Vision: Steam power is practical.

It is the only presently practical way to turn bio-fuels into mechanical motion. Thus, steam power allows the use of clean burning, domestically produced, renewable fuels that do not add carbon to the atmosphere when they are burned. These external combustion engines burn clean because they can have a large combustion chamber with plenty of dwell time and plenty of turbulence and an excess of oxygen over the stoichiometric ratio so the burn is clean of any of the standard pollutants.

Steam power is practical because of modern designs, modern materials, and new technologies. A modern steam power plant is about the same size and weight of a comparable output gasoline engine. A steam power plant has the further flexibility in that it has many components: combustion chamber, heat exchanger, expander, and condenser. These components can be made of many different geometric shapes and positioned throughout a vehicle, thus not requiring a large engine compartment. It is capable of burning any type of fuel—liquid, gas, solid, or pelletized; either domestically produced coal, bio-diesel production by-products such as glycerin, specifically grown cellulose, or ethanol production by-products such as lignin and cellulose in its unprocessed form.

Mission: To collect all of the information possible, to mine such information, and to sort it.

The information being collected comes in many forms. The most useful information is in the form of good running modern steam powered automobiles, followed by steam generators, and engines that have been dynamometer tested. There are prototype engines, designs, and inventions that have been made over the years and since abandoned as people passed on. It is possible to learn almost as much from failed projects as it is from successful ones because they teach us which paths to not take.

To this end I have collected books, about 600 titles with many of them being University text books, SAE Technical Papers, over 80 of them steam power related, 6,000 patent numbers, private notes and correspondence, and steam magazines from the 1930's on until now. I have done many interviews with people who knew steam people or who did the work themselves. This interviewing is an on-going project.

Goal: My goal is to write several books on this subject.

One book will be about the people who spent their lives working in their garages and shops, trying to make something that works. Another book will be a technical how-to book on modern steam design. To that end I am presently traveling around the country interviewing people. I have found steam people to be the most interesting, intelligent, and friendly people in the world. They do not all agree. Not only do they not agree with other steam people, few even agree with themselves. This is because steam power is very complex. It has many possibilities for designs. The many different theories and designs is what makes the study of steam so interesting.

The Conclusion: The conclusion is that enough information is available to make an efficient modern steam power plant.

New inventions and new engine designs are not needed. What new engine designs that are publicized every so often usually involve some variation on the rotary engine and they do not work with steam because of sealing problems and differential expansion from the heat in the steam. Steam enters the engine very hot and then rapidly cools as it expands and work is done which is the cause of differential thermal expansion. In a conventional piston and cylinder engine there is always room for incremental improvements and people are working on improved burners, heat exchangers, control systems, valves and valve timing, and variable clearance volume engines that will increase the thermal efficiency of steam. A great deal of engineering will be necessary before commercial production begins. The engineering is going to be very expensive, as is all engineering, but the basic knowledge for a good design is in existence.

A steam power plant is very complex because multiple heat exchangers are needed, corrosion and lubrication problems need to be solved, high turn-down ratio burners need to be engineered, and there are very few off-the-shelf components available. An even more serious problem comes from the fact that engineering schools no longer teach steam technology. Thus there is no reservoir of experience to draw on when doing the engineering work and people with experience are a critical part of the infrastructure necessary for a new technology to be engineered and practically manufactured.

Steam power has application in our modern world both in a high technology modern transportation system, in distributed power generation, and in a very low technology application for stationary power in a Third World setting. In both areas renewable fuels that are non-polluting can be used.

Reason: The reason for engaging in this project is because my interest in steam is based on emotion, as are all great passions. There is a primal fascination with making a fire and then using it to produce power. Any fuel can be burned and the whole process is nearly silent with just some fan noise and the clicking of moving metal parts. An internal combustion engine (hereafter IC), in contrast, has the fire unseen and inside the cylinders and because the combustion consists of intermittent explosions it is very noisy. The power produced by a steam engine can be made with highly variable torque, thus allowing it to operate without clutches and transmissions if one so desires, greatly simplifying the drive train. The entirely different feel while driving a steam powered automobile, as compared to an IC powered one, is one of the main emotional attractions to steam cars.

Modern steam developments are little known. The people who are working on them seldom write things down. When they die their work dies with them. There is a need to preserve the stories, the visions, and the experiences of those who have devoted their lives to working in this obscure field. Sometimes all we have left is a piece of equipment and all that we can do is to take it apart to see what the thought processes were of the builder. I want to preserve this technology. I want to save these pieces of iron. I want to remember these people.

Another attraction to steam power is that it is something a person can do in their garage with a lathe and a mill and a welder. It has not gone to the stage of complexity of present day computers and microchips where an individual cannot make a contribution to the world.

A steam power plant is made from fabricated metal. It does not use unseen electrical impulses to do its work. It is an area where one person can think and work and produce something of value to the larger society.

Steam power is a useful technology at many different levels and in many areas of life still in the 21st century. The modern rich person living in suburbia would benefit from a totally quiet, totally non-polluting steam lawn mower or leaf blower, for one example. The peasant in sub-equatorial Africa would benefit from a passive solar collector powering a low-tech steam engine that could pump clean water from deep wells. This would replace a noisy diesel engine dependant upon expensive imported fuel and requiring regular maintenance by a skilled mechanic. The Micronesian living on an atoll in the middle of the ocean would benefit from a golf cart sized vehicle that could burn whole and un-processed coconuts, husks and all, or just the husks after the copra was extracted, to drive around the island. They could use the same technology to power a fishing boat. The American farmer could burn excess, cracked, or moldy corn to power his farm tractors freeing him from the expense and logistics of using foreign oil. The maker of small robots or small two wheeled personal transportation vehicles needs a power source more compact, more long lasting, and more capable of using renewable fuels than batteries. At the present time everything from video cameras to mobile telephones to golf carts is dependant on battery power. The battery can either be replaced by a very small steam engine or can be locally re-charged by a small steam engine that burns locally produced fuel. The fuel can be anything from thorn bushes to oil palm nuts to camel dung.

There are two examples of these small electrical generators that were used during WWII. One was a radio battery charging unit that went in with the paratroopers and burned gasoline and the other was used by the British in isolated areas. It burned wood. It was very clever and it all fit in a small foot locker.

There are other possibilities, endless and unbelievable to the uninitiated into the technology of modern steam. As one example there are many benefits from and possible designs for a light weight high-torque low-speed steam engine for use in an ultra-light airplane which would eliminate both the exhaust noise and the propeller noise of the present power sources. Because a steam engine can be engineered for any torque and rpm range desired, the engine for an ultra-light aircraft would be more reliable than an IC engine because it would not need a gear reduction and the propeller would be much more efficient because it could be very large and slow turning.

A great deal of time could be used correcting the common misconceptions of steam power such as the belching of clouds of black coal smoke, the long time period required to get them fired up and started, the danger of the boilers blowing up, the need to stop every few miles to tank up with water, and that steam vehicles have to be heavy, rusty, and run on steel wheels. These were true conceptions about antique steam power, a technology 150 years old. None of these are true about modern steam, which is why, in fact, it is called modern steam, and why I am interested in it.

And finally, there is an element of idealism in working on an idea that has the potential to make the world a better place. A person's standard of living improves when there is no noise pollution or air pollution. The societies' standard of living improves when there is no pollution from the heavy metals used in batteries and when carbon is not added to the air when fossil fuels are burned, and when fuel sources are indigenous and not transported in tanker trucks and railroad tank cars. Economists refer to all of the above listed negatives as external costs. Usually they are borne by the larger society.

I have been fortunate to have been in the right place at the right time to have met some of the grand old men of the steam hobby; I have collected all of the steam hobby periodicals—Steam Car Developments and Steam Aviation, Light Steam Power, The Steam Automobile, Steam Power Quarterly, Steam Calliope, Modeltec, Live Steam, and the Steam Automobile Club of America Bulletin, as well as many steam boat periodicals. I have collected the classic steam texts as they are being thrown out of libraries and offered for sale on the used book internet market. I have been given access to the files of Bob Lyon who collected much and saved all and who was the first head of the Steam Automobile Club of America, founded by him in 1957. This material was preserved by his successor as SACA president, R. A. Gibbs. His son, Ed Gibbs, saved it all and gave it to me to keep. I have looked at, sorted through, and made scans of 20 file cabinets full of material from the twins, Calvin and Charles Williams, of Ambler, Pennsylvania. These files contain detailed records of the work of three generations in steam as well as a collection of reports not available anywhere else. I was given the steam literature collections of the late Bill Seiple, who attended many local steam meets and recorded most of them and of NASA engineer Doug Garner when he cleaned his garage out. I am the beneficiary of a complete listing of Society of Automotive Engineers technical papers relating to steam that Dave Nergaard has collected during his lifetime. Ken Helmick has put together a CD with 5,000 steam related patents on it in a searchable form. From George McNeir II in Wilmington, North Carolina I received the Stover engine and boiler that is all that is left of Professor Stover from the University of Pennsylvania lifetime's work in steam. I was at the late R. A. Gibbs' auction in 1995 and purchased many home made and unique steam engines. I collected much of Bill Cartland's home made steam engines and boilers and, more than that, have several hundred pages of his hand written thoughts and designs that distill a lifetime of work in steam. I have most of the steam things that the late John Wetz made. These are enormously clever designs, to be appreciated the more once one gets past the fabrication. John did not have much money to work with when making things. These are the main sources of information that I have access to and that I uniquely have access to. Something is learned from everyone that I come into contact with and this is not the place for an exhaustive listing of all of the knowledge available about steam.

All of these sources of knowledge have put me in a position unique in this world to present the story of modern steam developments. I take this responsibility seriously. My only wish is that I had the awareness, this 'Road to Damascus' experience, much earlier in my life.

There is an assumption in this modern day and age that all information is available on the internet, accessible with a little word description and a clicking of the mouse. It has been my experience that this is not true. Not only do I find very little solid steam information available on the web, I also find much of the easily accessible information; that put out by the proponents of Tesla turbines and complex rotary engines, to be less than useful. Often what is self-described as being modern and efficient is neither.

I hope that the reader will find this digest of the work that has been done in steam to be as interesting as I have found it.

Design options: One of the problems with steam engine design is that there are a great many different ways to design a heat exchanger and a great many different ways to build an engine, otherwise known as an expander, powered by a pressurized gas that comes from a source outside of the engine, such as the boiler or steam generator. The IC (internal combustion, Otto Cycle) engine has many constrictions on its design and thus there exists a standardized design well perfected over years of engineering, manufacture and use.

People thus see the limitless possibilities of ways of making steam and of turning it into rotary power and think that what the steam world needs in order to be practical is another good idea.

Therefore I am going to begin this dialogue by telling the right answer about design. The right answer is to use a mono-tube steam generator that turns out steam in the 2,000 psi pressure range and 1,000 degree F temperature range to make the steam and then to use a high re-compression uniflow engine running at high speeds, of close to 5,000 rpms using poppet valves and very short cutoff, to make the mechanical power. There have been two very successful developments based on these principles; the work of Jay Carter and his son Jay Jr. in Burkburnett, Texas and the work of the Williams brothers and their father in Ambler, Pennsylvania. There are differences in their work but each produced a modern steam powered vehicle that drove over 5,000 miles on the highways with performance and efficiencies approaching that of an IC engine powered vehicle. They achieved efficiencies 4 times greater than was possible with the historic Stanley steamer.

They each worked in near isolation and financed the work entirely with their own money. They tested their engines on dynamometers making incremental improvements as they went along. They were not promoters and thus their work is not widely known.

Presently Harry Schoell out of Pompano Beach, Florida, doing work under the name Cyclone Power Technologies, is doing development work on a steam power plant of his own design. Some of his design work is awaiting patent protection before it can be disclosed. What we do know is that Harry has a firm grasp of the thermodynamics of steam and that he is trying to solve many of the classic problems of steam, that of corrosion and lubrication. He is working on a unified engine which is one where all of the several components are in a very compact package.

By contrast, many people remember Bill Lear's work on steam engines from 1968 to 1971. He spent $10 million on steam development while engaging in endless publicity and self-promotion. Because of all this publicity many people say that because Bill Lear was a smart person and because he spent a lot of money trying to develop modern steam and he failed, therefore it cannot be done. It would take a book to document the mistakes made and lost opportunities of Lear's work. While this study would be instructive in showing how people can go about doing things the wrong way it would take time away from presenting the right answer. In the last two years I have located ten of the people who worked for Lear and interviewed them. Most of them went on to work for Cornelius Dutcher of Steam Power Systems in San Diego. There they made a bus for the California Clean Bus project and a small car for the Clean Air project. The car is presently on loan to the Petersen Museum in Los Angeles. The last work done at SPS was on a test engine that achieved 22% thermal efficiency while its goal was 27% thermal efficiency. The work on this engine and a further analysis of the engine are available from the Steam Automobile Club of America Storeroom.

Just to finish up a little more on the Bill Lear story, Peter Scott Brown, who had worked on steam projects in England for Sir Alex Moulton and then with Abner Doble in the early 1950's on the McCullough-Paxton steam project before working for Lear, said that Lear was the smartest person who ever fired him. Lear hired several people from the McCullough project but the real problem was that the first person to get him started on steam was Ken Wallis who only wanted to find some way to cheat at Indianapolis. He had tried gas turbines and now wanted to try steam in an attempt to get more power than the IC car engines were developing. Therefore the first people hired were race people from Southern California and only when the race car did not develop did Lear start to go into other and more practical areas of steam power. He was in too much of a hurry to do good development.

Here is basic steam theory, useful information both for those who do not know anything about it and for those who think they know something about it. Steam works because of the volume increase of 1640 to 1 that happens when water does the phase change from liquid to vapor. As a practical matter that expansion ratio does not continue as pressure increases, at 100 psi the expansion ratio is 270 to 1, and at 250 psi it is 114 to 1. The expansion ratio is important because it takes power to pump water into the boiler and given the large expansion ratio at the same pressure the water pump takes up a small percentage of the power generated. As an aside, the jet engine and gas turbine, using the Brayton Cycle, uses half of the power generated by the heated gases to compress air into the system.

Steam power is intrinsically inefficient because of the loss of heat used to boil water, to affect the phase change, because of the high latent heat of vaporization. When steam is condensed back into water, something necessary to do so it can be pumped back into the boiler to keep the process going, all of the latent heat of vaporization is lost. This is why there is a low thermodynamic efficiency intrinsic to a steam cycle. Needless to say many people have devoted much time to getting around basic laws of thermodynamics. It is not easy to do and a book can be written about the attempts. Davoud and Tinker and Jeremy Holmes have worked on re-using steam without condensing it.

A good and brief explanation of why the Rankine Cycle is not as efficient as the Otto or Diesel Cycle is given in the book: Introduction to Thermal Sciences, Thermodynamics, Fluid Dynamics, Heat Transfer by Schmidt, Henderson, and Wolgemuth on page 155: "The simple Rankine cycle does not have a very high thermal efficiency. The efficiency of the ideal cycle under the conditions given in Example 5-13 was found to be only 40%, yet the Carnot efficiency between these temperature limits is 59%. The difference is due to the fact that the Rankine cycle is not an externally reversible cycle. Heat is added to the Rankine cycle at temperatures below the maximum cycle temperature." And then the book goes on to give examples of regeneration to improve the theoretical thermal efficiency.

Steam power is very attractive because it is an external combustion engine which means that all fuel types can be used and they can be burned in such a clean manner as to eliminate air pollution. Air pollution is defined as carbon monoxide, unburned hydrocarbons, particulate carbon matter, amd nitrous oxide. It is attractive because of the flexibility in power transmission because it is a high pressure gas, able to be used in almost any kind of an expander.

There are many problems with steam power. A book could be written on the subject. What is needed more is a book that instructs people what not to do much more than what to do in making a steam power plant. There are many ways to err and someone somewhere has already made every possible mistake.

A smart person once said that engineering is a series of compromises. A steam power plant is a work of engineering and a very complex one at that because it uses heat and heat does many things. It melts metals. It carbonizes lubricating oil. It flows, always, and by radiation, conduction, and convection, from the heat source to the heat sink, obeying the Second Law of Thermodynamics. The efficiency of a heat engine was determined by Sadi Carnot as increasing with the difference in temperature between the heat source and the heat sink. Thus there is always the tension in steam engine design between using the hottest combustion temperature possible to make the hottest steam possible for high thermal efficiency purposes, and of designing for reliability and convenience of operation, which means lower temperatures and pressures. One of the stories told in steam circles has to be apocryphal. It is still worth repeating. The story comes from the 1950-53 McCullough-Paxton project under the direction of Abner Doble who was working on his Ultimax engine design. The documentation of the Ultimax steam engine is in Volume 1 of The Collected Papers of Abner Doble as sold by the SACA Storeroom. Abner was trying for maximum efficiency and thus was using very high steam temperatures. As the story goes, the steam was so hot that the cylinder walls glowed a dull red making it transparent enough so that the piston could be seen going up and down.

The basic principles of steam engine design were written by Professor Stumpf in his book; "The Una-Flow Steam Engine" 1922 by J. Stumpf, Second Edition. This is what is listed at the top of page one: 1. Steam Engine Losses.

The losses in a steam engine may be classified as follows:

1. Losses due to cylinder condensation (surface loss).
2. Losses due to the volume of the clearance space (clearance volume loss).
3. Loss due to throttling or wire drawing.
4. Friction loss.
5. Loss due to leakage.
6. Loss due to heat radiation and convection.
7. Loss due to incomplete expansion.

The genius of each of these points will not be appreciated until a person has spent half a lifetime thinking about and working with steam.

They are presented here, early in this explanation, for the purpose of reassurance, so that the new steam person will know that someone somewhere has already thought about steam theory at great length and has come to the right conclusions.

Professor Stumpf's work can be condensed to the simple axiom of steam engine design: keep the hot end hot and keep the cool end cool and do not let any pressure leak away. The hot end is the cylinder head where the steam enters at boiler pressure and temperature. The cool end is the other end of the cylinder, where the piston is at bottom dead center and where the steam has been cooled by expansion, and where the cooled off steam is exhausted if it is a uniflow design. Because a cylinder is a pressure vessel it is usually made in one piece and thus does not have any thermal breaks so there is a temperature differential from one end to the other. It would be better if the cylinder were made from a non-conducting material. In order to do this successfully much research needs to be done into materials.

It is not easy to find a ceramic or carbon fiber material that will handle the high pressures, the friction of the piston rings or the trunk piston, and the many heat cycles.

The reason for the great temperature difference between one end of the cylinder and the other is because steam contains a lot of energy in it. This is called enthalpy, sometimes spelled, enthalapy, and this means that steam has a lot more energy in it than compressed air at the same pressure and temperature. Therefore in a modern short cutoff engine, as steam expands 25 times in a cylinder it cools off from 850 degrees to 300 degrees F cooling off the surrounding metal surfaces. For purposes of thermal efficiency it is important to not lose any heat from the incoming steam, but to use all of its heat to do work. This will give a person some idea of the basic parameters of steam engine design. We understand that not everything important to steam engine design can be explained on one page. There is even less of a likelihood of a person understanding everything needed to know about steam by reading one page. Thus many important points will be made as conclusions first, and then the detailed explaining, and hopefully the complete understanding, will come much later.

The reason for bringing up Stumpf's Principles and the keeping the hot end hot rule is to explain why a the conventional IC engine design of a piston in a cylinder is also the best possible steam engine design and what is the basic weakness of a complex rotary engine design. And this brings up another important point that everyone thinks about when they first start thinking about steam power. More precisely this is what most people waste a lot of time thinking about when they go to design a new steam engine. The waste of time is to try to find a better working fluid than water. The perfect working fluid is the Holy Grail for which everyone seeks. It is equally unattainable. Cal Tinkham has even named it, unobtainium. Water is the best fluid. You can either take my word for it or waste a lot of energy that would be better spent solving the many other real and important issues in modern steam design. If an organic fluid is absolutely necessary then toluene is the most workable choce.

Before going into the fine points of achieving steam practicality and efficiency; not necessarily compatible goals, a real basic explanation of steam power is needed. The basic principles upon which steam operates are covered in mind-numbing detail in Keenan and Keyes.

This book is more properly called: "Thermodynamic Properties of Steam including Data for the Liquid and Solid Phases" by Joseph Keenan and Frederick Keyes, 1936 and 1948. These little 89 page hard cover books are going for one dollar on the used book internet market and everyone needs two or three of them around. Libraries are throwing them out as fast as they can to make room for more computer stations.

The mono-tube steam generator is a much better term to use than a boiler because boilers in the past were made of iron plates and used to blow up and kill people. Sometimes this type of a steam generator is called a flash boiler. Although a true flash boiler works on a slightly different principle, it is a good name for a monotube because it makes steam in less than one minute from cold startup. It is typically a few hundred feet of ½” schedule 80 black iron pipe coiled up into some combination of helical, frusto-conical, or pancake coils. Either way it is all one long piece of pipe. It is heated with a flame. Water is pumped into the pipe at the end furthest from the fire/flame, thus achieving counter-flow and good heat exchange of the heat from the combustion products. Somewhere along this length of pipe the water turns into steam at a high temperature. Technically that is called the transition zone and it is difficult to know exactly where this is happening. A monotube is a fairly effective heat exchanger. There is a high surface area to volume ratio. There is a good safety factor because of the pipe’s 8,000 psi burst strength. It is cheap and can be made using simple jigs. There are very few welds. There are many issues, but the purpose here is introductory, which is to show that water is pumped in one end of the pipe with a high pressure water pump, that takes work to do, and then it expands by volume about 500 times by the time it comes out of the other end as steam, and at the same pressure the water is pumped in at because it is one long pipe. The steam is a vapor, but it acts substantially as an ideal gas and according to the rules of Boyles’ Law. This pressurized gas runs through an expander, more commonly referred to as an engine, and gets turned into power. The big difference between a vapor and an ideal gas is that if the vapor cools too much it begins to condense into droplets of liquid and this phase change causes a serious reduction in thermal efficiency. As long as the steam is highly super-heated then it will not begin to condense while in the engine.

Therefore the first half of a steam power system, which is the burner and the boiler and the water pump and the control system for both the burner and the water pump, is just a means of turning fuel burned in an open flame at nominally atmospheric pressure into a high pressure gas enclosed in a pipe. There are very few other ways to use heat to make a high pressure gas. The other ways are the Ericsson Cycle, the Stirling Cycle, and the Brayton Cycle. None of these are as compact or as flexible as the steam engine, the Rankine Cycle. A good introduction to the principles of all heat engines can be found in the book: “The Evolution of the Heat Engine” by Ivo Kolin.

The second half of the steam power system is the engine. As a general rule the modern steam engine looks a lot like an I.C. engine. It has a crankshaft, connecting rods, pistons, cylinders, and poppet valves. As another general rule it is one fourth the size of an I.C. engine of equivalent power. This is because it has twice the number of power strokes per revolution as a four cycle Otto engine and it has double the MEP of an I.C. engine. MEP stands for Mean Effective Pressure. MEP is a way of measuring or defining the pressure pushing down on the piston during its power stroke. It is a useful piece of information because this is what causes torque. What this shows it that the steam engine itself, the expander, is only a small part of the entire steam power system. The burner, boiler and condenser are equally important and together they often weigh more than the engine.

Valves: The steam engine needs valves to let the steam into the cylinder and to let the exhausted expanded steam out of the cylinder. There are any number of valve varieties out there. At last count I have seven different types in my collection. Which kind a person chooses determines much about steam engine design. You would do well to not respond as did one new and enthusiastic attendee to a steam meet who announced that he was going to make a steam engine. Whereupon one of the old timers politely inquired, by way of making conversation, about which kind of valve he was planning on using because this is the usual icebreaker for a long steam discussion, and the newbie said that he had not thought about it much, he just planned on going to the hardware store and buying some valves.

The great axiom of steam engine design is that there are two kinds of valves: poppet valves and those that leak. That said, for years Doble used piston valves (also known as spool valves, the same thing and the exact same design used in hydraulic power systems) because they could be operated by a harmonic drive, which is another way of saying an eccentric drive or crank drive. The harmonic drive produces a sine wave. A crank is easier to make than a cam shaft with lobes, which is necessary to actuate poppet valves and involves some complex machining.

Another common error made by all new people to steam is to suggest that it should be easy to convert a regular I.C. gasoline engine to steam. They think that all one has to do is to take the carburetor off the intake manifold and replace it with a pipe fitting for the incoming steam line. Some minor fiddling with the cams is in order to change it from a 4 cycle to a 2 cycle action and then it is done. This has been tried more than once and never with any success. A listing of all of the reasons why this does not work would fill a book and our time may better be spent at this stage in our steam education to explain what does work and why instead of enumerating all of the things that do not work.

A cautionary tale is in order before leaving, albeit temporarily, the subject of valves. That caution is about rotary valves. Rotary valves are like rotary engines; there is an initial and seductive attractiveness to them. Everyone thinks that they are the solution to all the world’s steam problems. Without going into detail I will just state that they leak when they are cold and seize up when they are hot. This leaves a very short time period during which they actually work. Richard J. Smith had years of success using rotary valves and converting Mercury two-cycle outboard motors into steam engines, but he was a genius.

There are many reasons why steam powered automobiles did not become the standard instead of gasoline powered ones. One of the many reasons is because at the time automobiles were being developed, in the 1890-1910 years, steam power had been in wide use for a hundred years. During that time not much had changed in the way of technology. Because it was successful, or at least useable, little innovation took place. As an example of this way of thinking, the Stanleys used the same boiler and engine principles of the locomotive in their automobiles. They were clever in making everything as light weight as possible thus creating a high performing vehicle. However they were not forced to be innovative as were the IC engine developers. So there was a psychological problem in that the infrastructure, which means engineers, universities, text books, and mechanics, were all set up to make and use big pressure vessel boilers and old slow double acting slide valve engines. Therefore there was a lot of inertia built in. To some extent new technologies were needed, such as electric arc welding and high strength tubing, to make light weight steam generators. It all did not happen fast enough to save steam cars.

High Recompression Uniflow: The high recompression uniflow engine was popularized by Professor Stumpf. He was trying to use a piston and cylinder engine to achieve the same thermal efficiencies as a steam turbine. Thus he studied the heat flow within the engine and hence the uniflow engine.

The father and sons Williams, Calvin and Charles, in the 1940's and the team of Dick Smith and Karl Petersen in the 1960's independently and both apparently inadvertently, discovered the high efficiency steam engine while doing empirical research. No one has made public any of the test results; hence the matter is being debated to this day by believers on each side of the matter. Assuming the truth of the alleged and hinted at results, here is how it works: The Williams called it the Williams Cycle and claimed that it was different than the regular steam Rankine Cycle, which is what a steam engine is called. This nomenclature has only added more fuel to the fire and the creation of more smoke to obscure a rational discussion. The reason for exploring this matter at great length is because both the Williams and Karl Petersen claim efficiencies higher than is theoretically possible with a steam engine. Such claims are always a good way to lose credibility. If such claims are true, then a steam engine can achieve the thermal efficiencies of a gasoline, or even possibly, a diesel engine, thus making it a whole new world of prime mover possibilities.

If the high thermal efficiency claims are really true, then it is because during part of the cycle the steam engine works as a heat pump. A heat pump turns mechanical motion into heat by compressing a gas. It is a well known concept and it is used to provide heat to houses because more heat is produced by compression than is produced by simply using electricity in a resistance wire or by burning a fuel to produce heat. Until some dynamometer tests are done with a Williams' steam engine it will be the discussions that are the most heated.

Tradition, psychology, or just plain human nature has quite a bit to do with steam engine design. The earliest use of steam power was to propel paddle wheel boats and then locomotives that pulled very heavy loads at slow speeds. Steam power worked very well in these applications and it was the only possible motive force that could work. This is because there did not exist, for well over the first one hundred years of steam power, either a clutch and gear box drive train that could handle the kind of low speed torque required in these applications, or a hydraulic pump and hydraulic cylinder combination, or an electrical generator/electrical motor combination that could produce low speed high torque and easily reversible mechanical motion. Locomotives and even more so paddle wheel boats needed very slow speed and high torque power in order to work. To this day the transmission of very high torque is by some system other than a clutch and gearbox.

As one example of the practicality of coal fueled steam power, the Panama Canal was dug with coal burning Bucyrus-Erie steam shovels. Earth moving equipment ceased being steam powered only when diesel powered hydraulic systems were perfected. Railroad locomotion ceased being steam powered only when diesel powered electrical generators and motors were perfected. Both the hydraulic and electrical power transmission systems avoid the used of a clutch and gear box. A large enough and durable enough clutch is still not available that will handle these high torque demands.

Because the Stanleys followed locomotive design, their engine was geared directly to the ring gear in the rear axle. It had neither a clutch nor a gear box. Both reversing and changing the torque of the engine were done by a sliding block that changed the valve timing. This was the Stephenson reversing link and it provided forward and reverse directions as well as shortened cutoff. Many steam enthusiasts to this day prefer this type of a power transmission system in a steam automobile. These engines have a very smooth torque transmission. Thus they accelerate smoothly and because of the low rpm's of the engine they have very little mechanical engine noise. Other builders of steam cars, such as Jay Carter and the late Pete Barrett, have designed steam engines with torque characteristics very similar to that of an I.C. engine. Jay Carter's bump valve engine would run at 5,000 rpm. Pete Barrett's engine was a modified VW engine bolted to the standard VW transaxle and so it ran at I.C. engine speeds of around 3,000 rpm. These employed a very short cutoff of the intake valve and a long expansion of the steam before exhausting. These engines, then, are bolted to the existing conventional automotive drive train of clutch and manual transmission. There are plenty of arguments either way and sometimes in the middle of the arguing a good reason is actually given.

Burners: Steam power uses an external combustion burner. This can be fired with anything that burns. Most of the automobiles use liquid fuel for energy density reasons and convenience. The burner types are many and difficult to make. The early steam vehicles used vaporizing burners and pressurized fuel tanks. This is because they did not use any electrical power on the vehicle and the standard burner gun that is so common in house furnaces had not been invented yet. It was invented by Abner Doble's brother in 1911 and called the NOKOL specifically for use in a steam engine boiler and for the convenience of starting the car by turning on a switch while sitting inside the car. It pumps kerosene or Number 2 fuel oil through a nozzle at about 100 psi and this makes a find mist that is lit using an electric sparker. The more common models now are the Beckett and Riello burner guns. These do not have a turn down ratio.

Vaporizing burners were a good idea until the pilot light blew out in the wind or the vaporizing tube filled with carbon because it got too hot or any of many other problems developed. Other than that they were quiet and compact with a blue flame. The advantage is that they are self contained not needing a fuel pump or an air blower. All one needs is a match and a blow torch to get the forks heated up to start the pilot light. With the pilot running all night both the car and the garage it was in were kept warm all winter and then it was ready to go in the morning. In fact, one of the real advantages of a steam car at the turn of the last century is that it would start in cold weather whereas an IC car was very difficult to start in the cold.

Attempts to get high turn-down ratios for the burner, which were important for vehicles that had widely varying power requirements, often used a spinning cup burner. Ed Blakeman was one of the first to demonstrate it at the early meets. Then both Jay Carter and Pete Barrett used them. They had a very low power requirement and did a fine job of atomizing the liquid fuel. They could use a variable flow rate.

Recently the Babington burner was resurrected for use with waste oil or used french fry oil or any heavy liquid fuel contaminated with solids that would not work in a pressure atomizing nozzle. This burner used a very small amount of compressed air to atomize the fuel and a low pressure-high volume pump to get a fuel flow over a small hole that had the compressed air blowing through it. A person has to see one of these things work in order to both understand it and to believe what a good idea it is. The fact that it is analogous to the way a whale breathes does little to assist in the understanding. I have seen one working on waste oil and it does a beautiful job.

John Walton out in the Isle of Man for years was selling plans for what he called a Freeheat burner. He did a variation on the vaporizing burner/blow torch concept by using an air compressor to blow a large volume of compressed air through a helical coil that was placed in the fire. This very hot air was then used in an air atomizing nozzle to both atomize and partially vaporize waste oil. This again was very effective because there were no small nozzles to be plugged with solids and because there was no oil being vaporized in a tube in the fire. A vaporizing tube carbons up quite easily and is to be avoided if possible.

Besler preferred the air atomizing nozzle and used one on the 1969 Chevelle SE-124 car. He wanted fool-proof burning and went to the trouble of putting a small dc motor powered air compressor in the corner of the engine compartment to supply the compressed air.

Right now people are working on corn and pellet burners to power a steam vehicle. These are a little more difficult to design than one would first suppose. However, they are the future of steam power because corn kernels and wood/sawdust pellets and bio-mass pellets are easily handled with grain augers and stored in grain bins and transported in grain trailers. They are also pure bio-mass and have all of the benefits of biomass as regards domestic fuel production, non-production of greenhouse gases, and locally diversified fuel production. They are much more efficient than the process that makes a liquid bio-fuel. Liquid bio-fuels require large processing plants and a great deal of energy input to distill the alcohol. Usually this energy input comes from either coal or natural gas, and thus the fuel produced costs a lot in the way of carbon dioxide production. Ethanol from corn is just another way to turn two solid fuels into one liquid fuel. The advantage of the liquid fuel is that the whole infrastructure of IC engines is already in place.

One of the better designs for a solid fuel, meaning wood, burner for steam production comes from the late John Wetz. He placed the fire physically above the boiler coils and pulled the fire through the boiler with a fan. Thus when the vehicle is stopped and does not need steam the heat from the hot coals is above the coils and does not heat them up. Jay Carter made a design for a small solid fuel fired electrical generator plant that used a movable sheet metal shutter to protect the super-heater coils from the flame when they did not need heat. Either of these principles can be used as they both show a possible design solution to what could be a very serious problem. The basic problem with solid fuel is that it takes a while for the combustion to get going and a similar time lag for it to quit producing heat. The solution is to have some type of a storage system where the heat is stored in a pressurized water tank. This would save the heat otherwise wasted when the car engine was stopped and have an instantaneous source of power when starting up. If designed properly, a steam engine is a natural hybrid.

Combustion theory is a whole another complex engineering question. We could go on, but the message at this point is that building a good fire that is controllable and has a high turn-down ratio and that burns cleanly is a critically important part of the steam engine. This is the starting point. Much work has been done and solutions have been developed for the clean burning of all fuel types. The history of steam automobiles has been that the fuel burned is always the by-product from something else. Because any fuel can be used by a steam car, the cheapest one is always chosen. The early cars burned gasoline because petroleum was refined into kerosene for lighting purposes with the by-product gasoline being dumped into the streams. Then when gas cars became popular the steam cars burned kerosene which was a by-product of gasoline production. Now a steam car can use by-products from the bio-fuel industry as well as waste products from the agriculture, wood and paper industries.

Because steam vehicles use whatever is the cheapest fuel it is difficult to predict the future well enough to tell what fuels will be used. At this time and with the present infrastructure the cheapest fuels are wood chips and small coal pellets. The reader may be puzzled at the mention of both coal and wood chips as potential fuels for a steam engine. Depending on the times and on the ideology there are two goals for alternate fuels. One goal is domestic production; meaning no use of imported oil. This means coal, which is available and cheap. The other goal is a clean, non-polluting, non-carbon dioxide producing fuel. This means wood chips.

A few years ago when corn was $2 a bushel, then corn kernels were by far the cheapest source of fuel.

Some people get emotional about the issue of fuel and therefore we have no illusions that this attempt at a rational presentation will be successful. When discussing coal there are two great issues: the one being that there is no such thing as clean coal aside from the term sounding good; and the other being that the U.S. has huge reserves of coal and it is the cheapest of all fuels. Burning coal does not involve someone shoveling chunks of coal into a large fire box. Coal can now be powdered and sprayed through an ordinary fuel nozzle and burned in a small combustion chamber. Powdered coal costs the equivalent of 20 cents a gallon of gasoline. If it is cleaned up of sulfur then it costs the equivalent of 40 cents a gallon of gasoline.

At the present time half of the electricity in America is produced by burning coal. This means that half of the purportedly clean electricity used by purportedly non-polluting electric cars comes from burning coal. Therefore it is my suggestion that symmetry prevail and that steam cars should be given the same dispensation as electric cars and so the ideal fuel for steam cars should be half coal and half wood chips thus achieving cheap and domestically produced fuel.

Controls: The next subject is one of controlling a mono-tube boiler. Many people have tried and few have succeeded. At the present time people are developing the small LaMont type of a boiler that has the combined the benefits of a mono-tube and of a water level boiler. It has the advantages of being reliable because the tubes are always full of water and thus they do not burn out and of being half the size of a similar capacity mono-tube because of increased heat exchange. A circulating pump is required in order to gain all of these benefits. One has been made and proven but it is not available to copy. As soon as a reliable circulating pump is available then the LaMont will be the heat exchanger of the future.

In the meantime this is a synopsis of the various approaches to controlling the mono-tube. It is said that Henry Ford did not look to steam for automobile power because he did not believe that mono-tube control was available. Abner Doble worked on this subject his entire life and did not come up with a completely satisfactory engineering solution, which indicates how difficult the problem is. The problem is that there is no way to tell what is going on inside the mono-tube which is about 500 lineal feet of ½" to ¾" diameter tubing. Except for the control issues it is a very good design. It has a lot of surface area to volume so that there is good heat exchange between the fire and the water. It has very little water, generally less than half a gallon, thus being quick to start and safe to operate. There is almost nothing to blow up and explode. There are very few welds so it is cheaper to make than most boilers. It is very difficult to control. Control has to do with producing steam at a precise temperature and pressure and maintaining that temperature and pressure under all kinds of driving conditions from sitting at the stop light to accelerating up a hill.

Controlling a boiler means that the water is pumped in when needed and the fire is modulated as needed. Both of these inputs affect the quality of the steam coming out the other end of the tube. What is desired is steam at a precise pressure and temperature. The reason for the steam temperature being critically important is very complex and will be dealt with later. For now you just need to know that steam temperature needs to be at least 700 degrees F in order to have sufficient power and it needs to be kept under 850 degrees F so that the lubricating oil is not carbonized. Interestingly enough, the pressure is controlled by turning the fire up and down and steam temperature is controlled by turning the water pumps on and off. The basic control is to read the exit steam temperature and when it gets too hot to turn on the water pumps. The water coming through the tubing cools things off and thus cools off the steam temperature. This is a good idea except that it does not work because the monotube is a very long tube and there is a lot of specific heat in the tube and it takes a long time for the incoming water to change the output steam temperature. This is called hysteresis. Therefore what happens is that by the time the steam cools off enough to be read to turn off the water pumps, the coils are full of water and this means that the boiler is flooded. When this happens very little steam is produced and what is produced is too saturated to have any power and there is a very real possibility of priming which means that slugs of water will leave the boiler and go to the engine and this completely destroys the engine because of the incompressibility of a liquid.

The various solutions involve some type of a feed-back loop being designed into the design. Doble used a normalizer, which is really a small de-superheater. He had most of the water from the water pumps going into the bottom of the boiler and a small tube going to the tubing a few feet from the end and just before the quartz rod controller, which reads the exit steam temperature. This feed-back mechanism worked by telling the temperature sensor when the pumps were working and this cooling off of the steam turned off the pumps before the boiler became flooded.

The Mobile Steam Society tried to put a temperature transducer about a third of the way into the tubing from the steam end. Actually they put a temperature sensor on each pancake coil. The purpose was to read the steam/water temperature and thus to determine the location of the transition zone, which is where the water was boiling. If this could then be kept a set length back from the end of the mono-tube coils, then the boiler would never be flooded and never run dry. The original temperature transducers were welded to the outside of the boiler tubing at various spots. Unfortunately this did not work out well. For one thing the reading was of the temperature of the outside of the tube and not of the steam inside the tube. For another thing the frequency and degree of temperature cycling caused the welds to break and the temperature sensors to fall off.

Roger Ulsky developed a controller that was dependant on a computer program. He read exit steam temperature and used it to turn the water pumps on and off, the same as others had tried. The difference is that in his the computer chip that got input from the temperature transducer read very small changes in the temperature and took many readings a second. The program sensed very minute changes in the trend of the temperature and used these trends to turn the water pumps on and off. This appeared to work very well.

The Williams brothers used two quartz rod controllers. One of them read the water temperature before it went to the superheater. This would turn the pumps on and off and prevent flooding of the coils. The second controller read exit steam temperature after the superheater coil and would control the normalizer to adjust the final steam temperature precisely. This makes a lot of sense.

Richard Smith designed helical coiled boilers. He attempted to use the entire length of the coils in the boiler as expanding and contracting to control the water and fuel. Few people were able to make this work well, or at all.

John Wetz came up with a very clever controller that was based on simple expansion and contraction of the iron tubing without needing the quartz rod to provide the fulcrum for the control lever. John's system is too simple to look at and far too complex to explain. The system reads three inputs: the temperature of the cold water coming in, the temperature of the hot steam going out, and the heat from the fire as it comes on and off. The expansions and contractions of the iron tubes caused by these three factors were mechanically hooked up so that they multiplied the effect, thus exaggerating the motion and making the reading very quick acting. The feed-back loop took into account the fire coming on to start to turn on the water pump and also took into account the cooling effect of the incoming water to start to turn off the pump. The way this works is absolutely genius.

Gar Dickerson has designed a mono-tube boiler scale that weighs the boiler and thus controls the amount of water inside it. This prevents the boiler from flooding. If it works as planned it is a very clever and original idea. The boiler is hinged on one side and mounted on springs on the other side. Gar has calculated that his boiler holds three gallons of water and the springs can be specified to respond to this amount of weight change. Gar is making the Doble Triple as described in John Walton's Doble book. Doble designed this engine while he was in England in the late 1930's working for Sentinel Truck. To our knowledge he never made one. As a triple expansion engine with re-heat it was designed to get better than a ten pound water rate. That means ten pounds of water boiled per hour to produce one horse power. As a benchmark, the Stanley operated at the 25-30 pounds of water per horse power hour.

Many people have attempted to combine the benefits of the mono-tube boiler with that of a pressure vessel water level controlled boiler. The names Olfeldt, Bolsover, and Lanterman all come to mind here. It is a good idea and many people have made many variations on that theme.

The latest popular idea for a steam generator is the LaMont boiler. This boiler has many advantages; it is half the size of a regular mono-tube boiler and the tubes are always full of water so they never burn out. This is another good idea and one that keeps getting re-invented every few years. There is much to learn about boiling water and many books on that subject. At this point I am reminded of a comment someone made a few years ago on one of the green energy website discussion groups. There were the usual comments about how to turn a heat source into mechanical motion and someone said that steam was a good idea and it was simple because all one had to do was to boil water. You should keep this in mind as we go into the details of nucleate boiling, multi-path steam generators, and the combination of radiant, convection, and conduction heat transfer. Besides the LaMont there is the Benson boiler that also has some renewed popularity. This works at super-critical pressures and also does not burn out the tubes because they are always full of liquid, in this case a liquid at 3200 psi that is one fourth as dense as water and can be called either hot water or liquid steam.

Boiler Efficiency

A boiler's efficiency is simply the ratio of the amount of heat that is put in one end, from the fire, and the amount of heat that goes up the smoke stack. Usually 80% efficiency is good enough. It is always possible to get higher efficiencies, but that involves a much larger and heavier heat exchanger because after most of the heat is extracted from the flue gases the temperature difference between the gasses on the outside of the tubes and the water inside the tubes is so low as to make heat exchange happen slowly. There are a number of means of assisting this and finned, or as it is also called, extended surface, tubing is one means and multi-path tubing is another. As with all engineering designing a practical boiler consists of a series of compromises. It is always a balance between size and weight and efficiency and cost of fabrication and reliability.

Multipath means that there are a lot of small diameter tubes for the water and steam to flow through instead of just one larger tube. The cross section area of all of the small tubes has to equal the cross section area of whatever monotube pipe it replaces, in order to handle the same amount of water flow, plus the total area needs to be somewhat larger to account for the increased surface friction resistance to the flow. The reason a multi-path works is because of geometry. The cross sectional area of a round pipe is a square function and surface area of a pipe is a linear function. "So, a lot of small tubes has a lot more surface area than one big tube and one of the important factors in heat exchange is surface area. There is another and more subtle benefit to smaller tubes, which has to do also with geometry and that is the smaller the tube the tighter the arc and the stronger it is as a pressure vessel, meaning that the wall thickness can be less for equivalent strength.

There is a long history of multipath boilers for large stationary power plants. There is John Thompson Water Tube Boiler Ltd, of Wolverhampton, England as a good example. In the auto area, Saab-Scania in the 1960's designed a steam car that used tubes that were nearly as small as hypodermic needles. Lear had a six path multi-path boiler with circulation provided by a six cylinder water pump. The recent, 2009, British Land Speed Record steam car had a 40 multipath boiler. The distribution manifold was about 3" in diameter with 4mm OD and 2mm ID stainless steel tubes. They did not get good even circulation and had a tendency to burning out tubes.

The advantages of a multi-path steam generator are balanced by the disadvantage of burning out tubes because of uneven flow and the extra engineering of a circulation pump. Finned or extended surface tubing is another way of accomplishing the same thing. The downside is that any time the water pump does not pump enough water everything overheats and the fins are melted.

Fins are theoretically a good idea because the metal that is doing the heat exchanging is not under pressure. The problem with a monotube boiler is that the heat exchange surface is the outside of a tube that has to withstand high pressure, so it is thick and heavy. Any time one can get heat exchange without a pressure differential is a big plus. Some work is being done using eutectic salts as an intermediate heat exchange fluid. This works because the salts will have a high temperature and not a high vapor pressure, so one gets the heat exchange from the gas to liquid at atmospheric pressure, meaning cheap construction using thin materials, and then the high pressure heat exchange is liquid to liquid which is much more efficient than gas to liquid.

Velox Boiler

A good description of a Velox boiler is found in the text of patent #4,455,837 by Joseph C. Firey. He was trying to make a coal burning gas turbine power plant that made steam as a by-product as there was heat here and there in the process. It looked pretty complex to me and thus probably not of practical value. The description is good:

"The common form of pressurized furnace steam boiler is the Velox boiler wherein an air compressor delivers compressed combustion air into a sealed and pressurized furnace where combustion with added fuel occurs. The combustion gases are cooled when passing over the boiler heat transfer surfaces and steam is generated at pressure inside the boiler. After being thusly cooled, these combustion gases are then expanded through a gas turbine engine whose work output is used to drive the combustion air compressor. By use of adequately high combustion pressures, the net work of the gas turbine engine can exceed the work input to the air compressor and a net useful work output results. As compared to the more usual atmospheric pressure furnace steam boiler, the Velox boiler has the advantages of a smaller size for a given capacity and the possibility of generating a new useful work output, whereas the atmospheric furnace boiler requires some work input to drive the forced and induced draft fans."

Firey does not explain why the Velox is more compact. That is because heat exchange is a function of many factors and one of them is the densities of the two fluids that are exchanging heat. Therefore if the combustion gases are compressed to three atmospheres, which is what was done in some of the Navy experimental destroyers, then theoretically, the heat exchange is three times better than that done at atmospheric pressure. Later on Firey describes the problems of using a solid fuel in a Brayton Cycle engine; which is mostly turbine blade erosion from particulate matter, ash and all. His patent was an attempt to get around this problem.

The reason that boiler temperature control is important is because steam quality is critical to a steam engine operating properly. The steam temperature needs to be at least 700 degrees F for there to be any heat energy at all contained in the steam. Theoreticians are able to explain why this is so. I am told that this can be gleaned from studying the steam tables and looking at a Mollier Diagram. Then the steam temperature cannot be over 850 degrees F or the oil that is injected into the steam line to provide upper cylinder lubrication to the piston and rings is carbonized. This is a bad thing to happen. Then, according to Carnot Theory, the hotter the steam the more efficient the engine is going to be which is why people talk about 1000 and 12000 degree F steam as an ideal. That is where compromises start to take place and why Harry Schoell is trying to lubricate his engine with water, thus avoiding the oil lubrication issues.

Most people would like to start their steam experience making something that is fun. This means something that is safe, possible to build, and reliable. It usually means solid fuel fired with relatively low pressure and low efficiency. A high efficiency steam engine involves some thought and a lot of expensive engineering. That can always come later on. It is psychologically more rewarding to have something that actually runs to look at while designing the ideal future engine.

What is needed then is a low speed-high torque engine that is self-starting. This would be a two cylinder double acting one with harmonic valve drive to either a slide valve or piston valve setup. The two cylinders can have either a side by side or a 90 degree Vee shape with a flat crank. If side by side then the cranks have to be at 90 degrees to be self starting. This is the standard Stanley steam engine layout. It is intrinsically unbalanced and also impossible to balance with counterweights. This limits it to operating at less than 1000 rpm. A Stephenson reversing link is the standard method of reversing the engine and of shortening the cutoff. Shortening the cutoff is called “hooking up”. The shorter the cutoff, the more efficient the engine is and the lower the torque.

There is a problem with having too short a cutoff combined with too low an intake pressure. One example was a small engine made by a person who had visited the steam club meet for a day and a half and listened to the experienced people talking about how good bash valves were because they were so efficient. They were efficient because there was a 25-30 to 1 expansion ratio. After that he spent a year trying to get a bash valve engine to run and without any success. The reason was because he was using 25 psi intake steam. A bash valve has something like 5% cutoff. Jay Carter made engines with this, or less, cutoff run very well. He used 2,000 psi steam and a 50 thousandth lift on the bash valve with the bash valve being a Chinese hat design with a lot of circumference for steam flow, which got enough steam into the cylinder to do some good. If a bash valve is used with 25 psi steam, then after the piston has moved half an inch it is pulling a vacuum for the rest of the stroke, which is why it does not run.

The Vee geometry with a 90 degree Vee uses a single throw crank in order to be self starting. It is self starting if it is a V-4 with single acting pistons or a V-2 with double acting and a fairly long cutoff for starting. It is a very good design if one is using a camshaft and poppet valves because one cam can operate the cam followers for both cylinders. A relatively long cutoff is needed for either of these double acting engines to be self starting.

One of the best examples of a vehicle made following these design principles is Jim Tangeman's wood fired garden tractor. It is such a successful design that it goes way too fast for its chassis. It is too high, too narrow, and too lacking in a suspension. The shortcomings in that area only emphasize the success it has in making steam and getting moving. I spent half a day driving it around, up and down the roads in high gear and around the orchards and through the mud puddles in low gear. A person should not have that much fun.

Jim Tangeman's tractor boiler was a Worthington Type with three drums on the top for steam/water separation and a lot of welding. It is referred to as a natural circulation boiler. A natural circulation boiler has up comers in the hot part of the fire and down comers in the cold part, or well shielded from radiant heat. These are vertical pipes that take the water from the steam separation drum at the top and transfer it to the distributor drums at the bottom of the boiler. What happens is that the steam bubbles form in the hot part—the up comers—and as they rise to the surface they draw the water in the tubes with them. At the top the water and steam bubble mixture shoot into a relatively large separator drum that is water level controlled to be about half full of water. Here the steam bubbles go to the top where they are drawn off to pass through a section of pipe called the superheater and then on to the engine. The water in the bottom of the separator drum then flows by gravity down through several relatively large diameter tubes—the down comers—to the bottom two drums. The up comers draw their water from these lower drums and the circulation flow continues. Make up water is pumped in from time to time to replace that water turned to steam. Some kind of a water level sensor tells the pumps when to pump.

There are innumerable numbers of lessons to be learned from a boiler such as this one. The first lesson is that it is almost impossible to ruin such a boiler. A wood fire does not burn as hot as a coal or petroleum fueled fire. The tubes are always full of water, at least if the operator is paying close attention to the sight glass to see where the water level is at and the electrical conductivity water sensor is working to sense water levels in the separator drum and there are no problems with the check valves in the water pumps or the drive to the water pumps and some debris has not clogged the bottom tube going to the sight glass thus giving a false water level reading there.

The other lesson to be learned from this boiler is the large amount of work involved in making it. There is much cutting, bending, drilling, and welding going on. A person needs to enjoy metal fabrication before making one of these.

The other lesson has to do with heat exchange theory. As one might imagine there are books written on this subject. To start with a person needs to understand the basic geometry of a circle and this means an understanding of the square-cube rule. In other words as the pipes or tubing get smaller the surface area to volume ratio gets higher. Heat exchange is a function of many factors and square footage of the surface area of the heat exchanger is one of the easiest design factors to control; the more the better.

What becomes clear is that the easiest and lightest way to increase surface area is to have a lot of little tubes. At some point practicality steps in. The small diameter tubes will clog with lime deposits from the water or from debris or flow will be restricted. As soon as this happens then the tube overheats and burns out causing a stop to the steaming activities. With a large leak the boiler quits putting out pressure although usually, just before that happens, the leak sprays water all over the fire, putting that out.

A water level boiler is easier to control than a monotube boiler. In a water level boiler it is real simple. The volume above the water level is always full of saturate steam. When this saturated steam is piped through a pipe that is closer to the fire, then the steam is heated and superheated, making it much more efficient. Non-superheated steam starts to condense and precipitate out droplets of water as soon as the pressure drops, which means as soon as the piston starts to make its down stroke. Water condensing in the cylinder during the power stroke is not a good thing because when steam turns to water a lot of volume is lost and thus pressure drops rapidly.

Another important issue is a slug of water getting into the engine. This is bad at several different levels. A slug of water can get into the steam line under several conditions. Having the boiler too full of water is the easiest way to have this problem. A poorly designed steam separator drum will also cause this problem. Baffles are needed. Then there is a condition known as priming. When the throttle is opened suddenly, a lot of steam is used up, the pressure in the boiler drops, and large bubbles of steam form and cause a surge of water to be carried to the top of the boiler. When a slug of water gets into the steam line two bad things happen: the engine produces no power, because it is steam that has pressure and enthalpy and can expand, and secondly, because water is incompressible, the turning rotating engine breaks. Usually the head is broken off, ruining the casting and sometimes the connecting rod bends or the overhung crank pin bends. It is a really bad thing to happen. It discourages people from working with steam.

We have talked about Jim Tangeman's boiler and now we need to talk about the engine. It is a very old-fashioned design, a two cylinder with piston or spool valves, as they are sometimes called, and a 90 degree crank. It also is very useable. Jim bought some casting kits that were made for a live steam small locomotive. He used these for the cylinders and built the rest of the engine up. It has a nominal two inch bore and stroke. The cylinders are cast iron and can be obtained from LocoGear of Lake Worth, Florida to be found at www.LocoGear.com. The original casting kit was for a three cylinder Shay locomotive model

If a person wants to make something like this there are some casting kits available. To be self-starting there need to be two cylinders hooked together at right angles. Or a chain drive to a jack shaft is one possibility of doing this. From England there is the Stuart-Turner 5A engine with slide valves. Or PM Research from Pennsylvania has castings for a small piston valve engine. R. F. Hasbrouck sells plans for small steam engines that do not require castings. They are machined from solid blocks.

If a person looks enough there are old Locomobile engines available in the $1500 to $2500 range. A new engine with piston valves and an enclosed crankcase can be purchased from Strath Steam in Australia. If one can afford it this is by far the best choice.

Bill Cartland converted small Briggs and Stratton engines to steam. The best way was to add a VW cylinder to the top of a small engine thus using the existing engine crankshaft with the piston and cylinder working as a cross-head. It is important to think about all of the problems caused by getting water into the oil in the crankcase. This is why the crosshead engine has its advantages.

Any single acting engine will leak water and steam past the rings and into the crankcase. There it mixes with the oil and makes a large amount of mayonnaise that not only erupts from the oil breather pipe every so often but also does the bearings no good. There are several solutions. One is to run a steam pipe through the crankcase heating it up to above 212 degrees before starting the engine. This keeps the steam as steam and boils the water off. Another solution is to use non-detergent oil that will not emulsify as readily. Another is to continuously pump the oil/water mixture into a centrifugal separator.

The Leslie engine used a long trunk piston with two sets of rings, top and bottom. The piston skirt was longer than the stroke. While the piston was not hour-glass shaped, the effect of having the two sets of rings was almost the same. Ports were very cleverly built into the side of the cylinder and open to the exhaust manifold going to the condenser. Thus any steam or water that leaked past the top set of rings was drawn through the ports to the condenser by the condenser vacuum. The lower set of rings helped to prevent leaking into the crankcase. This was a clever system to keep the pressure from pushing the steam past the rings and into the crankcase.

The Williams brothers dealt with this problem by using the single-acting crosshead engine design. The engine was taller than a trunk piston engine but not as tall as a double-acting engine. This design also avoided the extra height of the double-acting uniflow engine and of the considerable extra weight of the long piston. In a double acting uniflow engine the piston has to be longer than the stroke so that the exhaust ports are not uncovered too soon on the power stroke. The piston is usually made in two parts so that it is hollow.

Improved Boilers: The monotube boiler is pretty good. An early example from the 1880's was made by Herreschoff. A montube boiler can be made from pancake coils, helical coils, frusto-conical coils, or hairpin bends and a cross grid design. Traditionally the monotube boiler is a single path; meaning that it is one continuous tube. There are advantages to it being a multipath, meaning more than one tube is used, usually parallel to each other and usually of smaller diameter than if only one tube were used. These are seldom successful. The current thinking among people who have spent their lifetime thinking about steam favors the LaMont boiler. A multipath LaMont has many advantages. One is that it is 40% the size of an equivalent monotube. The other advantage is that it never burns out.

The benefits of multipath are that it is a cheap way to get increased surface area for heat exchange. Another way, and one that is commercially available, is to use what is technically referred to as extended surface tubing. Commonly this is called finned tubing. Finned tubing is a good idea until one tries to bend it or until the battery supplying current to the burner blower motor runs low and soot forms and clogs up all of the fins or when for a brief period of time the water pumps do not work and the boiler over-heats and all of the fins melt off into little globules of glowing metal. It is also expensive.

In a multipath design there are usually 6-10 smaller tubes with a cumulative cross section a little larger than the single tube cross section would have been. The advantages are that as the tubing gets smaller its surface area to volume ration goes up and the tubing gets stronger because of the geometry of a cylinder, meaning that the tube wall can be thinner giving improved heat transfer across the tubing wall. Everything is good and better except for the fact that the tubes in a multipath boiler burn out often and many times. The reason the tubes burn out has to do with the difficulty of maintaining equal water flow in each tube. The reason for this problem is because when a lot of tubes come off of a long manifold there is not equal pressure, or flow, going into each tube. The disaster is that the tube with the least water flow will heat up faster than the others and then it will have more steam bubbles which will further slow down the water flow and heat up the tube until it is all steam and no water flow and the tube glows red hot and burns up.

There are several solutions to this problem. One is to have a separate water pump or water pump plunger for each tube. This gives an equal and positive flow into each tube. Thompson's solution is to have a 100 psi or so pressure drop across a nozzle into each tube. Because the pressure drop is stronger than the differences in pressure in each tube there will be equal flow in each tube.

Another way to get equal flow would be to have some kind of a rotary positive distribution valve that would meter water sequentially into each tube. There may be other solutions. The important point is that a person needs to design something for a solution. One cannot just plumb all of the tubes into a manifold/header pipe and then hope for the best.

LaMont Boiler

A LaMont boiler is more or less a monotube boiler with the addition of two things. One of the things is a circulation pump and the other is a pressure vessel that separates the steam from the water and provides a water level that controls the make up water pump. The circulation pump circulates water through the system at a flow rate 5-10 times as much as would be pumped in by the feed water pump. Of course a feed water pump is needed to replace the water converted to steam. The circulation pump only needs to operate at about a 5 psi head because it only has to pump against skin friction inside the tubes. It does not have to pump against a pressure differential because it is only circulating within the pressure system. The pressure vessel/separator drum is usually located outside of the fire area although there are some packaging and insulation benefits from putting it in the middle of everything and wrapping the coils around it. The separator drum is always vertical and the top one third is for saturated steam. A water level sensor is placed where needed and this controls the feed water pump. The circulation pump draws from the bottom of this separator drum, pumps the water through the coils that are in the fire and shoots the other end of the tube or tubes into the drum near the top where, with the assistance of some baffles, the steam bubbles separate from the water.

The benefits of having rapid water flow are many. The tubes are always full of water and not steam so they do not burn out. Conductivity between the water in the tube—the water side—and across the metal wall thickness to the outside of the tubes where the flame is—the air side—is so good that there is less than a 50 degree F temperature differential between the hot side of the tube and the water inside the tube. The real benefit of this rapid water circulation is that it strips the little steam bubbles off the inside tube walls where they are constantly forming because of nucleate boiling. When there are a lot of bubbles lining the wall they insulate the water on the inside of the tube from the hot metal wall of the tube. This insulation prevents heat conductivity. There are some other benefits of rapid flow of the fluids engaged in heat transfer. This is why a LaMont boiler is less than half as large as a once-through mono-tube boiler.

Because of the rapid flow through the tubes they are all about the same temperature and thus there is not the temperature gradient of a counter-flow mono-tube. Also, because the steam is pulled from the top of the separator drum, it comes off as saturated steam. Thus two other things are needed; a super-heater and an economizer. These are just more coils of tubing, albeit in different places, and for different purposes. At the expense of a small circulation centrifugal pump and a pressure vessel a person gets a boiler of half the size and with greater reliability. Because it is a water level boiler it is very easy to control. Because it is not a counter-flow heat exchanger it can be made of helical coils instead of pancake coils. Helical coils are much easier to wind than pancake and they package into a smaller volume.

There are books on these things. A good book on heat exchangers/boilers is "Steam Generators" by Dagobert W. Rudorff, 1938. A good book on boiling water is "Boiling heat Transfer and Two-Phase Flow" by L. S. Tong, 1975. A good book on the natural circulation boiler is "The Kidwell Two-Flow Ring-Circuit Water Tube Boiler" by Edgar Kidwell, 1923. The subtitle of this book pretty well tells it all: "Containing a lucid explanation of the principles underlying correct boiler design and operation, their application to boiler analysis and how they are correctly applied in the design of the Kidwell Boiler, with other information valuable to those who wish to generate more steam for less money." A good general engineering book on the subject is the fifth edition of "Principles of Heat Transfer" by Kreith and Bohn, 1993. The best calculations come from "Compact Heat Exchangers" by Kays and London 1964. The first sentence in the introduction of the latter book is informative: "The design of a heat exchanger involves a consideration of both the heat transfer rates between the fluids and the mechanical pumping power expended to overcome fluid friction and move the fluids through the heat exchanger."

This flurry of interest in the LaMont happened because an auto worker in Detroit, Tony Grzyb, reinvented the LaMont boiler for use on his steam powered bicycle. This news then got to George Nutz, an MIT educated engineer, who then researched this and publicized it on John Woodson's web site and championed it and then designed a boiler for Rod Teel in New Hampshire who then built one for his steam boat. It has a very nice 12 volt permanent magnet motor driving a centrifugal pump and drawing very little electricity. Tony used mechanical plunger pumps for circulation achieving about a 2-1 ratio of circulation to evaporation. He still had most of the benefits of a LaMont even with this system.

As a person might imagine such a good idea was not original, it was just little known. Out in Culver City, California in the 1960's Roy Ferrier had made his shop boiler a LaMont. He machined his own circulation pumps and even had one for the main boiler and one for the economizer. He made the vanes for the centrifugal circulation pump by milling slots into a thick disc. It was not very efficient mechanically because of the broad flat area at the end of each vane. Roy wrote nothing down and did not share much information with others after one person tried to steal and patent his steam power system.

Bill Besler favored the “spill over” boiler system that had some of the advantages of the LaMont but not all of the benefits such as the compactness. This system was well explained in his report dated September 30, 1957 for Contract Nonr 2159(00) and entitled: “Design Study of a Steam Power system for a Landing Craft” performed for the office of naval research amphibious branch. This is a modification of several other systems and its main benefit is that it works easily. The other real advantage and one that Besler mentioned, is that a spill over, which pumped about 5% more water into the monotube boiler than could be evaporated, acted as an automatic and continuous blowdown. This meant that any sediment or chemicals in the water were discarded automatically. Besler did not trust his customers to periodically blow down their boilers.

Monotube Boiler Control systems:

Monotubes are notoriously difficult to control. In a boiler, the technical term: control, means to produce steam at a precise temperature. This is very difficult to do. Great minds have spent a lifetime thinking about it and the best example is Abner Doble’s boiler design notebook. Steam temperature control is important because below 700 degrees F steam contains relatively little power and above 850 degrees F the steam temperature ruins lubricating oil. A finer steam temperature control than a 100 degree range is preferred. There are several things happening in a monotube boiler. If you spend half a lifetime thinking about it most of these things will become obviously apparent. The heater is always trying to make things hotter. The water being pumped in is always trying to make things cooler. The water level is moving all over the place because the water is boiling away into steam while the water pumps are adding water. Meanwhile the automobile is alternatively stopping at stop lights and accelerating rapidly between the stoplights obviating any possibility of balancing the heat added and the water added to produce a steady supply of steam. Sometimes the burners are on all of the time and sometimes only part of the time, depending on the amount of work the engine is doing. When the boiler is run hard, meaning the burner is on all the time, then the transition zone moves to near the top of the coil stack. When the boiler is run easy, meaning the burner is on only part of the time, the transition zone, where the water is turning into steam, is nearer the bottom of the coil stack. As one can see, the superheater, which is all of the tubing full of steam and above the transition zone, changes length. It is not easy to control the amount of superheat when the length of the superheater varies.

The White steam automobile had a fully modulating control system. When in adjustment this worked perfectly. A complete explanation of that system will be added to this discussion.

In a non-modulation system, such as Doble's, what most people do is to turn the burner on and off based on a pressure sensor, usually based on the Bourdon Tube, and turn the water pumps on and off based on a temperature transducer in the outlet steam. This is a good idea in the abstract because adding water cools things off when they get too hot. The problem arises because there is a great deal of hysteresis in the system. The specific heat of black iron is such that several hundred pounds of it, when hot, is able to boil several gallons of water. Therefore by the time the output steam has cooled down enough to send the signal to turn off the pumps, the boiler is nearly full of water and it takes a long time to get the steam back up to the right temperature. This wide fluctuation in steam temperature is called "hunting". There are any number of possible solutions.

The fire is usually, at least by Doble, set to come full on or full off. This is because he was using basically oil furnace gun technology. The air was pumped in by a single speed electric motor powered squirrel cage fan and the fuel was injected through a pressure atomizing nozzle of a pre-set flow rate. A pressure atomizing nozzle is set to operate at one pressure and one flow rate. The Delavan nozzle, made in Wisconsin, claims to be able to operate at a flow rate between 1 and 10 gallons per hour of fuel oil. When this is used one will need to vary the air flow to match the fuel flow. The fuel and air ratio was set to give a slightly leaner than stoichometric ratio and the burner was either full on or completely off.

A variable rate burner can be made, but not easily and not using simple off the shelf components. The spinning cut atomizer has been preferred because it is not pressure dependant and can atomize liquid fuel over a wide flow range. Jay Carter, for an example, was achieving a 25-1 turn down ratio on his burner. The Williams used two nozzles so that one could be used for around town driving and then both would come on for full cruising power. The Mobile Steam Society used three nozzles of three different flow rates and a variable speed electronically controlled air fan. They could then use any combination of these nozzles to give a highly variable fire.

The water pump is controlled by an electrical signal. Sometimes an automotive electric air conditioner clutch is used to turn the water pump on and off. The Doble used an electric solenoid to open and shut a by-pass circuit back to the water tank. The pumps ran all of the time, but only against a load, or a pressure head, when water was needed. Some smaller steam systems used a variation on the Stephenson reversing link to vary the length of the stroke of the water pump. John Wetz used an electro-magnet to pick up a steel ball bearing check valve from its seat in an aluminum pump housing to control the water flow. When the solenoid picked the ball bearing check valve off its seat the plunger on the pump continued to go back and forth, but no water was pumped.

Many people wonder why a steam car cannot be driven just like a gasoline car where the torque of the engine is adjusted by stepping on the accelerator. For an example and because steam is made by the heat in the burner, all a person would need to do is to push on the accelerator and increase the burner and make steam and go. Jay Carter was able to do this. He had a very small boiler coil stack and a variable pressure boiler control system. Few others have been able to do this. In most steam engines there is too much hysteresis in the system, too much thermal lag, too much specific heat floating around. Then what a person tends to do is to put in a little reservoir of hot pressurized water to use as an energy storage system. This is a good idea. It takes a few minutes to get it all warmed up, so a person does not want to start it up cold and drive out onto the freeway in front of a large truck. The problem here is the basic problem with all hybrid vehicles, which is to be able to predict the future and know when to store energy and when to use up the stored energy. It helps to know when there is a mountain to climb and when the next traffic light will turn red.

All that a hybrid vehicle is is a relatively small engine and a relatively large energy storage system. The general rule in modern IC automobiles is to have a 5-1 ratio of power potential in the engine to power needed to go down the level road at highway cruising speeds. About 30 horsepower is needed to maintain highway speeds on level ground in a regular sized car. The extra power is there for acceleration purposes. In an IC engine this system is not efficient because of pumping losses, although that only applies to a gasoline engine because a diesel engine does not suffer from pumping losses, just one of several reasons it has a higher fuel economy than a gasoline engine. Therefore a hybrid uses a smaller half-sized engine for steady speed driving and the stored power for acceleration. The stored power is usually in the form of electricity in batteries. Batteries are not all that great because they have very low energy density and they are not able to charge up rapidly and this fact limits their value for retrieving energy during regenerative braking. Capacitors are better for fast charging. A hydraulic fluid over nitrogen system using carbon fiber pressure tanks at 23,000 psi works well, but does not have as much engineering invested into the system as the electrical battery hybrids. We do not have the time to get into flywheels and clock springs and compressed air as energy storage systems. The issue usually gets down to the energy density of all of the components in the system and losses during the energy conversions from one form to the other. Because this all involves engineering it all involves a lot of compromises being made.

In a steam engine system the logical thing to do is to store energy in the form of heat. Then if one is going to do that then all one needs to do is to get out a Physics and Chemistry Handbook and look up the specific heat tables. Specific heat is the amount of energy stored in one pound, or any weight for that matter, of material. Water is 1. Steel is 0.1 and Aluminum is 0.23.

The amount of stored heat in several gallons of water pressurized to 1200 psi explains a lot about how the 1906 Stanley Rocket was able to go so fast at Ormond Beach, Florida in 1906. It went 126 mph and the next year went 150 mph before the lack of good aerodynamics of the upside down canoe body with a flat bottom became obvious. To begin with it was a very light vehicle, being an upside down canoe on four bicycle wheels. Then the extra large boiler had 5 gallons of water heated to 1000 degrees and pressurized to 1200 psi. The water pumps were turned off for the record run. This was for two reasons besides the obvious one of saving the power needed to pump water: firstly the pumps were not designed to pump against that much pressure without metal bending, and secondly, twice as much power could be produced for the size of the burner if no cold water was introduced into the boiler. The burner was on full blast and this provided superheat for the steam and heat for the latent heat of vaporization for the hot water.

Here is an example of the maximum possible energy storage in water and here we will use 5 gallons, about 45# of water, as an example. This is workable with modern materials. First we need a pressure vessel that will hold 5 gallons of water at 3200 psi, except a close reading of the Keenan & Keyes pressure tables shows that water at 3000 degrees F and 3200 psi has expanded four times so we need a pressure vessel large enough to hold 20 gallons—about 3 cubic feet capacity. The reason for choosing 3200 psi is because this is where steam goes super-critical. It remains a liquid at that pressure, albeit a light liquid. So then we heat the water to about 3000 degrees F. This figure is chosen because that is about as hot as a kerosene fueled burner will get and it is about as hot as the newer inconel alloys will get without melting. The question becomes: how much energy is stored in this pressure vessel full of hot water. We do not refer to this tank of hot water as being a boiler. Boilers have a tendency to blow up and kill people so we do not have any of them sitting around.

Steam Safety

A Stanley boiler might look like a boiler, however it has two modifications that other boilers do not have. First of all it is wrapped with either 2 or 3 layers of 300,000 psi tensile strength piano wire and secondly it is full of hundreds of 13/16 “ copper tubes that will then collapse one at a time if the boiler pressure gets too high. Before collapsing and letting steam pressure leak out, the copper tubes act as stay bolts, holding the top crown sheet and bottom sheet together. Stanleys have either never or so rarely that human memory does not remember, ever blown up. A boiler is defined by the ASME as being a pressure vessel that has a direct flame impinging on part of it and has water on the other side of the piece of metal. Boilers are referred to as having an air side and a water side. The flame business is what causes the problems with boilers because if there is no water on the other side of the metal where the flame is impinging then the metal gets red hot. There are two problems with red hot iron. The first problem is that it loses strength as it gets hotter and approaches its melting temperature. The second problem happens when someone adds water to the red hot boiler or some water sloshes around in the boiler and hits the red hot iron and flashes into a large amount of steam so suddenly that the pressure relief blow off safety valve cannot release the pressure as fast as it is being created. Therefore we do not encourage the use of boilers. We admire from a distance and encourage those interested in the preservation of historic technologies to do the work necessary to keep old traction engines running. By and large these people work hard and are very careful. Still, one hundred year old iron has had many opportunities to corrode. Sometimes scale will build up insulating the steel from the cooling effects of the water, thus allowing it to be heated red hot. There are some serious issues that have to do with stay bolts and crown sheets that create emotional discomfort in my psyche. An explanation of these technical issues will follow as we have the time.

And so if we have a pressure vessel full of 45 pounds of hot water all insulated and isolated from any burner we then need to figure out how much energy it contains. If we pipe saturate steam from the top of this tank and run it through a steam engine until the pressure in the tank drops down to 500 psi then we will have boiled away about half of the water and produced a lot of energy. The way this is figured out is to study the Kennan & Keyes steam tables. It is interesting to note that because of the latent heat of vaporization one cannot store enough heat in water to boil all of it away by dropping the pressure. When the fire is out the steam is always saturated. In real life a superheater with its own fire, called a trimming fire, would be hooked up to superheat the steam coming from this storage tank.

Here is a brief presentation of steam boiler legal issues. A law was passed in 1878 by a Treasury Department order specifying that all steam launches must be operated by a licensed engineer. Shortly after that naphtha engines were invented and became popular for self-propelled pleasure boats. They were easy to operate and did not involve shoveling coal into the fire. Yarrow made one in 1888 and most were made by F. W. Ofeldt of New York. A naphtha launce was smaller, lighter, cheaper and much quicker starting than the steam launch, besides getting around the law.

Naphtha was the name at that time for what became gasoline. Naphtha was both the fuel source and the working medium. This was a good idea because naphtha was a by-product of kerosene refining, so it was cheap and readily available. It was also not steam because it did not use water as the working fluid, although the principles were exactly the same; the use of a liquid that was boiled into a vapor that was run through an expander. These ran at a lower pressure than steam and for some reason were safer, although having a lot of hot gasoline vapors around the boat caused the occasional fire. These sold like hot cakes right up to around 1900 when the internal combustion engine began to be reliable and lighter than the naphtha ones.

Some interesting comments on the safety or more precisely, the hazards, of steam power in the 19th century come from the 1901 book published by Audel & Co.: "Maxims and Instructions for The Boiler Room. Useful to engineers, firemen & mechanics, relating to steam generators, pumps, appliances, steam heating, practical plumbing, etc." On page 285 is the heading "Hazards of the Boiler Room" that states: "During the twelve years between 1879 and 1891 there were recorded 2,159 boiler explosions; these resulted in the death of 3,123 persons, and in more or less serious injury to 4,352 others. Besides these there were innumerable other accidents during the same period, caused by other means, which emphasizes the gravity of this cautionary "chapter of accidents." Every boiler constructed of riveted plate and carrying a high head of steam, holds in constant abeyance, through the strength of a disruptive shell, a force, more destructive in its escaping violence than burning gunpowder. To the casual observer there is no evidence of this; and it is only when a rupture takes place of such a character as to liberate on the instant the entire contents of the boiler that we get a real demonstration of the fact. Unfortunately a steam boiler never grows stronger, but deteriorates with every day's age and labor, subjected, as it is, to all sorts of weakening influences; and fractures often occur, which if not at once repaired, would speedily reduce the strength of the boiler to the point of explosion."

This is a good description of the classic antique pressure vessel boiler and why steam has such a reputation for danger. Needless to say, modern steam is modern because it does not have these same dangers. We now have steam generators, made from small diameter tubing of nearly 8,000 psi burst strength, and holding very little water, usually from a quart to a gallon. Thus there is nothing to blow up and kill people. Those of us who work in steam are aware of the hazards of steam power and we keep that constantly in mind.

While on the subject of steam safety it is incumbent to mention the American Society of Mechanical Engineers that was founded in 1880 by prominent mechanical engineers to mainly work with steam power, which was the only source of power at that time. Since then the ASME has published rules on pressure vessel and boiler construction. At last count a complete set of these rules could be purchased for about $2,000 and covered many feet of library shelving. Every State in the Union and Province in Canada has adopted the ASME rules for their laws. Also every State and Province has written exceptions to these rules. The exceptions have to do with small hobby steam things such as live steam model railroads or over the road vehicles or steam generators. Some define the size of the unregulated boiler by grate area in square feet, by boiler water capacity in gallons, by diameter of the tubes, with some being anything under 6" in diameter being exempted from the regulations. The National Board of Boiler and Pressure Vessel Inspectors out of Columbus, Ohio in 2008 put out a "Synopsis of Boiler and Pressure Vessel Laws, Rules and Regulations, by Cities, Counties and States of the United States, and Provinces and Territories of Canada". This can be downloaded and printed from the internet.

Baker Boiler

As with absolutely everything else to do with steam these things have been thought of before. One of the better examples, and one worthy of serious consideration in a modern steam system, is Dr. Hartley O. Baker's steam generator Patent 1,409,515 1922. The heat exchanger was substantially a monotube boiler. A lot of design work went into separating the water from the steam so that slugs of water did not get into the engine. The energy storage system was a large diameter tubing wound into a helical coil that went around the outside of everything. Cleverness was shown at several different levels because it has the efficiencies of a monotube combined with the convenience of a storage vessel. It was safe, economical, and easy to fabricate.

A monotube steam generator does not have any reserve energy storage. A Stanley boiler does have a lot of storage and this is why they are fun to operate. The problem, one that has to be addressed by all hybrid vehicles, has to do with knowledge. The problem is that no one knows when stored power is going to be needed. No one knows when, during modern traffic conditions, a vehicle will need to go up a hill, or accelerate from in front of a large truck. Of course a system could be designed that always has the energy storage at full capacity. Then one is not able to recapture the energy of regenerative braking, and one can never predict when the light is going to turn red or when an accident will stall traffic on the freeway. Therefore, while it is possible to combine steam power with any of the existing battery electric hybrid systems, it makes little sense to do so when all that one needs is a heat storage system so that a lot of steam can be made in a short period of time. When considering energy storage the issue is always energy density. A pressure vessel full of hot water has very high energy density.

Thermal Storage

Unfortunately a pressure vessel full of hot water also has a lot of pressure because of the vapor pressure of water. What is needed is a material that has a high specific heat and no or very little vapor pressure. One possibility for thermal storage is aluminum, because it has 3 ½ times the specific heat of iron. Another is mentioned in patent application US 2008/0121755 A1, publishing date May 29, 2008. The material mentioned is Lithium-hydrid (LiH). The patent application is for an airplane that will use solar power to stay aloft for an indefinite period of time. It appears that batteries have a much lower energy density, which means power stored per unit of weight, than a tank full of hot LiH. The patent shows a very large fuselage for the airplane with the top half of the fuselage being of some transparent material such as clear plastic and a parabolic trough collector mounted inside the fuselage. During the day the airplane will fly at right angles to the sun absorbing large amounts of heat and using some of it for powering a steam engine and storing some of it for use at night. It is an interesting idea.

The next subject has to do with sizing the boiler/heat exchanger. Heat exchanger efficiency is figured by measuring the ratio between the heat generated by the burner—heat in—to the amount of heat going out the other end and up the smokestack—heat out. 80% to 85% is considered an acceptable ratio for a mobile steam generator. It is always possible to make a more efficient heat exchanger. It does not take brains to do so, it just costs weight, volume of space, and money; which are all used to add heat exchanger surface area. Therefore it would be best to design the boiler for producing steady power at highway cruising speeds and then to over-fire the boiler, by quadrupling the flame size, when acceleration is needed. Some heat is wasted going up the smoke stack for this short period of time and a lot less weight is being hauled around by making these design compromises.

Some studies need to be done. But it appears to me that having a large boiler and a large fire that comes on intermittently, say a fourth of the time, is not very efficient. The reason is because when the fire is off no heat exchange is taking place, so all of that tubing is being hauled around for naught and then when the large fire is on some heat goes out the chimney. Therefore the compromise to be made in making an automobile for driving in modern traffic and highway conditions would be to design it for maintaining highway speeds on level roads and then over-firing it, which means to have a fire several times bigger than the steam generator can efficiently handle, for those short periods of time when more power is needed.

Over-firing is not a possibility in the Stanley system. The reason is because in an over-firing situation the water in the Stanley boiler “lifts” from the bottom sheet, which is what the flat piece of metal is called that forms the bottom end of the cylindrical boiler. This flat sheet is strong enough to withstand the boiler pressure because of the hundreds of vertical copper tubes, held in place by flared ends and steel ferrules, acting as stay bolts. Lifting is caused by a lot of steam bubbles forming on the bottom sheet, lifting the water level and insulating the fire from the water.

There are rumors that years ago in the Portland, Oregon area Bruno Galliano was able to successfully over-fire a Stanley boiler so that it could run down the road at 65 mph steadily. The usual original Stanley could maintain 45 mph. Galliano had replaced the Stanley blue flame vaporizing burner that was under the boiler with a 12 volt furnace gun pressurized nozzle burner of twice the Btu’s of the original Stanley burner. Here is what we think happened inside the boiler to make it work so well. None of us looked inside the boiler to know for certain, this is just a well-educated conjecture. The gun burner blew tangentially onto the bottom of the bottom sheet. This heating of one side with direct flame caused localized boiling and the rising steam bubbles on that side caused a rapid water circulation around the horizontal axis, if one can visualize that. As the water rapidly went up, over, down the other side, and across the bottom it scoured the steam bubbles off the bottom sheet, thus avoiding the lifting problem and consequent scorching of the Stanley boiler. This is an excellent example of a natural circulation boiler, albeit in one that is not designed to be one.

Stanley people always talk about scorching a boiler. They do not explain it, they just talk about it as though it is both a bad and an inevitable thing that is going to happen sooner or later during the steam car driving experience. Here is what I think happens. First the water pumps do not pump into the boiler. This can be because of a leak, a false reading in the sight glass, a broken pump drive, or some rust particle gets under the check valves. In either case the boiler runs dry of water, thus causing the bottom sheet to get really hot. As the boiler runs dry steam pressure drops because there is less and less water to boil and as the water level gets lower there is less heat exchange surface so the pressure sensor calls for more fire to make more steam pressure. Usually by the time the boiler runs out of water, the steam pressure drops to zero and the steam car stops, two things have happened; the operator has figured out that there is a problem and he turns off the fuel flow. The other thing is the scorching of the boiler that happens instantaneously. Overheating the bottom sheet red hot causes expansion issues and the tubes then leak. The solution is to re-swage the tubes. Usually everything is caught before iron is melted and holes are burned in things. Re-swaging is an experience. The burner pan is dropped, the car operator grabs a 3# maul and a tapered swaging tool and then crawls on his back under the car to spend the next couple of days hammering uphill to re-expand the steel ferrules. One learns many things during this experience with the main one being that it is a lot more work to hammer uphill than to pound downhill.

The antique steam automobile community has several different approaches. Each one has merit and most of the people involved are emotionally committed to one approach. Some people try to remain as absolutely authentic as possible to the original factory manufactured machine. Some add a few things to improve the Stanley. That there were possible improvements is clear from a glance at the Cruban after-market parts catalog. What most people do is add a water column to the boiler with some kind of a water level sensing device to signal small lights in the dash. This is usually a series of spark plugs wired to some dc electricity. Water across the spark gap conducts electricity enough to sense water level. Some, such as the late Richard French, went to some length to quiet the water pumps. He made some parts out of Delrin plastic to minimize wear and then added spring loaded plungers to take the water hammer from the pumps and even out the shock and water flow. Other people are making complete automobiles from scratch, but to original designs. The reason for this is because of the high price and low availability of real steam cars. One has to respect the several approaches to owning and operating a steam automobile. It is a major commitment in time and money to maintain and operate an old steam car.

That said, there is another possible way to slightly modify a Stanley boiler that would avoid the lifting and scorching issues. To my knowledge no one has done this. The Stanley boiler, as originally designed, has a flat bottom sheet with several hundred tubes swaged into it. The ends of the tubes stick out a little bit where they are flared out and a steel ferrule is inserted to keep the ends tight. There is a slight rounded off effect at the ends. If it were a sharp right angle where the tubes met the bottom sheet then the aerodynamics of the flow of the gasses into the tubes would create a vena contracta, which means that there is some turbulence where the gasses make the corner and the flow is faster in the middle of the tubes than at the surfaces of them. In fact, the combustion gas flow is away from the vertical tubes for a few inches.

The result of these two effects, the tubes projecting a little and the sharp edge of the tubes, is to both restrict the flow and to limit the heat exchange for the first few inches of the tubes because the hot gasses are not touching the walls. There is another common problem with Stanley boilers is the aforementioned scorching where the combustion gases directly touch the dry bottom sheet, over-heating it.

My proposed solution will solve all three of these issues. It is best illustrated with a drawing. I will also attempt to explain it with words. The modification is to take a piece of sheet metal composed of some high temperature alloy and position it about a quarter inch below the existing bottom sheet. Then holes are punched into this sheet metal in line with the tubes such that there is created a nice streamlined flare leading into each of the tubes. The sheet metal does not have to perfectly touch the edges of the tubes as there can be a slight gap. The new sheet metal shields the old bottom sheet from direct fire so that it will not scorch. The flares direct the flame into the tubes so there is a good aerodynamic flow so that there will be little back pressure on the fire. The aerodynamic flow of the hot gasses will be touching the tube walls so that there will be much better heat exchange at the bottom two inches of the tubes, which is where the water always is and the boiler will be more efficient. The only problem will be finding a high temperature alloy that will not melt or distort while being touched by the blue flame of the vaporizing burner on the Stanley.

Instead of using sheet metal, this new added piece that is doing both insulating and streamlining of the flames, could be made out of a ceramic casting. There is considerable expense in making such a casting mold and there would need to be an accurate and uniform tube pattern in all Stanley boilers for this to work. Otherwise a ceramic bottom plate is the best design.

The steam hybrid vehicle has been thought of before and so has the compressed air vehicle. At one time people have used a Stanley steam engine as a compressed air engine and using an IC engine in the front of the car to drive the air compressor. At first blush this is a good idea because it makes an excellent automatic transmission and one that even has a reverse built into it. There are two basic problems with using compressed air as vehicle power. To begin with air has a much lower enthalpy than steam so it will not expand as much and thus not make as much power for an equal sized engine. Then, secondly, a lot of heat is generated during the air compressing process and this heat is often lost, making the system very inefficient thermodynamically. In the early years of automobile development the drive train was not well developed. Clutches slipped and gears jammed. Eventually synchromesh gears were invented and automatic transmissions developed. Until then many other solutions were tried including using a Stanley engine with compressed air.

During WWII in the Los Angeles area one Frank R. Perry worked on developing a steam powered car. The main reason was to be able to burn kerosene that was both cheap and plentiful and not rationed as was gasoline. His engine was a V-4 uniflow with poppet valves and of 3 1/16" bore and 4 ¼" stroke. It used stock Packard and Marmon pistons and connecting rods. Perry came up with a number of improvements over the usual steam engine. He added some alcohol to the water to keep it from freezing and then he added some green dye to the water so that it appeared to be more exotic.

Perry came up with the original hybrid engine with regenerative braking. He proposed using a small air compressor and air tank as an integral part of the power plant. The small single cylinder air compressor as illustrated in the brochure does not appear to be engineered well for absorbing the necessary energy from regenerative braking. It would have worked only when decelerating slowly. This could always have been corrected by installing a much larger air compressor. Then when more power was needed and the boiler was not producing enough steam at enough pressure the compressed air could be used in the steam engine, as it would operate through the valves exactly the same as steam. The details of Perry's plumbing design are not available, but it would be simple to use the compressed air by opening a valve into the water line just before the boiler so the air would go through the boiler being heated by the fire and giving more power to the air. The downside of mixing air with steam and water is that it would need to be pumped out before the condenser would work properly. Also air and steam make for corrosion issues.

The French company Motor Development International has a compressed air car that can be viewed on their website: theaircar.com. This appears to work because carbon fiber scuba tanks are used that are good for 4500 psi and because they invented a folding connecting rod that slows down the expansion phase of the engine thus allowing the expanding air to extract more heat from the ambient. It is not stated explicitly but it appears that this car can be run on the Ericsson Cycle when away from city driving. We do not know if they have overcome the intrinsic thermal inefficiencies of the compressed air cycle. If a person looks at this from an economic viewpoint, efficiencies do not matter so much when electricity is cheap. About three-fourths of the energy is wasted when electricity is used to compress air and the compressed air is then run through an expander. In many places that system makes economic sense.

Using compressed air as part of a steam hybrid cycle might work if the air were run through the superheater part of the heat exchanger so that the air has more enthalpy in it. The real problem is that air in the water and condenser system causes all kinds of problems. First of all it destroys the partial vacuum that is the benefit of a good condenser. Secondly air combines with the water to form carbonic acid and other corrosive compounds. Therefore it would be better to not go to the expense and weight of an air compressor and compressed air storage system but to use the steam and the heat itself as a storage system.

Perrymobile

The Perrymobile was an interesting idea and one that almost worked. It is not clear from the history if Perry was successful at bilking unsuspecting investors, the usual mark of success of steam automobile developers. Little is preserved in print, although some mention is made of Bing Crosby and Henry J. Kaiser being interested in his project. He sold some prints at $25 each and left town in a hurry which implies that he found some investor money. It is pretty clear that he had not done much real testing of this engine design because the intake steam lines were much too small to produce any real power from the engine. It appears that he sold some casting kits along with the plans.

In 1952 his engineer assistant James H. Lawler of South Gate, California manufactured a few more of the engines and installed one of them in a small tractor. Some of these engines are still around most notably in Chuk Williams' T-Model steam powered roadster.

Because steam is a compressed gas that creates power by expanding through some type of an expander because it does not need to be a complex cycle that draws in air and fuel and combusts it before the expansion cycle, such as an IC engine has to do, there are many more opportunities to be creative in making an expander. There is a temptation that few can resist to make more elaborate and complex and unworkable expanders. Usually these involve some rotary or vane engine that are either impossible to seal, so the steam pressure leaks out all over, or it is difficult to keep the hot parts and the cool parts far enough apart.

The creative expander designs do nothing to increase the efficiency of a steam engine and often decrease it. An expander is a pressure vessel. The most efficient pressure vessel is a sphere and the second most efficient one is a cylinder. Because we have a moving part that needs to be sealed, the piston, then a cylinder is the preferred geometric shape of an expander using piston rings for the seal.

Another advantage of this piston and cylinder design is that it has been explored over the years of use in IC engines and it is pretty much perfected.

One example of a creative steam engine design and one that was made with beautiful machining is the nutating disc steam engine made by the late Charlie St. Pierre of North Carolina. There is one moving part, a disc, and it runs on one of the many variations of the “Z” crank. It is dependant entirely on close machining tolerances for sealing, meaning that it is easy for the high pressure steam to leak into the low pressure parts. Because steam cools rapidly as it expands there will be differential thermal expansion causing distortions and further steam leaking.

Because a steam engine is only a small part of the steam power system and because it is so simple, because it is powered by a constant supply of pressurized gas, creative people use their creativity to make increasingly complex shapes that will turn pressure into mechanical motion. St. Pierre’s work is brilliant in its design and stunning in its metal work. The parts involve two cones, a thick disc, a sphere and the outer housing is the inside of a torus. Everything fits. There are a couple of sliding seals but in several key areas it is geometrically impossible to make a seal. In this situation a seal would perform the same function as a piston ring. This nutating disc has the equivalent of four cylinders so there is a smooth overlap of the power strokes. One of the main problems with these rotary engines is differential expansion of the metals due to differences in temperature of the steam as it expands while passing through them. This differential expansion will either bind things up or loosen things up as the engine works.

Bob Bourque, who works with very high pressures at the Los Alamos National Laboratory, has stated that a steam engine is a pressure vessel and that the ideal pressure vessel is a sphere and the next best one is a cylinder. Bob also said that if you cannot keep it from leaking, then you do not have a steam engine. A steam engine needs to have such things as piston rings to keep pressure from leaking because it is not possible to make an engine with close enough tolerances to keep steam from leaking out. Steam is a much smaller molecule that air and thus it leaks easier. That is why nutating discs and vane engines and Lysholm air compressors do not work as steam engines. Another problem is thermal isolation. It is important to isolate the hot end, which is where the hot steam enters from the intake valve, from other metal parts that have contact with the cool expanded steam. Many rotary engines, including the Wankel, are not able to isolate things as well as a long cylinder.

The best study of what is involved in high pressure and high efficiency steam engines is the Dutcher Industries, Inc. Final Report – Milestone VI “Construction of an Improved Automotive Steam Engine

Design Per CAL Trans RFP TA 77-1” by T. J. Smith. The work was done between January 1978 and June 1980. Here is the summary:

“The purpose of this research and development program was to determine the potential thermal efficiency of a small (50 Horsepower) automotive-type steam engine. The goal was to demonstrate a thermal efficiency of 27% with a laboratory engine.” The follow up report to this one is by Brobeck and Renner. It is entitled “Review of Testing and Evaluation of an Improved Steam Engine” WMB&A Report No. 4500-189-10-R1 December 1981. Both of these reports are available from the SACA Storeroom.

In conclusion, they went to very high temperatures and high pressures and no matter how many piston rings they installed on the test engine they still got 10% blow-by, which goes to show how important good sealing is to make a steam engine workable. The maximum thermal efficiency they demonstrated was 22%. The value of the Brobeck and Renner follow-up report is in the degree of analysis they did to the Dutcher engine looking for a few more percentage points of thermal efficiency. One can learn a lot about steam engines by studying these two reports.

Bob Edwards, who worked at the Oak Ridge National Laboratory was more to the point in his analysis of complex steam expanders and considerably less polite. He said that many of these complex mechanical designs were “monkey motion”. This term did not imply an endorsement of them.

Here is some history of the Dutcher Industries project. In the 1960’s the government funded some steam power research because of the urban smog problem. After the 1972 oil crisis the government dropped all clean air projects and put money into alternative and domestic fuel sources and fuel economy. Then a few years later when the price of oil dropped to $10 a barrel all government funding of alternative fuel sources was dropped. One might learn a few lessons here about depending on the political process to obtain money for long range technological developments.

Dutcher Industries was one of several companies that were funded by the government. Dutcher Industries was a business owned by Cornelius Dutcher. Very little is known about his history. He shows up a few years before this as an investor in a pure stock swindle run by a fellow out of Scottsdale, Arizona and it is rumored that Benson Ford’s kids put some money into his steam project when it was located in San Diego. When the company was formed it was called SPS, Steam Power Systems and it had produced a steam car and a steam bus for the State of California. They had funding to work on a thermally efficient steam engine. They took an Italian diesel engine as the base of the engine and kept bolting individual cylinders onto it for their tests and ran it on a dynamometer. Later on the name was changed to Dutcher Industries. Many of the people who worked there had worked for Bill Lear on his steam project.

A short history of Steam Power Systems is that it started with Ken Wallis, the same fellow who had made two turbine Indy cars and then talked Lear into a steam Indy car. After a couple of years Lear fired him so Ken moved to San Diego and talked Dutcher into making steam engines. He started with a single cylinder marine engine and then expanded that to put it into a Cortina car, although no one can remember if it ever ran. Ken started with no money and a very conservative steam engine design, a double acting compound. A car was made that is now in the Petersen Museum with a four cylinder engine and a monotube steam generator made by Solar Turbine. A bus was made for the California Clean Air Bus project with the same design expanded. After a complex valve train was tried they hired Brobeck to design a Doble type of piston valve. There is more to the story.

It is time to become acquainted with the work of Sadi Carnot (1796-1832). This name needs to be given the French pronunciation if you want to do any name dropping around physicists or engineers. Carnot said that the hotter things were the more thermally efficient they were. With regards to steam engines hotter and more pressure go together. When attempting high thermal efficiencies in steam one keeps bumping up against materials issues and lubrication issues. In fact, the Dutcher engine was water cooled so that the rings could be lubricated because the steam was so hot going into it that the iron was glowing red hot. They made one attempt to insulate the top of the piston with a piece of carbon or ceramic material. This should have worked because there was no need to have any strength in this material. The thermal stresses immediately fractured it and ruined the cylinder and piston. It may be possible with new materials to insulate the cylinder and the piston.

This is another example of why it is not possible to take a conventional IC engine and convert it to steam power. The IC engine is designed to get rid of the heat in the cylinder that comes from the combustion of the air/gas mixture. First of all the cylinders are water jacketed. The piston is made of high heat conducting material and has a long skirt on the trunk piston so as to get heat down into the lower block area. There is such a high temperature differential in a uniflow steam engine between the heat in the head and the temperature of the block at the bottom where the exhaust ports are located that the block will warp and accordion out unless individual cylinders are cast. In a steam engine the opposite situation to that of an IC engine prevails. Any heat lost from the incoming steam means lower thermal efficiency. All of the heat in the steam is needed to be preserved so that it can be used for expansion and pressure.

Tom Stoecker, who lives in Southern Illinois, and who has spent his adult life thinking about steam, says that for a person to be successful in steam they need to get past all of the bad ideas before they can get to the good ideas. The implication of this is that a person needs to start working in steam early in their life; otherwise they will not have the time left to get past all of the bad ideas. The other implication is that no one is smart enough to not have any bad ideas at first. The other implication is that no one is smart enough to not have a lot of bad ideas about steam at first.

Tesla Turbines

One of the great bad ideas in steam is the Tesla turbine. There must be some seductive attraction to it because many people are promoting it. I will be brief in my derogation of the Tesla turbine on the theory that if you do not think I know what I am doing, then, talking more will not make it better. I inherited from the late Bill Sieple's estate two PhD thesis from University Microfilm on the Tesla turbine. One of them is by Beans, Elroy William, 1931- "Performance Characteristics of a Friction Disc Turbine" Pennsylvania State University Ph.D., 1961. The other one is North, Richard Charles, 1932- "An Investigation of the Tesla Turbine" University of Maryland, Ph.D., 1969. Both of these used compressed air and water as the medium for powering these test turbines. I did not read them carefully but went right to the conclusions, which that they were at best 20% mechanically efficient. You should keep in mind that high temperature steam has a much smaller molecule than ambient temperature air and so would be even worse for efficiency. Here is where knowing something about Reynolds numbers would help.

You would do well to keep in mind that 1000 psi steam produces a nozzle velocity of 4,000 feet per second and it has about half the molecular weight of air. These two factors are important when dealing with turbine theory. The second thing to keep in mind is the inherent structural weakness of a Tesla turbine. Large holes need to be cut into the discs close to the axle, which is also where the centrifugal force is concentrated, which are for exhaust of spent steam. Then there is the differential thermal expansion of the hot steam at the outer edges of the discs and the cool centers. Thus, if the Tesla rotors do not fly apart and kill people they end up distorting so as to look like a stack of cornflakes. After looking at the 20% mechanical efficiency and the structural problems of a Tesla turbine we do not have to look at how many hundred thousand rpm's a small one has to turn and what the torque characteristics would be and how large the gear box and constant velocity transmission would need to be for this to work in a vehicle.

A regular bucket turbine works if the tip speed is one half the velocity of the steam coming out of the nozzle. This would be a tip speed of 2,000 feet per second. As an example the Lear bus turbine was 5 ½" in diameter and turned in the 30,000 rpm range and put out 300 horsepower. It would be fairly efficient if the exhaust steam from this impulse-reaction single turbine then went into a radial entry turbine with variable nozzles. However, to be practical a very good transmission would be needed so that it could run at one speed all of the time. For more modest horsepower ratings a much smaller turbine disc would be needed and thus the rpm would be up over 100,000 rpm with all of the attendant issues. Also turbines do not scale well because of the issues with sealing the edges of the turbine disc.

Tethered Racing Steam Boats

There is a rule that racing improves the development of whatever it is that can be raced; airplanes, cars, and boats. Significant work in modern steam power has come from the most unlikely source—the one meter tethered racing boats over in England. This practice started in 1903 when only steam power was available as small IC engines were not developed then. Work in this area has been reported in the British publication: Model Engineering. The history is told in the little book "The History of Model Power Boats" by Edgar T. Westbury 1950 published by Percival Marshal & Co. The technical book complete with good prints and photos is "Flash Steam, Its application in model and full-size practice" by the same Westbury and printed in 1949.

Steam boat racing has some history in the US on the East coast. It still continues in England and personal communication says that the present world record holder uses a single cylinder nominal 1" bore and 1" stroke steam engine that produces 16 hp at 10,000 rpm and the little boat goes 120 miles an hour. Needless to say fuel economy is not an issue with something that is on a 100' tether in a shallow pond and needs to make 5 revolutions to complete the race. The burners are modeled on the blow-torch with a vaporizing burner. The boilers are one long helical coil mono-tube boiler. The flame extends several feet out behind the boat when it is going. Over the years every type of engine from 1-3 cylinders in every possible configuration and every type of valve gear has been tried. This illustrates what a high speed light weight steam power plant can do.

There are very few people who spent years working on steam. This means devoting their lives to making things, perfecting them, and continuously testing them under load. These people are Bill Besler, Jay Carter, the Williams' family, Roy Ferrier, the MSS group out of Oak Ridge, and Pete Barrett. These people used their own money. Significant contributions to modern steam engine work were done by John Wetz, Bill Cartland, Richard J. Smith, Charlie Keen, Bill Ryan, and now Harry Schoell. In the late 1960's and early 1970's some government money, both Federal and from the State of California, went into steam development. The main projects were the S.E.S. people based out of M.I.T. who spent about $7 million of EPA money developing a steam car. The steam generator was very good. The engine was designed by Ricardo in England and was not very innovative. The S.P.S. project out of San Diego used the Solar Turbine division of International Harvester to design their burner and boiler. Brobeck out of the Oakland area used basically Doble technology to make a bus. General Motors worked on their own steam car, the SE-101, and commissioned Bill Besler to make one, a 1969 Chevelle conversion, the SE-124. The numbers were the displacement in cubic inches of the expanders. Bill Lear put about $10 million of his own money into steam development. A book could be written about his work. Stated very briefly, Lear did not have the temperament to do the steady incremental development work that steam engines require. If something did not work well the first time it was tried he abandoned that line of work and went on to something entirely different. That is not the way to do steam engine development.

Something can be learned from each of these projects. The government funded work produced a great many reports and technical papers. One might think that producing papers and reports was the main purpose of government funded work, if one were to look at this with a jaundiced eye. Most of this is written up in Society of Automotive Engineers technical papers. There are about 60 of them that are steam related. Otherwise much information can be gleaned from the steam related patents. To date there are about 5,000 of these. Steam power plants are fairly complex so the related patents can cover everything from burners to heat exchangers to control systems to water pumps. Each component is important.

Pete Barrett was insistent on the use of a basic IC engine which was, in his case, the VW air cooled engine. Thus the existing crankcase, crankshaft, and connecting rods and pistons could be used. The VW engine leant itself to steam work because it was common and cheap and, more importantly, it had individual cylinders that could be unbolted and replaced with custom machined steam engine cylinders and valves. A mistake Peter made that was very easy to see in retrospect was to attempt to fit the entire steam system into the original engine compartment of the Volkswagen. Some problems developed because of overheating caused by the small space, insufficient insulation on the combustion chamber, and wire shorting out problems. Most of the difficulty had to do with access to all of the components. The assumption made, and found out to be an incorrect one, was that the engineering work had been done. In practice things were continuously in need of disassembly and reworking. This would have been much easier to accomplish if the components had been laid out and bread boarded in the vehicle, are even better yet set up in a shop and run under load on the bench.

An example of how steam development work goes is one of the many annual reports Pete gave at the September Danville, Illinois steam club meets. The entire report, complete with photos, was of mounting hardware that held a ten speed bicycle to be carried along the passenger side of the VW fiberglass kit car. This having a readily available personal transportation system allowed for a wider radius of test runs to be made. The vehicle was run until it quit running, the tow vehicle and trailer was driven out from the shop, it was hauled back, diagnosed, fixed, and run again. This is the pure definition of engineering. Prior to the bicycle clamping mechanism development much valuable time was lost walking back home.

One other lesson from Pete Barrett is that a person without the persistence to do this work and the devotion to steam power does not get very far in steam work. Lear was an example of the entirely opposite type of personality. The reason for the need to work with steam until it breaks is because there is very little engineering experience available these days. In other words things cannot be designed well in the first place because of the lack of engineers to do the good design work.

And the sole purpose of this essay is to introduce modern steam power. Hopefully everyone will conclude that modern steam power is possible and then they will conclude that it is very complex, and finally conclude that somewhere someone knows how to avoid many common mistakes made in steam power plant development.