A replica of the first vehicle powered by a hydrogen-fuelled internal combustion engine by Rivaz.

From the 1820s to the 1860s, in the industrialised world of the time, inventions and patent applications transpired yearly, trying to improve the usefulness of engines and their components.

As mentioned before, historical accounts of the time, even in the most industrialised countries, are a little vague at best. My research found three pioneers being credited with inventing the electric motor: Zenobe Theophile Gramme in 1826, Michael Faraday in 1831 and Thomas Davenport in 1834.

In the 1830s, the exact year unknown, Robert Anderson of Scotland developed the first electric carriage. It was driven by rechargeable batteries which powered a small electric motor. Those batteries were very heavy, expensive, and the vehicle needed to stop all too often for re-charging. Another fifty years of trial and error, guess and go, success and failure, were needed until the French Gustave Trouve introduced a more or less acceptable electric “automobile” in Paris in 1881. (That now universally familiar term was only later coined by the French.)

Looking back in history, during these years many keen inventors made countless bold attempts to free themselves from the horse and wagon mode of transport. But it was more a matter of coming up with new ideas based on their curiosity, or creating gadgets for their own convenience, than to set up a new industry; far too many details remained unresolved for too many years for that to happen.

In retrospect, perhaps the most significant historic event for transportation, for industry and possibly for humanity, conceivably the “crack of dawn” of a new age

came to pass in Wales, a part of the United Kingdom, in 1839. That year is regarded as the birth date of the fuel cell, and Sir William Robert Grove is considered the “Father of the Fuel Cell”.

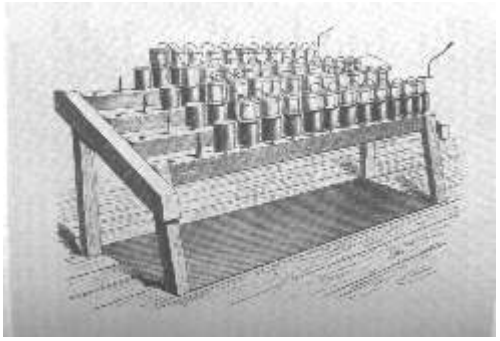
Sir William Robert Grove

This noteworthy event, though, was unrelated to electric motors or combustion engines; more or less a “mishap of science by design”, an origin shared by many other great products.

While a few learned people of that time knew of the principle of electrolysis and creation of gases, they did not use this knowledge for any practical purpose. Some years prior, in 1802, Sir Humphrey Davy had fashioned a simple gadget that could create a mild electric sensation when touched. He did not document his experiment to any degree and it was soon all but forgotten.

In January of 1839 the German/Swiss chemist Christian Friedrich Schönbein wrote an article in one of the scientific magazines of the time about his discovery of ozone and about the reaction of hydrogen and oxygen. But it was no other than William Grove to document just one month later, in February of 1839, his observations in the "Philosophical Magazine". He had conducted a series of experiments with his second invention which he termed a "gas voltaic battery". He explained the possibility of the creation of electricity by the reaction of hydrogen and oxygen. Grove later presented his invention in all its details. He had established that, when running an electric current through water, it would split this into hydrogen and oxygen. He reckoned that, if it worked one way, it should also succeed in reverse. To prove his theory, Grove built the world's first “fuel cell”.

William Robert Grove (1811 – 1896) had studied law. He also studied chemistry ("natural science" at the time) and was a professor of physics at the London Institute from 1840 to 1847. He demonstrated his first invention, a platinum-zinc battery by using it to light up one of his lectures. His scientific and legal background led him to work as a patent attorney and as a judge. Grove was knighted in 1872.

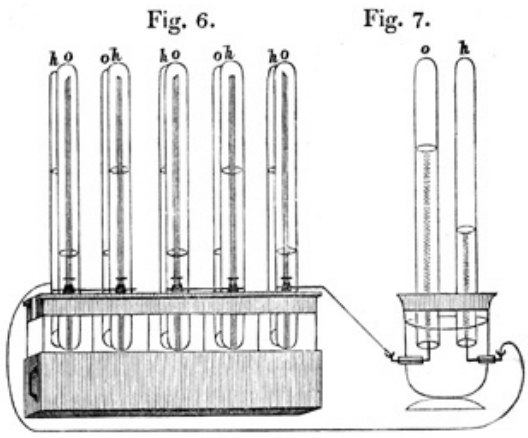


Grove's platinum-zinc battery

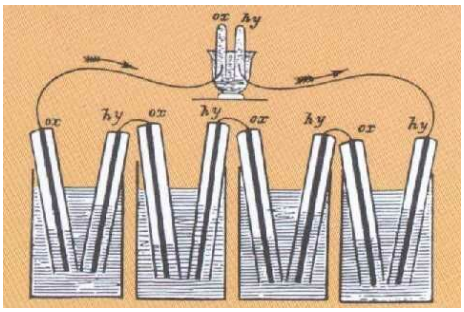
Grove's experiments had proved that electric current could be produced with hydrogen and oxygen. His questions about the by-products of that process -heat and water- could not be answered with the equipment of that time, and with the chemical theories known a century and a half ago. Later researchers would have to solve those puzzles.

Much less did anybody know at that time what to do with an invention such as this, a Fuel Cell. No practical or commercial application was to be found for more than a century. Totally useless in its time.

But what a blessing it is, to be able to fall back onto such an invention at this critical time for the future of nations and nature.



Sketch of Grove's experiment of separating oxygen and hydrogen from water



Another sketch of the gas battery's operation.
Why are today's inventions so much more complex?

You have to wonder what the multi-talented mastermind of William Robert Grove could have accomplished in the right time at the right place; what a creative genius like Leonardo da Vinci could have designed, had he worked for General Motors or General Electric. The great imaginative thinker Albert Einstein was born at the right time, lucky he, being understood and appreciated.

In part 2 we will get to know a few more of the persons that played a major role in bringing the fuel cell to the point where practical applications could begin, and we'll explore the first usage of what hopefully soon will be as commonplace as … (your choice of word) Work with me here, imagine, dream, invent, create, construct, bring thought and skill together. Always.

P. S. I ask for clemency and absolution from FC aficionados in case of using illustrations without quoting the source; in my enthusiasm I may have forgotten to take note of this. If you contact me I'll give credit where due. Thanks.

Illustration sources: #6 to #10 by Wikipedia Encyclopedia

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Hydrogenics Corporation / Stuart Energy Systems

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