THE ADVANCED RANKINE CYCLE ENGINE AND THE APPLICATION POTENTIAL FOR USING THE CYCLONE ENGINE IN THE AUTOMOBILE.

PREFACE.

Should the reader begin with preconceived ideas based on past observations and existing steam cars and does not possess the ability to put those ideas aside and review the engineering with an unbiased view, then he should not proceed any further. There have been sufficient advances in the art in the past ten years that have drastically changed the entire engineering aspect and benefits potential of this power source for automotive use. It cannot be dismissed from consideration based on prior work and preconceived ideas based on outdated examples.

This paper is written to explore and discuss the possibilities of specifically applying the Cyclone Rankine cycle engine to the automobile. The Cyclone engine specifically, because it alone of all the steam systems proposed, is the most advanced, has a most competitive net efficiency and could be the closest one to full scale production if sufficient funding were provided. It is not a wishful proposal; it exists right now in various sizes.

The worldwide intent to reduce climate change and the proposed recent US government fuel mileage mandates has had a major impact on the American automobile industry. Couple this with the ongoing financial problems the industry is undergoing right now and a rational vehicle power source is a subject that must be reviewed with concern and dispatch.

One must acknowledge the economy for the motorist in driving a Diesel powered vehicle, an engine notorious for long life with minimal service demands and high torque output and better fuel mileage than any spark ignited Internal Combustion (IC) engine. It is reported that about 70% of European new car sales are now Diesel powered. This engine has a serious NOx problem; but recent developments by Daimler-Benz, BMW, VW and others in Europe and Japan have at least put this gas under some control; but at a furious cost for the exhaust system. Future work may provide a more cost effective solution than the present urea injection system now used.

When and if a satisfactory and reliable Rankine cycle engine is available and publicly demonstrated, it can be offered with confidence to the automobile industry as an alternate to the Diesel engine. Until that time, only the Diesel is considered to be satisfactory for the automobile. With the battery electric perhaps usable as a purely city car when a drastic reduction in cost of the battery pack is seen by the market.

By considering a large reduction in the use of fuels in the automobile, the Federal Government is not acknowledging the operational problems that such a reduction will cause the average car buyer. The immediate response by the Automotive Industry is to propose small displacement, highly turbocharged engines that will meet the requirements. Such engines are heavily stressed and the possibility of high maintenance costs to the car owners is a definite probability. The apt term used for these engines is “grenade engine”.

The position taken in this paper is that actual mileage alone is only one part of the solution. Where this fuel comes from, the reduction of CO_2 and if the nation should continue to rely on foreign oil are also subjects that must be competently reviewed and serious improvements implemented. A reasonable total and long duration solution is urgently needed. Not a panic driven grasping of power systems ideas that are more science fiction than realistic. Multiple bicycle pedals under the seats of a public bus would be amusing, albeit a bit smelly and actually work, but hardly practical. Various TV programs even gave this idea airtime as a serious proposal.

Home produced fuels are one good solution and are coupled to the specific engines these fuels can be used with successfully, along with how well these fuels can be used in the automobile. A few of these home produced fuels do not have the energy content per pound as gasoline or Diesel oil, so mileage for the same power output is reduced. CO_2 is still produced when burning these fuels, as all contain hydrogen and carbon in their molecules. Some fuels cannot be used with the spark ignited IC engine and the most cost effective are only usable in the Diesel engine or the Rankine cycle engine. That fuel is carbon neutral and that one parameter is more important than the actual mileage obtained. Pure bio fuel oils and the Cyclone engine are viewed as long-range successful potential candidates.

INTRODUCTION.

The steam car as it exists now has not received the engineering improvements where present material and engineering advances plus revised fuel-burning conditions will amply demonstrate the dramatic gains that are now reality. To date: since the Federal Government funded clean air car projects of the 1960-1985 period and the amateur work going on today, such past steam power systems do not provide the necessary improvements required to ensure either commercial success or the high level of pollution elimination that is demanded today .

The old antique steamers and most of the projects to date, show only that Band-Aids and some detail advances in specific areas have been applied to basically 19th century technology. What was necessary was a total review in all areas of Rankine cycle engineering and then concentration on advancing the work in those areas. The Cyclone Power Technologies Company Inc. has done this and the new developments are showing dramatic improvement.

Each specific area will be explored and discussed, not only the actual hardware, but also the reasons why these improvements were done.

WHY CONSIDER THE STEAM ENGINE FOR AUTOMOTIVE USE.

The reciprocating positive displacement steam engine and the electric motor are the only two power sources that correctly match the torque/speed loads of the automobile. The automobile requires full and high starting torque and only both of these power sources provide this condition. The electric car is now receiving serious attention and some production; the Rankine cycle powered vehicle is not.

The electric car success mainly depends on the new Li-ion polymer batteries for energy storage. They are presently very expensive; however rapid advances are being seen in mass production of these storage cells for automotive use. There are other aspects of electric car propulsion that are yet to be solved. The charging power source, the fire danger of using an alkali metal, disposal of spent cells, cooling requirements of these batteries and the environmental needs of the utility power plant increases that would be required if such vehicles were really in mass production. Disposing of the increased production of CO_2 would be a major concern. Sequestering carbon in rock strata is a poor temporary solution. A better one is to not produce it at all by using carbon neutral fuel.

The bulk of electrical power is still generated by burning coal or natural gas in the United States. The battery electric car is not pollution free as many developers claim. The vehicle, yes, the power source definitely not. It has only been moved many miles away; but it still produces pollution that must be controlled. It is also not efficient when considering the pound of fuel burned in the power plant, as compared to the actual power delivered to the rear wheels of the vehicle.

There is one pending problem that would become very serious if electric cars were to be adopted in really large numbers for city use. The nation's power grids are already in trouble and many have seen brownouts and blackouts when the grids are simply overloaded in the summer. This problem is already recognized and utility companies are planning enlargement of the grid networks. However, the advances in electric car development are not being matched by construction of the new transmission grids.

Many futurists and environmentalists champion the use of fuel cells with hydrogen as the primary fuel. The entire energy consumption and cost to produce and use this source is high and there is no nation-wide distribution network to supply the hydrogen. There are serious storage problems with vehicle hydrogen systems and there are operational problems and safety issues that would need considerable investment to overcome. Fuel cells do work and they show high conversion efficiency. Cost and the entire system acceptability are matters yet to be resolved.

Demonstration fuel cell vehicles are good publicity and show technical competence; but not practical everyday use for the consumer at this time. It may also occur that manufacturers may see that fuel cells and their associated support hardware are just too complex and expensive to continue with.

Basing any new power source for the automobile is easier and cost effective when existing fuel distribution networks are used.

Compressed or liquefied natural gas and hydrogen, hybrids, plug-in-hybrids, alcohol and combined systems are not long-range solutions. These fuels still produce CO_2 in their production and use and that is important to drastically reduce if climate change is to be controlled.

<u>ENGINE CHARACTERISTICS AND COMPARISONS.</u>

The immediate consideration is just what automotive power source could satisfy all the needs and then is it really practical and cost effective and satisfactory for the average motorist. The other main consideration is whether a new engine can quickly be put into production, even on a limited basis.

The Cyclone Rankine cycle engine can accomplish this.

One major thermodynamic loss is present in the Rankine cycle engine that is unavoidable, the loss from the heat of vaporization of water. This means adding 947 BTU/lb just to effect the phase change from liquid to gas, then rejecting that heat to the atmosphere in the condenser where the exhaust steam is changed back again into water. This process is done with none of this energy used for the production of power and it is a total loss. For the competent engineer, this means more than just average attention must be paid to minimizing any other heat, fluid flow and friction losses in the system and also the most efficient expander possible must be selected for use.

The spark ignited IC engine and the Diesel engine are not self-starting from rest. They require some outside power source to put them into operation, the electric starter. Both demand that when the vehicle is stopped or waiting in traffic some means of disconnecting the engine from the load is needed. Either a manual clutch or the torque converter in a vehicle with an automatic transmission is the common means of accomplishing this.

The torque/speed relationship of either engine is at minimum when only idling, so a multi-speed transmission is mandatory. This now is provided in almost every vehicle by a costly computer controlled six or seven speed automatic transmission. In contrast, the steam engine produces maximum starting torque when the high pressure steam is first admitted to the engine. Thus the starting torque is highest when first starting out and it often is a massive amount. Even with the vintage steams cars of yesterday, this torque can and did amount to over 2,000 lb/ft. making the acceleration of such a vehicle extremely dramatic and very exciting for the driver and passenger with almost total silence. Torque is acceleration while horsepower is speed.

Torque can be varied in the steam engine by a wide amount by use of variable inlet valve timing, described as “cutoff” control in steam engine parlance. Varying the duration of how long the incoming steam is being admitted to the cylinder changes the expansion ratio in the cylinder. This provides this engine with massive starting torque when demanded for acceleration or hill climbing with longer admission timing, long cutoff. Use of short cutoff and thus larger expansion of the steam in the cylinder when cruising along on the highway gives the maximum economy of steam use. Long cutoff uses more steam than short cutoff; but this is commonly only a short duration event.

The result is that in most steamers, no transmission is required, although a two-speed transmission with a neutral position has been shown to be a very large advantage. Reversing the engine is accomplished by changing the valve timing 180° and this means that no special reverse gearing is needed as the engine reverses itself. This provides a very major cost saving over any IC engine for vehicle use.

The prime goal of the responsible scientific community is to reduce as much as possible the CO_2 level produced by industry and the automobile. It is also charged with seeing that the total energy consumed in any new system being adopted is as low as practical. The secondary goal is the use of homegrown fuels and to not depend on foreign oil as the base fuel material. Basing one’s fuel supply future on unstable and often unfriendly nations is a risky business. Alcohol and fuel oils from plant material and algae are the two receiving the highest attention. The reduction of the exponential speed of climate change is the primary emphasis for all of this work.

There is one feature of the Rankine cycle engine regarding fuel consumption that is very beneficial. When the vehicle is in city traffic conditions, residual heat does the main job of maintaining the steam conditions. For a vehicle in stop and go traffic the burner is off most of the time only coming on for brief periods to maintain steam pressure and temperature. In city

traffic the Rankine cycle engine enjoys better fuel mileage than when on the highway where the burner is on primarily all the time. With city driving the IC engine must consume fuel to keep running continuously so as to remain in operation.
However, this means that the necessary powered auxiliaries, such as the power steering pump and the power brake vacuum pump, must be driven by some separate source such as an electric motor. The battery can substitute for the alternator for these brief periods. These needs require some very careful consideration and a competent energy balance to make the decision. It would be helpful if the electrical system were 24 volt or the proposed 42 or 48 volt now being considered.

The Rankine cycle engine is external combustion. When properly designed, the burner provides the very best possible pollution control over any fuel burning IC engine with absolutely no pollution control hardware needed. Another cost saving over the gasoline and Diesel engine. This condition is accomplished in several ways. The combustion air pressure in the firebox is less than one pound per square inch and the fuel particle has a long residence time in the burner, insuring totally complete combustion. If the combustion temperature is held down below 2300°F by means of secondary air admission to the firebox, then NOx is not produced. This does not harm the cycle efficiency. To date, net reproducible cycle efficiency of the Cyclone engine is 28%, with 32% in the immediate future, already making the Rankine cycle engine competitive to the gasoline engine.

In certified testing already done with calibrated instrumentation, the Cyclone shows no unburned hydrocarbons, NOx is almost immeasurable and CO_2 is neutral when pure bio fuel oils are used. The burner of the Cyclone engine can use any liquid fuel that can be supplied to the fuel pump. Alcohol, gasoline, Diesel oils, kerosene, vegetable oils, or particularly the pure bio fuel oil now being produced from plant waste or algae are all usable fuels. This is done with no special control systems or modifications to the burner fuel delivery system or the combustion chamber.

The reduction in CO_2 production must be compared to the IC engine burning gasoline or a gasoline-alcohol mix like E-85. Fermenting various cellulose materials with enzymes produces the alcohol. The process generates large amounts of CO_2. The IC engine burning gasoline or alcohol produces CO_2 in the exhaust. Unavoidable, as carbon and hydrogen are the component molecules that make up alcohol.

The energy content of alcohol per pound is less than gasoline or Diesel oil. Alcohols are around 8,500 BTU/lb. while the petroleum fuels range around 19,000 BTU/lb. To obtain the identical power output from the same engine when burning alcohol one must increase the fuel flow rate. It is also advantageous to increase the compression ratio to take advantage of the high octane rating present in alcohol. If done, this results in engines that then cannot be fueled with burning gasoline again as destructive detonation takes place with piston damage occurring.

Burning alcohol in the IC engine with its changing internal pressures and temperatures also produces some dangerous byproducts that are health hazards.

One important restriction present is that the Diesel engine cannot use alcohol fuel and the spark ignited IC engine cannot use these bio fuel oils. What is desired is an engine than can cleanly use any liquid fuel without any compromise. The selections available just got very small.

The Diesel engine when burning this bio fuel oil also shows a neutral carbon emission condition and a high net efficiency. However, as the Diesel cycle depends on a high compression ratio for the ignition phase and a resulting high combustion temperature, the NOx generation is a very serious matter. NOx is inherent with any Diesel engine and unavoidable.

Soot is a result of momentary imbalance in the air/fuel ratio. Some reports identified the universal use of turbo-charging with the Diesel engine and one particular transition point that is the root cause of the soot production. Open the throttle and the fuel flow rate is immediately increased; but the turbocharger has not spooled up to the point where the excess air is produced. This condition causes an over rich mixture and soot is the result, the belch of black smoke when an older big truck takes off from a stop. Manufacturers are now including variable vane systems and two-stage supercharging in an effort to maintain the right air/fuel ratio at all speeds and loads, a mechanical supercharger and a turbocharger in series. Or smaller twin turbochargers that spool up faster.

Some industrial Diesel engine manufacturers have stopped supplying these engines for truck use, as the cost of efficient NOx and soot pollution control devices has driven the cost of these engines beyond what the customers will accept. Caterpillar is one who took this path in 2008.

Automotive users of the new Diesel engines while very well with fuel consumption, very durable and giving a high torque output, are using involved, expensive and complicated exhaust converter systems to meet the EPA pollution standards. These require the addition of special fluids to the exhaust stream to control the NOx and converters and filters to handle the soot production. This addition and some mandates from the EPA to insure that this fluid system always operates, have added unnecessary high cost to the new vehicles that offer Diesel alternatives to the usual gasoline engine. Their new common rail fuel injection systems are computer controlled, adding more cost and potential reliability problems that are already being noted. Some data suggests that all the usual large interstate truck Diesel engines now require such a pollution control addition to meet near term government mandates and that the cost is up to $14,000.00 per engine (Cummins). This is simply not acceptable to truck owners. A new power source for them is needed.

One inspection under the hood of any new IC automobile will amply illustrate just how complex and costly all this pollution control and engine management has driven matters. For the vehicle owner, all this hardware and electronics translates into some eye watering repair bills down the line. An alternate engine for them is also indicated and the Cyclone neatly bypasses all of this.

What is still a present viewpoint by the entire Automotive Industry is that the Rankine cycle system was such a miserable failure during that Clean Air Car program the government sponsored between 1960 and 1985 that they refuse to even give it one glance today as a potential candidate. What is needed here and soon is a nice installation of a Cyclone engine in a modern automobile and for it to be exhibited and demonstrated. If it really is shown to be as successful as it should be, then these previously held viewpoints should be erased. This has not been done to date.

The historical version of the automotive steam system has always been a collection of components all tied together by a maze of plumbing and fittings. The Cyclone was designed from the start as an integrated one-piece unit of impressive compactness. The photograph at the end of this paper shows the current developed automotive Cyclone engine for automobiles. Every single component that makes up this Rankine-Schoell cycle engine is packaged into one neat unit and it will easily fit where the present IC engine is located in the vehicle. The only outside connections are the fuel line, the cable supplying electric power to the combustion air blowers, plus the forward-reverse lever and the output shaft.

The moving parts count in the Cyclone engine is drastically reduced when compared to any IC powered vehicle. Compared to the present automotive IC engine and automatic transmission, the Cyclone is simplicity personified.

The control of the steam pressure and steam temperature has been a vexing problem with some earlier steam car systems. Early addition of electric controls to the Doble and other steam cars in the 1920's only managed to add some unreliability issues. The Cyclone engine is able to employ simple relay logic controls fed by thermocouples and a pressure switch to control the water feed and burner operation, or the simplest of microprocessor control modules.

The cost savings here with this engine are a major improvement over the highly complex computer systems now employed with the IC gasoline engine in vehicles for engine and fuel injection management. The noted cost savings over any hybrid, plug-in-hybrid or other such pasted on additions to the gasoline engine are going to be a major savings in the production costs over those vehicles.

There is one additional issue with employing any steam system for vehicle use, the labor time to retool the assembly lines to manufacture the engine. However, every single major automotive company makes special high performance models in limited production. Mercedes-Benz has their AMG division, GM makes higher performance Corvettes, Chrysler makes the Viper, and on and on. They are already used to small production runs.

The tasks to assemble the Cyclone engine are not involved, only different and there is no logic to consider that producing such an engine would cost even as much as these high performance special cars. This is not seen as a problem for even limited production. Careful analysis of the complete Cyclone engine indicates that it will be less expensive to produce than the present high performance limited production cars, not to forget that it eliminates the complicated and expensive automatic transmissions now in universal use.

There is one other previous operating demand with the old steam cars that not only limited the cycle net efficiency; but also added frequent and involved maintenance needs that could not be ignored. These centered on the need to inject special steam cylinder oil into the steam line to the engine to lubricate the piston rings and valves. This oil contaminated the heating surfaces in the steam generator forming carbon that had to be cleaned out on a frequent basis. It also coated the steam side surfaces in the condenser and reduced the heat transfer rate by a considerable margin. It also limited the maximum steam temperature that could be used to about 750°F, thermal breakdown of the oil and this put a cap on the net cycle efficiency. Any failure of the oil injection pump and instant engine destruction was often seen.

From the start of the development of the Cyclone engine this oil need was rejected in toto. The Cyclone is a totally water lubricated system. The specially developed crankshaft and connecting rod bearings and the piston rings use only the deionized or distilled water that the engine cycle uses. This enabled the company to work with much higher steam temperature and this made a drastic increase in the net cycle efficiency of the Cyclone engine.

This is simply the most dramatic and major improvement in the Rankine cycle engine seen in the past sixty years. The Cyclone engine has fine durability and this invention has well proven its worth. Of course material research was needed to accomplish this feat, but it was done successfully.

This was the most critical, important and pivotal development by Cyclone Power Technologies Inc. Without this oil elimination, the Cyclone engine would never have gone beyond the efficiency of previous steam car power systems.

Two operating conditions are demanded to make the Rankine cycle steam engine competitive to the gasoline or Diesel engine. Very major increases in the power density and improved higher net cycle efficiency were absolutely essential.

Power density is gained when the operating pressure is increased. The steamers of old ran at pressures between 500-1200 psi. The Cyclone uses steam at up to 3200 psi; coupled with this are the use of very low clearance volumes and a very short admission cutoff at speed. The combination has proved to be very successful.

The efficiency gain is obtained by increasing the steam temperature from 600-750°F up to 1200°F. The Cyclone is also shown to gain high net cycle efficiency by the use of carefully designed heat exchangers that recover waste heat in the cycle and recuperate that heat back into the cycle where appropriate. There is a material limit to how high one may go with steam temperature, so careful attention to recovering all possible otherwise wasted heat and returning it to the cycle is in order and has been done. Thermal and mechanical losses were given the most intense development in order to reduce them to the lowest possible amount. This is ongoing detailed improvement development.

As the Cyclone engine demonstrates high net cycle efficiency, one becomes aware that any drastic increase in operating steam conditions is simply not needed. The engine already is competitive to the IC and Diesel engine and automatic transmission package seen in the modern automobile. Where further development will be seen, is in minimizing thermal and friction losses.

Considering all the advances in the technology that Cyclone Power Technologies Inc. has invented and demonstrated makes this one engine a very suitable candidate for vehicle propulsion, both in passenger cars and interstate trucks.

THE DEMONSTRATION VEHICLE SELECTION.

The first vehicle to employ the Cyclone engine is critical to how this engine will be received by the motoring press and particularly the automobile enthusiasts and wealthy collectors, the ones who would be the first to purchase such a car, should it be followed by a limited production model.

Does one choose a sub-compact car like the SMART, or a more reasonable small vehicle such as the Ford Focus, or go further and demonstrate a nice high performance vehicle that would be impressive when shown at car exhibits? Would a mid range family sedan be more appropriate? The Cyclone is quite adaptable for any first vehicle use. The package must create a good, usable and desirable vehicle.

The considered first public application should be a high performance vehicle, in the author's opinion. These are on the market as production cars right now and many high quality limited production specialty vehicles and kit cars are also available for installation of the Cyclone engine. Such a vehicle attracts attention and press coverage is frequently the result. A converted C-4 Corvette is suggested.

To date the enthusiast car publications do not even know the Cyclone engine exists. These have huge worldwide sales and are very well read. Most important when one considers introducing such a new power system for the automobile.

The company should not contemplate producing any complete car on their own. The capital investment, time and production costs are not realistic for a company such as Cyclone Power Technologies Inc. There are a sufficient number of available vehicles on the market, in one form or another, that can easily supply the complete host car at reasonable cost. Be it either a conversion of a production gas car, or an installation in one of the specialty cars.

What with the present confusion and financial problems the Automotive Manufacturers are facing, the suggestion is that the company forms some type of alliance with one of these specialty car makers. Chrysler has visited the company and there was interest shown by GM and Ford. This is not considered to be any intent to adopt the Cyclone at the present time, but only an effort of due diligence by the car companies. The major interstate truck manufacturers are starting to show interest, as their Diesel engines now need high cost pollution control. The overall cost of this exceeds what their customers will accept, so some other rugged power source is needed.

The military have also shown interest in the Cyclone for their age-old need of a multi-fuel engine of light weight, small size and silent operation for battlefield operations and other often classified applications. However, this is something that they constantly have investigated over many years as a real need is there and the Stirling cycle engine has not provided any answer.

The company is presently concentrating on their waste heat version of the Cyclone and contracts are already in hand. The adaptability of this version to use solar heat fills a worldwide need for local electric power generation in third world and less developed nations and that is a correct business decision by the company.

The vehicle adaptation of the Cyclone engine is becoming an important matter and some demonstration is needed in the immediate future. It takes time and effort to make the automobile companies take notice. They need to become well educated to the advantages shown by the Cyclone engine over the often science fiction and fantasy engineering approaches they now pursue.

The battery electric car is developing a market for a reasonable city vehicle. The makers are too busy with their own major problem of a cost efficient source of power batteries and will not be seen as even investigating the Cyclone as a secondary line for production. The proposal is an automotive store offering clean city cars and also long distance vehicles for family use. While the electric is a suitable city car of growing high interest, it is not suitable for any long trips.

Should a really competent installation be done in some nice high performance car and testing proves the concept, then there may be interest by the surviving Automobile Manufacturers. The Cyclone powered demonstration car is the first priority to accomplish this task.

James D. Crank is a retired engineer with Lockheed and one of the foremost experts on automotive steam engine systems. During his long year career with Lockheed, Mr. Crank worked in senior research positions on many important projects, including: engine development for the Ground Vehicles Department, primary battery systems for the Triton II missile, battery systems for the Hubbell Space Telescope, heat shields for the Mercury and Apollo space systems, and dynamic solar and nuclear space power systems for SDI. Mr. Crank was also a Research Engineer for the Stanford Research Institute where he worked on explosive cladding of materials for cylinder construction in Porsche and Mercedes-Benz, among other projects. Mr. Crank also has over 50 years experience in restoration, repair and driving of various steam cars, including the total redesign of the complete Doble crankcase assembly and cylinders for the Series E Doble steam cars (with 10 sets constructed), and the design and construction of the current speed world record holding steam car. He served as a consultant on steam car restoration to Harrah Automobile Collection, Nethercutt Collection, Jay Leno Collection, Stephen Finn Collection, and the Besler General Motors Chevelle steam car, among others; a consultant to the State of California on the steam bus development program; and is on the Board of Advisors of Cyclone Power Technologies. He is the owner and president of Doble Steam Motors Corporation, and is currently working on a book about the history of the Doble steam car and its founding family.