White Paper on

Quantum Parallel: The Saint-Hilaire “Quasiturbine” As The Basis For a Simultaneous Paradigm Shift In Vehicle Propulsion Systems

An entry into the “Post Piston Engine Era” for Optimum Efficiency and Environmental Benefits

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In the context of the international environmental and resources depletion discussions such as the Kyoto Accord, and taking into account the general population conviction that climate changes are currently endangering our planet, there is a new sense of urgency mandating that no energy technologies can be discarded, and this is particularly true of any sound engine concept breakthroughs. The Quasiturbine technology is among the very few energy and environment tools we have to address our present concerns, and one precious new means available to improve our vital collective objective. It goes without saying that acknowledging its existence may fall into the realm of a social obligation. – The Author

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for their contribution and collaboration to this analysis,
and their help in making the French translation available.
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**He would also like to dedicate this work to his Father,
scientist and inventor Rufus Stokes, whose development
of advanced pollution control technology garnered him a position in
The U.S. Department Of Energy’s presentation “Pioneers In Energy”
http://www.eia.doe.gov/kids/pioneers.html.
His family is gratified and humbled that he is included in this compilation of the works and efforts
of some of the greatest scientists, inventors, and innovators in history.**

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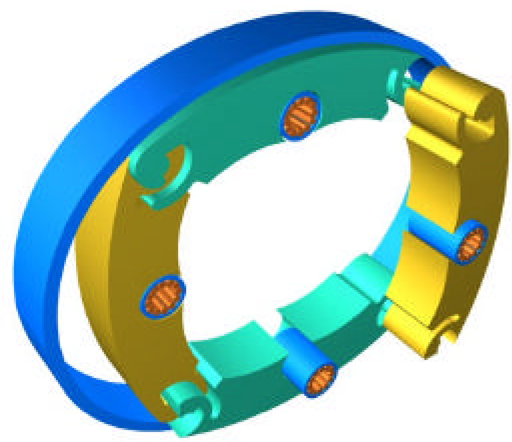
I - Introductory analysis

The Piston engine perhaps unquestionably, has been at the center of mechanical energy conversion for almost 2 centuries and as such, has been a pivotal technology in our development and transformation into a modern society. But why are piston engine replacement attempts representative of such a long sequence of failure? Is it so difficult to do better? In this vein, human intellect has managed to create at least 3 obstacles: First, sine wave crankshaft motion has been long assumed as the best way to convert linear motion into rotary motion, and was never questioned. Second, the historical record shows that early internal combustion engine concepts were first "ad hoc proposed" and later built and tested, rather than being conceived for a specific solution (Otto engine historians may differ with this view). Third, our great theoretical physicists had a preference for atoms and cosmos, and they completely overlooked the need for engine theory and concept design guidelines.

Recent research efforts by the Saint-Hilaire family directed by Gilles Saint-Hilaire, a Ph.D. in thermonuclear physics, have followed a very different modern computer approach wherein conventional engine characteristics were mapped against optimum physical-chemical characteristics, and subsequently demonstrating that all considered present engine concepts were off optimum in some respects. The Quasiturbine engine [1] conception has been developed from this optimum desirable characteristics table and has succeeded, at least theoretically, to optimize simultaneously the 14 most important engine parameters, including compatibility with the revolutionary photo-detonation mode (knocking) [2] which the piston cannot effectively tolerate. When taken together, these various improvements increase fuel efficiency, while simultaneously reducing exhaust emissions.



The simplicity of the Quasiturbine concept

Is the future a matter of breakthroughs? If few experts are expecting near-term major fuel cell improvement, the photo-detonation process utilized within the internal combustion engine qualifies as a major expected breakthrough which could save half the gasoline now consumed by vehicles, along with substantial environmental benefits. It is no surprise to experts in the field that a recent March 2003 MIT report [3] reached the following conclusion: *"Improving gasoline and diesel engine is the way to go. The Hydrogen car is no environmental panacea: The hydrogen fuel cell will not be better in terms of total energy use and greenhouse gas emissions by 2020".* With photo-detonation, the internal combustion engine is likely to become most fashionable again.

In ways not dissimilar to the para-pente or the delta-plane, the difficulty of the Quasiturbine is in its concept, not its construction. Unlike the Wankel rotary engine [4], the Quasiturbine has a four-face deformable rotor which solves the theoretical Wankel flaws at the base of certain functional inefficiencies, and provides new engine characteristics compatible with photo-detonation in the long term. The Quasiturbine is also compatible with the Otto and Diesel modes, with substantial benefits over current piston engines. Several proof of concept Quasiturbines have already been built and pneumatic educational prototypes are already marketed by *Quasiturbine Académique Inc.* [5]. Although this invention is quite recent, development has already produced the engineering design solutions for commercial products.

II - Engine combustion modes

If you ask a chemist the absolute best way to burn fuel, he (she) will tell you about photo-detonation... For the past 10 years, several engine research labs have been essentially trying to control the thermal ignition in piston machines, and none have yet succeeded. An informative report about on-going research at GM and Ford can be found in *Scientific American* [6]. Other information is available at [7].

The Otto engine mode requires compressing a fuel-air mixture (not pure air). Intake air pressure is controlled by the throttle valve, thus maintaining a vacuum in the intake manifold to properly mix air with a small quantity of fuel introduced. Consequently, the Otto mode is a near-stochiometric engine. As a result, it cannot create an efficient photo-detonation mode because of low intake vacuum pressure, which when compressed, cannot generally provide the amount of heat and temperature required for photo-detonation. Also, the near-stochiometric combustion temperature would also be too high.

Unlike the Otto, the Diesel engine compresses pure air (no fuel mixture) at atmospheric pressure. Consequently, air temperature rises, due to high compression ratio, to such a level that most fuel injected does burn. The problem is that the fuel injected goes through the 3 combustion phases: air-excess on the exterior of the injector jet, stochiometric in mid-area (too hot)¸ and fuel-rich in the center (a situation environmentally disastrous and difficult to control...). Because the Diesel accepts all intake air, its efficiency is not reduced by the intake vacuum pumping load, as is the case with the Otto. Operationally, the Diesel can be described as an overall air-rich-engine.

Photo-detonation [2] can be considered to be the best of both modes. It is homogeneous combustion without having intake manifold vacuum load. Most piston minded experts think the research work had to go toward the "piston thermal ignition control", (possibly involving the ultra high intensity spark concept) which is not the way of the Quasiturbine. Because of its significantly shortened pressure pulse (especially for the model with carriages), the Quasiturbine compression temperature increases mainly and rapidly at the pressure tip to exceed, by far, all ignition and combustion parameters (it is little affected by the engine wall temperature or otherwise in such a short time...). The combustion is then driven by the intense radiation in the chamber and does not welcome anti-knocking fuel additives. Except for those additives which absorb the radiation and increase the octane index, recent research aims at optimizing the piston engine often use the approach of variable length connecting rods allowing the compression ratio to be continuously set just under the photo-detonation (thermal ignition) threshold, regardless of the engine regime, but without ever exceeding it. Notice that the photo-detonation occurs or follows at slightly higher pressure than the thermal ignition designated in the US as *"Homogeneous Charge Compression Ignition"* (HCCI) combustion, in Europe as *"Controlled Auto Ignition"* (CAI) combustion, and in Japan as *"Active Thermo Atmosphere"* (ATA) combustion. Even if the researchers are passionate about the subject, the thermal and photonic ignition control in the piston is still an unsolved problem, but one that the Quasiturbine does overcome by better pressure pulse shaping.

The piston is not designed for such a violent (knocking) aspect of combustion as photo-detonation, therefore, a successful machine solution must get rid of the crankshaft sine wave piston volume variation.

III - Piston Engine Limitations

The piston engine has served us well over the years and deserves our respect even when compared with new, potentially more efficient, concepts. To better understand the operational disparities between the piston engine and the Quasiturbine concepts, the following list outlines the main conceptual deficiencies which tend to limit future prospects for enhanced piston efficiency even with advanced control technologies: [2]

- **The 4 engine strokes should not be of equal time duration.**
- **The 4 stroke piston makes positive torque only 17% of the time and drag 83% of the time.**
- **At mid-stroke, the gas would push more efficiently on a moderated speed piston, as opposed to its actually escaping in front of the gas at currently permissible maximum speed.**
- **The gas flow is not unidirectional, but changes direction with the piston direction.**
- **While the piston descends, the ignition thermal wave front has a hard time trying to catch the gas moving it in that same direction.**
- **The valves open only 20% of the time, interrupting the flows at intake and at exhaust 80% of the time.**
- **The duration of the piston rest time at top and**

bottom are unnecessarily too long.
- A long top dead center confinement time increases the heat transfer to the engine block, thus reducing engine efficiency.
- The inability of the piston to produce mechanical energy immediately after the top dead center.
- The proximity of the intake valve and the exhaust valve prevent a good mixture filling of the chamber (*Swiss engineer Michael May's head design addressing this difficulty in a rather significant way acknowledged via its utilization within the 1982 Jaguar XJ-S 5.3L V-12; the May Head "Fireball" high-swirl bathtub configuration resulting in a very high level of Fuel/air mixture atomization*) and the open overlap allows some un-burnt mixture into the exhaust.
- The inability of the piston to efficiently intake mixture right after the top dead center.
- Due mainly to the valve temperature sensitivity, the piston cannot effectively cope with fuel pre-vaporization, but to produce high specific power density, it does require fuel pulverization intake detrimental to combustion quality and environment.
- The instantaneous piston torque impulse is progressive, and would benefit from a plateau.
- The component use factor is low, and those components would benefit from multifunctionality.
- The average torque is only 15% of the peak piston torque, which requires enhanced construction robustness for a peak 7 times the average.
- The flywheel needed to smooth out the torque gaps and protect the crankshaft is a serious handicap to acceleration and to the total engine weight.
- The connecting rod gives an oblique push component to the piston, which then requires a generous lubrication of the piston wall.
- The lubricant is also the main piston heat coolant, which requires a cumbersome pan, and imposes low engine angle orientations variation.
- The need for a complex set of valves, camshaft and interactive synchronization devices.
- The valves inertia being a serious limitation to the engine revolution.
- The heavy piston requires some residual compressed gas at exhaust top dead center to cushion the piston return.
- The internal engine accessories (like the cam shaft) use substantial power.
- The poor homo-kinetic geometry imposes violent accelerations and stops to the piston.
- A design inherent difficulty in addressing noise level and vibration.
- At low load factor, the intake depressurization of the Otto cycle dissipates power from the engine (vacuum pump against the atmospheric pressure).

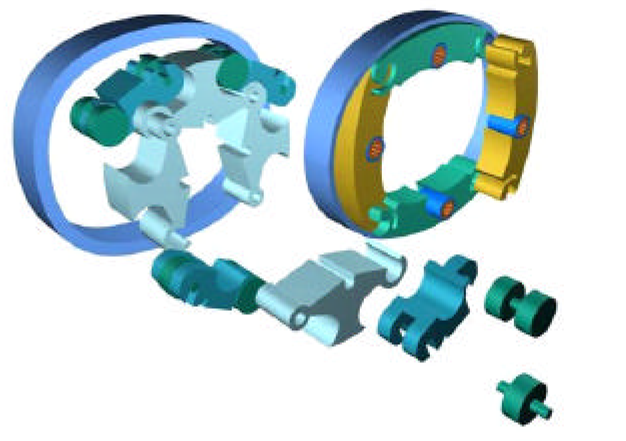
With this host of conceptual limitations, it may seem surprising that the piston engine has resisted most attempts of substitution during the last century, but this is because it has one implacable efficiency characteristic: Its expansion volume being rigorously generated by the pushing surface of the piston, which guarantees the validity of the optimum efficiency Pressure - Volume diagram.

IV - Photo-detonation Compatible Machine

Many in the past have been addressing mechanical problems with mechanical solutions. The Quasiturbine addresses more fundamental concerns for improved thermodynamic output and environment friendliness and benefits operationally through adherence to the Einsteinian ideal of simplicity. Einstein spoke *of "using the simplest thing that works, as long as it is the best thing.*" It is also said "*simplicity is the epitome of engineering efficiency*." Modern and continuous advances in all areas of technological development dictate another iteration of simplicity maxims: That "*efficiency in complex electro-mechanical systems results in simplicity of operation.*" At a time where technical complexity is no longer a synonym for marketing failure (electronic watches, complex computers, flying by wire…) simplicity in concept still seems to be a guiding success rule of our universe…

In harmony with this strongly supported postulation, the Quasiturbine looks at first like a rotary engine with a deformable rotor made of four identical blades, but because it has no crankshaft and does not follow sinusoidal volume motion, it has properties far different from the piston and the Wankel rotary piston engine [4]. These properties solve the theoretical Wankel excess relaxation volume flaws which make it less efficient, and provide new engine characteristics compatible with photo-detonation in the long term. The Quasiturbine theory optimizes the use of time by eliminating dead times, reallocating time among the different engine strokes and replacing the progressive torque impulses with impulse plateaus. This theory concurrently takes advantage of space by adopting multi-functional and homo-kinetic engine components which are indispensable at all times during rotation, and demands continuous flow at the engine's intake and exhaust. Each device in a family of Quasiturbine variants is at the crossroads of the 3 modern engines: *Inspired by the turbine, it perfects the piston, and*

improves on the Wankel. The Quasiturbine is a continuous flow engine at intake and exhaust. An engine's piston completes 4 strokes in two rotations, *the Quasiturbine completes 32*. Because it was conceived for thermal and photonic ignition, the Quasiturbine cannot be considered as a "rotary piston engine", *nor be correctly characterized by the piston paradigms*. Note however, that the Quasiturbine can be operated at lower a compression ratio in standard Otto and Diesel cycle modes, with substantial benefits as well.



The Quasiturbine concept
includes a wide family of options.
This figure shows a design AC
with a rotor supported by 4 carriages
and a different configuration SC
where the carriages are totally absent.
Notice that the central shaft
is not required for engine operation,
which allows direct insertion
of a generator or other device shaft.

The 4-stroke piston within car engines fires once every 2 revolutions and produces a positive torque about 17% of the time, dragging 83% of the time. To obtain a reasonably specific power density, we must use the combustion chamber as often as possible in every minute, which means rotating at an undesirably high regime, where it is difficult to avoid the limitations due to gas flow and valve inertia. The high rpm also imposes constraints which require a reduced piston course, and which call for a reduction of the crankshaft diameter and a reduction of the engine torque. Consequently, there is a more severe need for the gearbox and other kinetic aspects like the flywheel, which severely reduces the engine acceleration.

The Quasiturbine allows solving that dilemma by two unique characteristics (and they are not the only ones), which are:

- First, by firing 8 times by two revolutions in four stroke mode, which allows the use of combustion chambers much more often without having to increase the engine rpm, and without facing the fast gas flow problem, nor valve inertia since there is none.
- Secondly, it produces shorter pressure impulses with linear ramps allowing more precise self-control of the thermal and photonic ignition phases, and to overcome the obstacles limiting the high engine compression ratio, thus increasing efficiency, while maintaining the uniform combustion capability and simultaneous reduction of pollutants.

Since the combustion is initiated by the radiation and the pressure pulse is much shorter (particularly for the AC model with carriages), the shape of the combustion chamber and its Surface / Volume ratio has little effect here in such a short time, contrary to the case of the piston. In fact, the high ratio helps attenuate the violence of combustion.
Continuous intake and exit flow make better use of intake and exhaust manifolds, and allows a reduction of weight and volume of the engine by a factor 4. For over 50 years, researchers have been dreaming about the perfect engine; one which has uniform combustion, with a small combustion chamber (high compression ratio). This is what the Quasiturbine does by producing much shorter pressure pulses (particularly the Quasiturbine AC with carriages) and more accepting of photo-detonation, because compression and relaxation slopes occur with minimal time variance.

The Quasiturbine AC has a much shorter pressure pulse, which is the logical photo-detonation requirement. The beauty of the Quasiturbine is that it utilizes conventional "off the shelf", public domain, mechanical solutions and existing piston and rotary engine research. The combustion Quasiturbine is therefore a combination of the best elements of other internal combustion engines, as defined by the following:

- Quasiturbine photo-detonation of the homogenous fuel/air charge eliminates the electronic ignition requirement for most fuel. Electronic ignition in the piston gasoline engine is required because of intake vacuum and incompatible long duration compression "pulse structure" limitations in the cylinder.

- Photo-detonation completely combusts the fuel in the fuel/air charge because of the short, but powerful, pressure pulse and because of the fast nearly linear variation of the Quasiturbine's maximum pressure zone, which rapidly closes and re-opens the combustion chamber. The diesel engine can only incompletely combust the inhomogeneous fuel injected into the heated, compressed air in the cylinder. The Quasiturbine (unlike the diesel) is therefore a "clean homogeneous combustion" engine. It has virtually no emissions other than the standard products of combustion, e.g., CO_2 and H_2O. "Clean combustion" also implies that the Quasiturbine engine is more fuel-efficient than the diesel.

- Photo-detonation in the Quasiturbine occurs rapidly at top dead center. In the diesel engine, ignition of the injected fuel occurs somewhat after top dead center, usually about 12 degrees or so, is progressive with time and which contributes mechanically to protect the piston. The Quasiturbine's power stroke is somewhat longer "with early and late mechanical energy conversion" and the exhaust somewhat cooler, which also implies a more efficient engine.

- Because the temperature of stator/rotor is not significant in the photo-detonation process (light ignition) and because the shorter Quasiturbine pressure pulse is self-timing, premature ignition is not a concern. The combustion Quasiturbine can have a very simple cooling mechanism, such as air-cooling, mainly when operating on a high volatility, low specific energy fuel like natural gas.

- The Quasiturbine is suitable for multi-fuel use, including hydrogen combustion. It can also be operated in a combined thermal cycle mode (including steam and Stirling mode hook-up on the same shaft) thereby further increasing the efficiency.

- Finally, the Quasiturbine can operate in the more conventional Otto or Diesel mode, yet retains its added value characteristics when compared to the piston engine.

The principal difference between the Otto and the photo-detonation Quasiturbine is the mechanism of fuel ingestion, ignition and combustion. The Otto mode Quasiturbine uses a spark ignition, while the photo-detonation Quasiturbine eliminates the need for spark plugs and an electrical ignition system. In photo-detonation mode, the fuel/air charge auto-ignites with a short, powerful pressure pulse in the Quasiturbine's combustion chamber. With the exception of the method of fuel ignition and combustion, and lean fuel condition, the operational characteristics of the Quasiturbine engines in both modes are essentially the same from the user perspective.

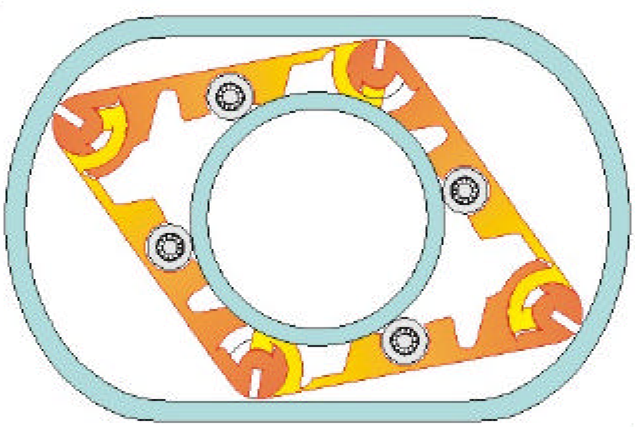
V - Energy efficiency

For the Otto piston engine, about half the gasoline used in the transportation sector is literally wasted to fight the atmospheric intake vacuum depression generated by the carburetor butterfly-valve (The engine-braking effect) [8]. This is also responsible for nearly half the pollution generated by gasoline transportation activities. The Quasiturbine photo-detonation mode is a solution which addresses this fuel loss and beyond.

The positive displacement engine combustion chamber is a non-desirable parasite volume from the standpoint of energy efficiency, since this volume must be pressurized in pure loss before being able to exert strong forces on the piston and so produce useful mechanical work. Ideally, the combustion chamber should be the smallest possible, which would imply a high compression ratio. The piston meets at least 3 major obstacles which limit the compression ratio: the mechanical robustness, the self-firing (photo-detonation), and the production of pollutants. At low compression ratio with a pre-mixed intake, the sparkplug produces an ignition thermal wave which propagates into the chamber, driving a progressive and uniform combustion, but somewhat incomplete. In a similar situation but with a high compression ratio, it is the radiation (light, somewhat like that of a laser) which ignites almost spontaneously, completely, and uniformly the combustion (detonation or knocking that pistons cannot withstand, owing to the overly long pressure pulse that it produces). In order to reach the pressure of the Diesel mode, a substantial concession has been made, which was to abandon the uniform combustion from a carburetor (gasoline injector) for the much less desirable diesel injector combustion. *The near-heretical implications of this statement are acknowledged.* (Note: Of interest is the "Cross-Fire" injection process – single point fuel injection -- utilized in the 1982 Corvette 5.7L engine;

essentially an injector/carburetor that fed all cylinders in a more precise way. Essentially, an "electronic carburetor").

At low load factor, the intake depressurization of the Otto cycle dissipates power from the engine since the throttle valve is almost closed and the descending piston acts as a clogged vacuum pump against the atmospheric pressure, followed by a partial loss of vacuum due to subsequent fuel vaporization during compression. In consequence, the engine in Otto cycle opposes all rpm increases (well known as engine compression braking) and this intrinsic resistance to speed augmentation is compensated by *constant and important fuel consumption*. The photo-detonation mode does not use any throttle valve and accepts without constraint all available air at atmospheric pressure (similar to the Diesel, where the pressurization energy is re-instituted at the time of relaxation). For this reason, the efficiency at low load factor of the photo-detonation engine is more than twice that of the conventional Otto cycle [8], and considering that the load factor of a car is on average about 10 to 15%, this is not a small difference. Indeed, superior fuel conservation being most welcome in traffic jams.



Quasiturbine high diamond eccentricity
(here noted 0,578 for the model
QTSC - without carriage)
may not be the most practical case
(corner angle goes from 90 - 30 to 90 + 30 degrees),
but it does emphasize the
"Saint-Hilaire skating rink profile".
Still higher eccentricity makes the
straight top and bottom legs convex, while still
maintaining an acceptable confinement profile.
The four pivoting blades rollers and the
central annular supporting track are also shown.

Quasiturbine energy saving comes from the thermodynamic of a shorter pulse tip, while getting rid of the inefficient depressurization Otto cycle, but also from the fact that the engine has no accessories to drive like camshafts. Other savings in transportation applications come from the simplification of the gearbox (8 to 12% there) and from the reduced mass of the vehicle. Ten other sources of savings are described in the Quasiturbine book (written in French) *"La Quasiturbine Écologique"* [9]. Furthermore, the Quasiturbine is suitable for combined heat cycles [10], such as the internal combustion Quasiturbine teamed with a the steam Quasiturbine, or with the Stirling [11] Quasiturbine, where estimates show possible combined engine efficiency up to 60% without even using the photo-detonation mode. Although not for near-term developmental targets, it is feasible within the decade.

The Quasiturbine offers the potential for significant increases in fuel efficiency due to several factors, including: virtually complete combustion of the fuel/air charge, high compression ratios, early and late mechanical conversion, absence of peripheral accessories like camshaft, and more. Each of these factors is addressed in more detail on the Quasiturbine website [1]. In fact, cost reduction is so important in transportation that even if Quasiturbine had a significantly higher cost (which is not the case), the fuel saving over the life of the vehicle would make the Quasiturbine engine a "no-charge" feature. This would be true even in non-photo-detonation Otto mode. Consider also that an accelerated, compared to piston, reduction in combustion chamber temperature, pressure and confinement time leads to less heat transfer toward the engine block, further contributing to efficiency improvements over the piston engine.

VI – Environmental Benefits

Regardless of the method of ignition and combustion, the Quasiturbine is a uniquely "clean combustion" engine. The pollution-related products of commercially available internal combustion engines include carbon monoxide, other un-combusted hydrocarbons and oxides of nitrogen. Carbon monoxide and un-combusted hydrocarbons are the result of incomplete combustion of the fuel in the engine. Oxides of nitrogen are formed because of the relatively long high pressure and temperature confinement residence time of nitrogen (from the air) in the combustion chamber. The Quasiturbine's unique engine architecture minimizes the formation of

these pollution-related engine products. Moreover, uniform ignition, and complete fuel combustion, can never be achieved in a piston engine at relatively high rpm, because the thermal ignition wave cannot follow the falling piston. With respect to carbon monoxide and un-combusted hydrocarbons, the Quasiturbine's combustion chamber movement, which is near linear, favors uniform ignition of the fuel/air charge to all areas of the chamber. As regards oxides of nitrogen, the high-pressure confinement residence time of nitrogen in the Quasiturbine combustion chamber is significantly reduced. Consequently, the chemical reaction that leads to the formation of oxides of nitrogen is retarded or prevented. If the reduction in "tailpipe" emissions were the Quasiturbine's only benefit, *it would be a major advance in engine technology.*

Another advantage of the photo-detonation engine is its low nitrogen oxides (NO_x) emissions from "air-abundant" temperature limitation. The Quasiturbine has the potential to be an oil free engine as required by hydrogen of the future. Because it has no dead time, it has a specific power density at least 4 times higher than the piston engine. In short, the asymmetry of the strokes and the precocity of the mixture intake and gas expansion (without excess volume during expansion) allow for a better initial mechanical energy conversion.

A faster reduction in the combustion chamber of the temperature, the pressure and the confinement time leads to less NO_x production. Excess air in the photo-detonation mode also helps to reduce the combustion temperature while achieving a more complete combustion.

VII - Quasiturbine and The Hydrogen economy

Due to the need for a drastic improvement in environmental and energy policy, scientists and engineers have in the past 10 years thoroughly explored the hydrogen society perspective. The decade of exploration leads us to the fundamentals and reveals unexpected observations: *We have already been in a hydrogen society for more than a century*. Research throughout the years have confirmed that a good way to store hydrogen is to link it with carbon atoms to produce, either gaseous, liquid or solid high energy density products, which are more convenient for transportation and mobile uses. The hydrogen storage method in carbon molecules is the most efficient. This is because not only does the hydrogen separate and burns to produce water vapor, but the carbon atoms also burn, producing carbon dioxide [12].

There are of course, high expectations of success from the utilization of hydrogen fueled power generation systems, and this has no doubt contributed to an observable slowdown in internal combustion engine development. Be that as it may, the recent MIT report [3] will be a turning point in terms of making the internal combustion engine fashionable again. So far, carmakers like GM have invested heavily in developing fuel cells to power electric motors in vehicles, while others like BMW have studied the burning of hydrogen in internal combustion engines. *Is it possible that this last solution may in fact be the optimum technological merging point for hydrogen use in the future?*

Excluding a nuclear source, hydrogen must be processed from some other fuel source, such as natural gas, with a corresponding loss of about 30% of the energy value of the fuel during processing. When the energy loss associated with processing is taken into account, fuel cells will only be about 35% fuel-efficient or so at most. In addition, because fuel cells are generally dependent on hydrogen, there are serious issues about production, transmission and storage of hydrogen fuel that must be addressed before hydrogen fuel cells can become a generally available option. An extensive study commissioned by the U.S. Department of Energy released in 2002, in conjunction with announcement of the "FreedomCAR" initiative, outlines the extraordinary complexity and cost of this undertaking (http://www.eere.energy.gov/hydrogenandfuelcells/pdfs/33098_sec1.pdf).

While hydrogen is the "Achilles heel" of fuel cells, the Quasiturbine has no such limitations. It is a multi-fuel engine and can use existing fuels and infrastructure (and even hydrogen, if and when, available). While the fuel cell may be an option for some distant tomorrow, the Quasiturbine is an option for today.

The photo-detonation mode is of a practical necessity for the hydrogen engine. In order to do work with a piston, the fuel-air mixture needs to burn at a speed faster than the piston is moving. Low hydrogen flame speed is a disadvantage shared with most other gaseous fuels. For comparison, a gasoline-air mixture has a flame front speed that ranges typically from 70 up to 170 feet/second in IC engines, while an ideal hydrogen-air mixture has a flame front speed of about 8 feet/second. An average vehicle engine rotating at 2,000 rpm (33 revolutions per second) produces piston linear speed of 45 feet/second in the middle-stroke,

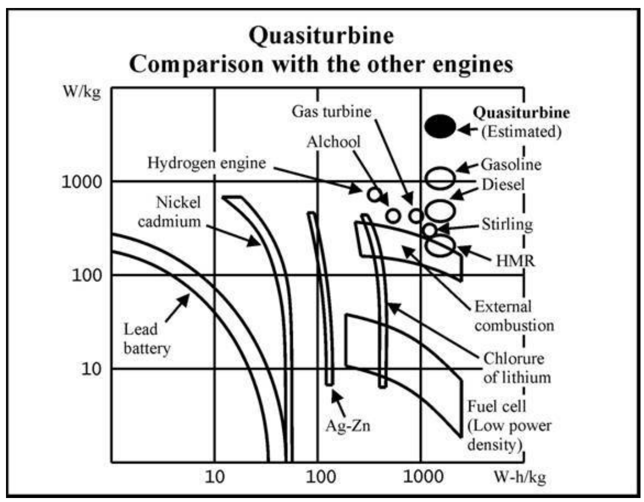
which is already 5 times faster than the hydrogen flame front speed. **The fact that a hydrogen-air mixture has a flame front speed of about 1/10 that of a gasoline-air mixture contributes to explain why hydrogen engines run at reduced power and low rpm under load.** ***However, the photo-detonation mode is extremely rapid and totally removes this limitation.*** **This is why the photo-detonation mode (not compatible with piston, but with the Quasiturbine) is so critical for the future of the hydrogen engine.**

Quasiturbine has all the characteristics required to run on hydrogen [12], and it further allows intake stratification, low photo-detonation sensitivity and even oil free engine possibilities (hydrogen having the characteristic of degrading all oil, which could be of interest on the long term). For all these reasons, the Quasiturbine will welcome the hydrogen economy when, and if, it becomes ready.

VIII - Vehicle Transportation Revolution

It is generally accepted historically that engine power goes up with displacement, but this is not quite true, and leads to substantial confusion in the world of engines. For all piston engines, the displacement is the maximum total cylinder volume, but the 4 stroke piston for example, intakes this volume of fuel mixture only once every 2 revolutions. In order to compare different types of engines, one has to get back to basics where the power of a theoretically good engine (which the piston and Quasiturbine are, but not the Wankel because of the P-V diagram) is proportional to its fuel-mixture intake capability per revolution, and not its displacement. Let's see what happens when comparing a 50cc four-stroke piston engine with a QT50cc Quasiturbine at the same rpm. Both engines have 50 cc maximum chamber volumes. The piston engine will intake 50cc every 2 revolutions, while the Quasiturbine intakes 8 chambers x 50cc = 400cc in 2 revolutions. ***The Quasiturbine will intake 8 times more chambers and fuel-mixture, and produces something like 10 times more power.*** **Obviously, the power is not proportional to displacement here, where engines compare on 1 to 1 by displacement, but on 1 to 8 by intake fuel-mixture volume and power. Consequently, to produce the equivalent power of a 4-stroke piston engine, the Quasiturbine displacement would have to be only 1/8 of it. Furthermore, in the long run the Quasiturbine maximum rpm will probably exceed by a factor of 2 to 5 the maximum piston rpm, because there is no valve and no crankshaft. Since the power goes up quasi-linearly with rpm, superiority will develop exponentially. All this would suggest to car manufacturers that it might now be necessary to note on the rear deck lid nomenclature** ***designating the intake volume per revolution, instead of the displacement*****. Consequently, for the same power and rpm, the Quasiturbine is about 4 times less cumbersome and 5 times lighter than a piston engine, and will be at least 20 % more efficient (the photo-detonation mode would even produce more power and be more efficient), at a much higher torque, which is what every experts are looking for. It will also be 20 times less noisy, which may not be what teenagers are looking for...**

Because of its high power density, zero-vibration, high torque and multi-fuel capability characteristics, the Quasiturbine is most suitable for transportation vehicle applications [13], conventional or alternative. Notably, alternative propulsion requires having on board the total energy storage, while the internal combustion engine only requires the petroleum fuel, and not the oxygen, which is taken out of the atmosphere while under way (a car fuel tank requires typically 2 tons of oxygen which do not have to be loaded onboard). For this reason, the internal combustion engine is in an unfair competition with alternative propulsion means, and is likely to be there for a long time…



RAGON Diagram - A comparison of several vehicle engines by their specific energy density and power density. Notice the low specific power density of the hydrogen fuel cells, on the bottom right hand corner of the diagram. Reference: Romance of the engines, by Dr. Tukashi Suzuki, SAE Publishing.

Electric Vehicles…

On average, vehicles travel 20,000 km per annum or less than an hour of service per day, using approximately 12% of their installed maximum power, which corresponds to an annual average power of 0.3 kW or 0.4 HP by vehicle. The paradox to be solved with these vehicles is that they require large instantaneous power, but relatively low annual energy consumption, while requiring a good mobility characteristic. A current hydroelectric dam water turbine produces 200MW, which could be enough in theory to drive a fleet of 800,000 vehicles, but lacks the mobility of readily available electrical connectivity. What about a small 1 HP onboard non-stop Quasiturbine Stirling generator for recharging the batteries? The source of heat could even be a small "fast decay nuclear pellet" [11] allowing this generator to run non-stop for years. If so, the Quasiturbine Stirling engine, coupled with hybrid electric technology, could open a new horizon for environment friendly, yes, *nuclear* vehicles.

For most areas of the world, liquid fuels (fossil or alternative) are still by far the best way to concentrate and to transport autonomous energy, and with the internal combustion engines as partners, they offer an unequalled prospective solution for mobility. The race for efficiency and environmental cleanliness is however becoming the critical argument. For this reason, Quasiturbine technology will be hard to circumvent. In the current precarious international energy and environmental context, this new technology is welcomed, and will be a major technological leverage for early-involved countries.

The fact that the equivalent power Quasiturbine occupies only a quarter of the space now used by piston engine, weighs only one fifth, uses a simplified gearbox (possibly only for reverse) and has no vibration and low noise, is sufficient to spark one's imagination. Add to this that it could be done competitively, once the Quasiturbine engine is mass-produced, and will further drastically increase engine efficiency and reduce pollution…

But the greatest impact could follow from the relation between the hybrid vehicle concept and the Quasiturbine photo-detonation engine [2]. The hybrid vehicle concept is interesting with the present conventional internal combustion engines because it is more efficient to run a 20 kW engine at full 20 kW at all times (despite the inefficiency, weight and cost of the storage system), than to run a 100 kW engine at 10kW most of the time. Notice that the present day hybrid vehicle offers about 50% fuel saving potential, ignoring the hardware energy investment. But why is this so? And why is it that if you lower the output power of an engine to 10%, the fuel consumption is only reduced by 25%? With the Diesel engine, it has to do with the non-homogeneous jet spray fuel mixture which requires more fuel to fire at idle. With the Otto gasoline cycle, it has to do with the intake manifold depressurization, which makes an idle engine work hard against the atmospheric pressure...

These piston engine limitations can be overcome by the photo-detonation Quasiturbine engine. It is not an easy road, but it is undeniably an impossible road for the piston engine. The shorter Quasiturbine linear-ramp-pressure-pulse allows it to withstand the very violent but complete and clean photo-detonation combustion. The photo-detonation engine has very little idle efficiency penalty, which means that a 100 kW engine can be efficiently and continuously used to produce only 10 kW of useful power. In this condition, there is no need to have a hybrid energy storage system, since the energy you do not need is kept stored in the fuel tank. Conversely, the vehicle still can be electrical, but now with an all-regime efficient high capacity modulated power generator instead of battery storage.

A substitute powerplant for
turbo-prop aircraft and Jet-Powered Hydroplanes?

Most engine applications do run under variable load factor (for example, land vehicles use on average 15% of the onboard engine's maximum power). Airplane and marine applications are obvious exceptions because they do require a high 70 to 100% load factor, and this is where the Quasiturbine concept is especially well suitable for very demanding applications. First, the improved early intake fuel-mixture characteristic of the Quasiturbine will be capable of maintaining "high engine power at altitude" for aircraft, and the zero vibration will make flying much more comfortable. Second, marine applications require low-end rpm and very high torque, two characteristics the Quasiturbine supplies without the need of any gearbox. Third, today's marine powerplants for fast and light boats are too heavy for hydroplanes, a major improvement with the Quasiturbine's factor 5 weight reductions. Fourth, because the Quasiturbine center is empty and well suitable to withhold a marine jet propeller screw directly driven by the four Quasiturbine blades, this propulsion system can be submerged as a complete package. The need for shaft and gearbox are thus eliminated, resulting in a further reduction of weight, and because the Quasiturbine does not have an oil

pan, there will be no risk of water intrusion. This represents the potential of responding successfully to a recent call for development of an alternative powerplant – reciprocating or rotary – to the jet engines currently the choice of Hydroplane racing teams.

IX – Operational Superiorities to The Wankel engine

Mr. Felix Wankel started working on the well-known "Wankel rotary piston engine" in 1926, and got it running 31 years later in 1957 for less than a minute. It took him almost another 10 years to have it in a car, at a time where nuclear reactor took only 4 years from concept to operation… Unlike today, Mr. Wankel did not have access to computer simulation, and he had to build it to determine operational characteristics, which, as it turned out, were very interesting, except for unacceptable unburnt fuel levels and high fuel consumption. Mazda continues to use this engine in its RX series, but experienced only limited success following the energy crisis of 1973.

Of course, no one is probably willing today to undertake a similar engine venture, and it is important to question thoroughly the potential technical drawbacks of any new engine concept. This is why the Quasiturbine scientists are spending much time and effort extensively comparing their approach with the Wankel and other designs through computer simulation. It is not the intent to present a wholly technical document, but a review of the main technical FAQ about this technology, in relation to the Wankel and the piston, is most appropriate at this juncture.

A - The maximum output efficiency depends on the extreme temperatures of the Carnot cycle. In gasoline engine operation, how can one double the output efficiency with the Quasiturbine without increasing the temperature?

The reference to doubling the output has nothing to do with the cycle of Carnot, but results from the fact that the Otto cycle requires a vacuum in the inlet manifold and that at low regime, pumping against this vacuum, the engine consumes energy to fight against the atmospheric pressure. Moreover, it is partly by removing the butterfly of the inlet manifold that the diesel engine makes its gains. The efficiency penalty is null at high load factor, but as the vehicles typical load factor is from 10 to 15%, the output is in practice extremely penalized (50% overall [8]). Photo-detonation thus doubles the effectiveness of the Otto cycle, without exceeding the limits of the Carnot prediction.

B - What does one mean by the theoretical defect of the Wankel? ... and why doesn't the Quasiturbine have this defect?

This question is fundamental, but unfortunately, it requires engineers to do a bit of physics. Indeed, the piston has a relentless quality which comes from the fact that the volume variation of the cylinder is rigorously generated by the movement of the piston surface push [4]. This makes the piston engine an effective machine which rigidly follows the Pressure – Volume diagram. Several years ago, the Quasiturbine inventors showed that the Wankel chamber volume is in early relaxation significantly larger than the volume generated by the effective surface of push. Consequently, the Wankel undergoes a geometrical loss of pressure in the early course of relaxation which fails to respond to the P-V diagram, and the accelerated adiabatic pressure drop cools the hot gas excessively and prevents complete combustion. Contrary to the Wankel, the evolution of the volume of the Quasiturbine chambers corresponds rigorously to the volume generated by the effective tangential surface of push and the Quasiturbine thus behaves completely like the piston in this respect, and follows perfectly the P-V diagram. The Quasiturbine thus does not have the theoretical defect of the Wankel.

Comprehension of this expansive operational data is essential to ensure that the Quasiturbine will not be subject to levels of intellectual resistance similar to that experienced by the Wankel concept. See http://quasiturbine.promci.qc.ca/FQTperformance.html (paragraph 4 and the figure which follows it), and in chapter 8 of the book (page 123) [9]

C - On the concept itself, will the Quasiturbine have the same disadvantages as the rotary engine Wankel, which could not easily adapt to the requirements of exhaust emissions as it relates to the important release of unburnt hydrocarbons and excessive fuel consumption?

Quasiturbine is absolutely not comparable with the Wankel in this respect, and it is devoid of its defects. Even if the Quasiturbine has the advantage of dividing the perimeter into 4, rather than in 3 like the Wankel, it should be mentioned that there are those who have typically, and wrongly, stated that combustion chambers of elongated form do not achieve complete combustion possible owing to the wedging of the flame in narrow zones at the ends. The defects of combustion and consumption of the Wankel arise rather directly from its theoretical shortcomings as explained

in "B".

D - How is the positioning of the Quasiturbine on the RAGON diagram justified?

This RAGON diagram positions the various vehicle engines according to the density of power produced versus the density of the source of energy, but it does not give any information on the effectiveness of the unit. The X-axis is the position allotted to the "gasoline" fuel and the Y-axis is the result of the specific power density of the Quasiturbine, to which about fifteen elements contribute. If a comment had to be made about this positioning, it would be to specify that it relates to Quasiturbine's power density output in Otto mode at the same rpm as the piston (the potential stems from the higher Quasiturbine rpm – a horsepower multiplier -- possible without valves and with continuous admission). ***Theoretically, a tripling of the RAGON plotted power points could occur with photo-detonation.***

E - The term "photo-detonation" introduces a concept of quasi-spontaneous combustion. Although radiated energy is proportional to the fourth power (T^4) of the temperature, it is difficult to understand the existence of such radiation before combustion initialization.

There are several elements confused here. Initially, the adiabatic compression of the mixture increases the temperature considerably, and at very high compression ratios, it creates it own intense radiation. In certain cases, thermo-ignition can indeed precede photo-detonation. In this case, the auto-lit pockets of mixture will contribute to increase the pressure, the temperature, and the radiation. In practice, thermo-ignition is acceptable, albeit a bit slower. For this reason, it is preferable to remove the anti-knock additives which behave like photonic absorbents, and which seek to extinguish combustion by creating a volumetric absorption of radiation.

F – Why is the Quasiturbine concept more favorable to HCCI combustion than the piston?

The references on HCCI [2] show that the piston engine turns well "without load" in HCCI mode, but not easily otherwise (even with admission contamination with the exhausts). The HCCI research relates to the control of the moment of ignition of the combustion, which is unstable since the pressure pulse of the piston is relatively long and flat on this scale. The Quasiturbine (especially the model AC) pressure pulse is 15 to 30 times shorter near the tip, which presents an auto-synchronizing effect of the thermo-ignition or photo-detonation, and an equivalent time reduction of the extreme pressure constraint. Furthermore, the Quasiturbine model with carriages offers a higher surface-to-volume ratio, which tends to attenuate the violence of the detonation.

G - Will the moving parts resist the temperature?

The difficulties related to the temperature exist in all engines and particularly with the piston valves and the blades of hot turbines. There is nothing here comparable (no valve) and the solutions are in the public domain.

H—How are lubrication requirements, if any, addressed?

Concerning the lubrication, the simple initial solution is to add a little ash-free lubricant to the fuel (the Wankel solution until the 90's), but a robust or commercial construction with ceramics seals should remove this need, as it did for the Wankel.

I - What happens to the loading losses at the time of passage in front of the intake and exhaust ports?

The disturbance is short comparatively to that of a piston valve, which obstructs the admission channel 75% of time. For now, the port is a sequence of holes distributed along the engine axis. The Quasiturbine admission and exhaust conduits load factor is 6 to 10 times higher than in the case of the 4-stroke piston.

J - How is the load controlled in the Quasiturbine?

An early mixture is introduced into the engine through fixed geometry ports. In Otto mode, a butterfly valve is used in the inlet manifold as in the case of the piston. In photo-detonation mode, one pulverizes (or atomizes) fuel in the open admission conduit (no butterfly valve), which leads to concentrations comparable with those made via the fuel spray injector in the diesel engine, however with the advantage of a uniform mixture at the time of combustion. The position of the ports can be slightly shifted to account for the flow inertia. There is no overlapping of the valves problem, nor that of admission and exhaust ports proximity, since they are respectively at opposed ends of the chamber...

K – Which containment system ensures the sealing?

The engineering of the seals set is described in the patent [1], and shown in the book [9] These drawer type seals are most conventional and quite similar to those used in the rotary or pallet pumps. The articulation is of itself an excellent sealing.

L - What about the power drive shaft? How do you lubricate it?

The drive shaft is not part of the engine, and this fact is advantageous for several applications, as for the Quasiturbine pump which can be placed in the center of the engine (the same for a turbine jet of boat propulsion, or a concentric generator). In the case of a conventional generator for example, this makes it possible to place the hooks on the generator power shaft itself and to slip Quasiturbine over, which removes all the problems of shaft alignment, since there is only one of them, that is to say the *generator shaft*. As this shaft mechanism is not an internal Quasiturbine engine part (although in its center), it is easy to lubricate if necessary.

M - The movement of the piston with the connecting rod-crank attachment is not sinusoidal and that obliges significant balancing in order to attenuate the vibrations due to the non-sinusoidal movement - What is it with the Quasiturbine?

This is quite true for the piston, and the Quasiturbine website [1] and book [9] show this variation compared to the rigorous sinusoidal movement. However, the vibrations of the piston engine are essentially due to the center of mass movement of the crankshaft, rod and piston assembly during the rotation, and even a rigorous sinusoidal movement of the piston would not remove this movement of the center of mass. The Quasiturbine has a rigorously motionless center of mass during rotation.

N - Does the complexity of the mechanism compromise the viability and the reliability?

Here, one largely underestimates the complexity of the piston with its rods, valves, rockers, camshafts, injectors. If it is true that complexity was historically synonymous with failure, it is not true today. The modern car, as an example, is of great complexity, and the Airbus commercial airliner is one of the most complex aircraft in the world while minimally expensive to maintain and to fuel. Furthermore, although electronic watches are several million times more complex than mechanical ones, they invaded the market competitively, *and without failure*.

O - Does the Quasiturbine have some disadvantages?

The last sentence of the book "*La Quasiturbine Écologique*" [9] stresses that there are 2 kinds of innovations: Those which improve the technologies in place and those which make them obsolete. The Quasiturbine has the major disadvantage, it can be argued, to be of the latter. Furthermore, contrary to the projected fuel-cells impact on national energy infrastructure anticipated in 30 years, the Quasiturbine has the inconvenience of an immediate impact. It thus appears that Quasiturbine *is not obvious* and if it were, it would have been invented in the past century. Clearly, much more can be written on the subject. *See* [1] www.quasiturbine.com and book. [9]

X – Strategic Technology and Economic Development

The automotive industry requires approximately 8 years and half a billion dollars to develop a next generation piston engine. Because the closing of the intake and exhaust valves is conducted 80% of the time, the transient flows regime is the main obstacle to a cleaner and higher specific power density piston engine, with the valve system as the limiting RPM factor when taking into account the environment. Current engine understanding does not allow for or care to comprehend the Quasiturbine concept. Moreover, only a modicum of piston engine developmental and operational strategies apply to Quasiturbine. While most of the piston development money goes into the engine head, where the valves are, the Quasiturbine has no valve and flow regime is quasi-continuous at intake and exhaust. This means that little money needs to be invested in Quasiturbine equivalent head development. Additionally, up to 6 years of difficult development can be avoided and several hundred million dollars in research spending.

In order to facilitate faster and more disciplined market penetration, the Quasiturbine Agence Inc. already announced its intention to present engine manufacturers with an opportunity to co-produce Quasiturbine engines for their production requirements.

Placing things in perspective, the computer industry is extensive, but it is minimal when compared to the multi-sector energy industry. Internal combustion engines small and large are used around the world and literally constitute the "nerves" of modern society. A new successful engine concept not only could help meet the Kyoto protocol, but by being more efficient, it would reduce fuel import and substantially affect many country external expenses or revenues. Potential economic development could be considerable for early-involved countries in manufacturing such an engine, and the integration in applications could offer great opportunities as well. The 10 HP and less engine market reaches about 1

engine per 5 inhabitants in many countries, which in itself would be a great - and new - replacement market. Transportation vehicles would be of course, a main target once mature engine technique is proven, and this will be of international interest.

It is the objective of this paper to attract the attention of the engineering and policy shaping communities, and announce that new emerging technologies exist which can, and will, serve as drivers of new confidence in a planetary future dominated by dynamic societies.

XI – References

[1] www.quasiturbine.com

[2] http://quasiturbine.promci.qc.ca/QTPhotodetonation.html

[3] http://web.mit.edu/newsoffice/tt/2003/mar05/hydrogen.html

[4] http://quasiturbine.promci.qc.ca/QTpasWankel.html

[5] http://quasiturbine.promci.qc.ca/QTAcademiquePneumatiqueJeu.htm

[6] Scientific American of June 2002
"A Low-Pollution Engine Solution - New sparkless-ignition automotive engines gear up to meet the challenge of cleaner combustion"

[7] http://www.llnl.gov/str/Westbrook.html

[8] http://www.vok.lth.se/CE/research/HCCI/i_HCCI_uk.html

[9] http://quasiturbine.promci.qc.ca/QTLivreFrancais.html

[10] http://quasiturbine.promci.qc.ca/GHGAlberta0205.html

[11] http://quasiturbine.promci.qc.ca/QTStirling.html

[12] http://quasiturbine.promci.qc.ca/QTHydrogene.html

[13] http://quasiturbine.promci.qc.ca/QTVehiculeE.html