Chapter 10: Automotive Systems

There are two or three main objectives for people who create automotive devices – increasing the mpg performance and reducing the harmful emissions are the top two priorities, while running the vehicle on water alone is the aim of a few people.

The first two objectives are readily achievable, but running a vehicle on water alone is not going to happen for almost everybody. This idea is peddled by con artists who sell worthless "plans" such as the HydroStar and HydroGen manuals, claiming that these will run a vehicle on water for anybody who wants to construct these simple devices. This is just not true, and you are welcome to download these worthless documents free from my web site http://www.free-energy-info.com/P61.pdf and http://www.free-energy-info.com/P62.pdf but please don't imagine that they will do anything worthwhile for you as all they are good for is discouraging people and parting them from their money.

Just before getting on to explain the construction details of practical systems, let me put the running of an engine on water alone in its proper context. The internal combustion engine which you own has an efficiency less than 50%. This means that at least half of the energy available from the fuel which you use is wasted and does not produce any useful mechanical output power. In many cases, that percentage can be as high as 90%, but let's be generous and assume that your particular engine is especially good and manages 50% efficiency.

The main way of running an engine with water as the only fuel, involves splitting water into hydrogen and oxygen and then burning those gases to power the engine. To be self-sustaining, the splitting of the water has to be done by the electrics of the vehicle and that means that the efficiency of the water splitting has to be more than 200% efficient. That just doesn't happen with simple systems, so please forget the notion of building some device in your garage with a couple of hours work and waving goodbye to filling stations forever – it ain't going to happen.

Just to set the record straight, it **is** possible to do just that, but the difficulty level is about the same as building a rocket capable of going into orbit, which is something well beyond the capabilities of most people, including me. This document does tell you how it can be done, but please understand that it calls for exceptional skills, very considerable expenditure and a great deal of patience, so for the time being, please forget about it.

What can be done quite readily and at low cost, is to construct a device which will raise the efficiency of your engine. This is done by feeding a hydrogen/oxygen gas mix (called "hydroxy" gas) into your engine along with the air which is drawn in to make the engine run. A device of this type is called a "booster" as it boosts the fuel burn, extracting a greater percentage of the fuel's available energy. An important side effect of this improvement in the burn quality of the fuel is the fact that unburnt fuel no longer gets pushed out of the exhaust as harmful emissions.

Another effect is that the engine has greater pulling power and runs smoother. Inside your engine, carbon deposits will have built up from previous un-boosted running. These deposits get burnt away when you use a booster and that extends the engine life.

Some people worry about the fact that burning hydroxy gas produces water and they imagine this water causing rusting inside the engine. What they don't realise is that the ordinary fuel used in the engine is a "hydrocarbon" which is a compound of hydrogen and carbon and that fuel actually splits up to form hydrogen which the engine burns. Actually, it is the carbon part of the hydrocarbon fuel which is the problem, producing Carbon dioxide (greenhouse gas), Carbon monoxide, and physical carbon deposits inside the engine. A normal fuel burn produces water anyway, but you don't get rusting inside the engine as the temperature there is so high that any water is in the form of steam or vapour which dry out completely when the engine is switched off. Adding a small amount of hydroxy gas has no adverse effects at all.

This document describes three different types of booster. One is the ultra simple, very low efficiency, 'hotsabi' unit which probably produces about 0.4 litres of hydroxy gas per minute using 10 amps of current. One is the "Smack's" booster which has medium efficiency and produces 1.7 litres per minute at a current of 20 amps. The third is the "7-cell isolated" generic design which has high electrical efficiency and can produce 2 litres per minute at 10 amps of current.

However, it does not follow that the greatest gains are produced by the largest gas flow rate. The 'hotsabi' booster gave it's designer an mpg gain of 50%. The 'Smack's' booster gives its designer a 25% mpg gain in spite of having more than three times the gas flow rate. Let me stress again that each engine is different and it depends on how inefficient the engine is to begin with, what sort of mpg improvement is likely to be produced by a booster.

Just to make sure that you understand what is involved, a booster is a simple container which holds a set of plates submerged in water which probably has an additive to make the water splitting easier. A pipe from the top of the container feeds the gas into the air filter of the vehicle, via one or two safety simple safety devices. Adding this gas causes a major improvement in the quality of the fuel burn inside the engine and cuts harmful emission to near zero.

As a consequence of this, it is possible to reduce the amount of fossil fuel being sent to the engine. This is **not** something which should be done **if** hydroxy gas is **not** being added as the engine is liable to overheat and some damage could occur. It is a completely different matter if hydroxy gas is being added. However, all recent engine designs have an Electronic Control Unit ("ECU") which controls the amount of fuel being sent to the engine. The ECU accepts input signals from an "oxygen sensor" placed in the exhaust stream, and often a second sensor after the catalytic converter to make sure that the catalytic converter has not failed.

Unfortunately, the much improved exhaust caused by the better fuel burn caused by the hydroxy gas, causes the ECU to think that the engine fuel-air mix must be too low, and so it pumps in more fuel in an effort to compensate. Ideally, this can be dealt with by adding a circuit board which adjusts the signal coming from the oxygen sensor so that it is correct for the improved fuel burn. Details of how to do this are included in this document.

So, to recap, the only practical device which you can build yourself and use to improve automotive performance is a 'booster'. Using a booster improves the efficiency of the fuel burn inside your engine and that results in more power, better torque, smoother running and vastly improved exhaust emissions. If the ECU is not adjusted or its input signal not controlled, the mpg figures may actually get slightly lower due to unwanted excess fuel being pumped into the engine. If a control circuit is used to correct this ECU error, then mpg gains will be produced.

So, what mpg gains can be expected? The worst I have ever heard of was 8% which is very rare. The lowest likely gain is 20%. Typical gains are in the 25% to 35% bracket. Not particularly unusual is 35% to 60%, while gains up to 100% and over have been achieved but they are rare. A realistic expectation would be a 33% gain.

There are many enthusiast forums on the web and a large and very popular one is the well-known http://tech.groups.yahoo.com/group/watercar/ forum. One member of that forum is known as "Eletrik". He is very experienced, and has produced a booster design which has been shown to be particularly effective. He calls his design "The Smack's Booster" because of his nickname. He has generously shared his design freely with anyone who wants to build one, and he will even build one for you if you want him to. His design is reproduced here as an introduction to the subject of boosters.

Smack's Booster

The Smack's booster is a piece of equipment which increases the mpg performance of a car or motorcycle. It does this by using some current from the vehicle's battery to break water into a mixture of hydrogen and oxygen gasses called "hydroxy" gas which is then added to the air which is being drawn into the engine. The hydroxy gas improves the quality of the fuel burn inside the engine, increases the engine power, cleans old carbon deposits off the inside of the engine, reduces the unwanted exhaust emissions and improves the mpg figures under all driving conditions.

This hydroxy booster is easy to make and the components don't cost much. The technical performance of the unit is very good as it produces 1.7 litres of hydroxy gas per minute at a very reasonable current draw. The following section shows how to make and use it, and any modifications, update information and advice are available from the http://www.smacksboosters.110mb.com web site.

Caution: This is not a toy. If you make and use one of these, you do so entirely at your own risk. Neither the designer of the booster, the author of this document or the provider of the internet display are in any way liable should you suffer any loss or damage through your own actions. While it is believed to be entirely safe to make and use a booster of this design, provided that the safety instructions shown below are followed, it is stressed that the responsibility is yours and yours alone.

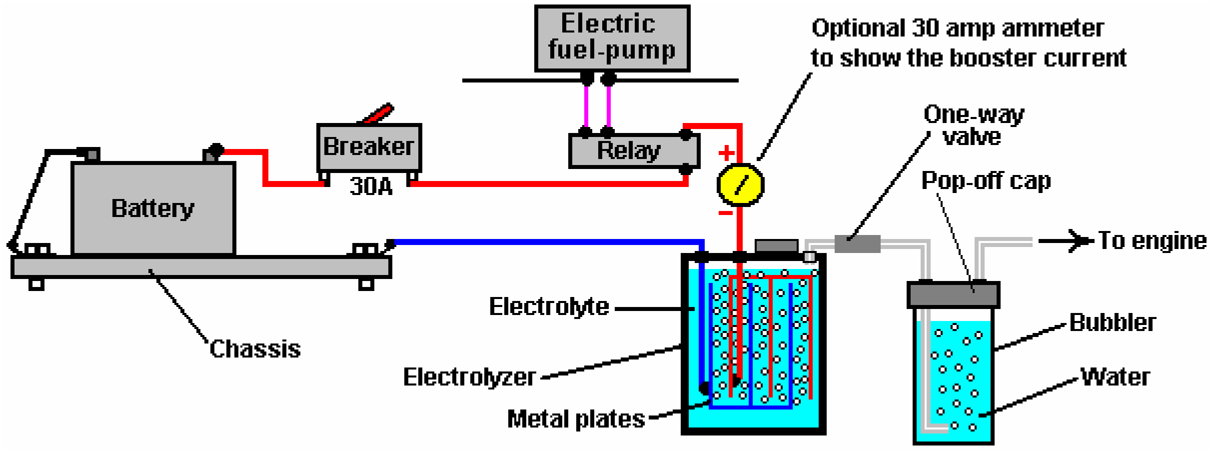
The Safety Gear

Before getting into the details of how to construct the booster, you must be aware of what needs to be done when using any booster of any design. Firstly, hydroxy gas is highly explosive. If it wasn't, it would not be able to do it's job of improving the explosions inside your engine. Hydroxy gas needs to be treated with respect and caution. It is important to make sure that it goes into the engine and nowhere else. It is also important that it gets ignited inside the engine and nowhere else.

To make these things happen, a number of common-sense steps need to be taken. Firstly, the booster must not make hydroxy gas when the engine is not running. The best way to arrange this is to switch off the current going to the booster. It is **not** sufficient to just have a manually-operated dashboard On/Off switch as it is almost certain that switching off will be forgotten one day. Instead, the electrical supply to the booster is routed through the ignition switch of the vehicle. That way, when the engine is turned off and the ignition key removed, it is certain that the booster is turned off as well.

So as not to put too much current through the ignition switch, and to allow for the possibility of the ignition switch being on when the engine is not running, instead of wiring the booster directly to the switch, it is better to wire a standard automotive relay across the electric fuel pump and let the relay carry the booster current. The fuel pump is powered down automatically if the engine stops running, and so this will also power down the booster.

An extra safety feature is to allow for the (very unlikely) possibility of an electrical short-circuit occurring in the booster or its wiring. This is done by putting a fuse or contact-breaker between the battery and the new circuitry as shown in this sketch:



If you choose to use a contact-breaker, then a light-emitting diode ("LED") with a current limiting resistor of say, 680 ohms in series with it, can be wired directly across the contacts of the circuit breaker. The LED can be mounted on the dashboard. As the contacts are normally closed, they short-circuit the LED and so no light shows. If the circuit-breaker is tripped, then the LED will light up to show that the circuit-breaker has operated. The current through the LED is so low that the electrolyser is effectively switched off when the contact breaker opens. This is not a necessary feature, merely an optional extra:

In the first sketch, you will notice that the booster contains a number of metal plates and the current passing through the liquid inside the booster (the "electrolyte") between these plates, causes the water to break up into the required hydroxy gas mix. A very important safety item is the "bubbler" which is just a simple container with some water in it. The bubbler has the gas coming in at the bottom and bubbling up through the water. The gas collects above the water surface and is then drawn into the engine through an outlet pipe above the water surface. To prevent water being drawn into the booster when the booster is off and cools down, a one-way valve is placed in the pipe between the booster and the bubbler.

If the engine happens to produce a backfire, then the bubbler blocks the flame from passing back through the pipe and igniting the gas being produced in the booster. A bubbler is a very simple, very cheap and very sensible thing to install. It also removes any traces of electrolyte fumes from the gas before it is drawn into the engine.

You will notice that the wires going to the plates inside the electrolyser are both connected well below the surface of the liquid. This is to avoid the possibility of a connection working loose with the vibration of the vehicle and causing a spark in the gas-filled region above the surface of the liquid, and this volume is kept as low as possible as another safety feature.

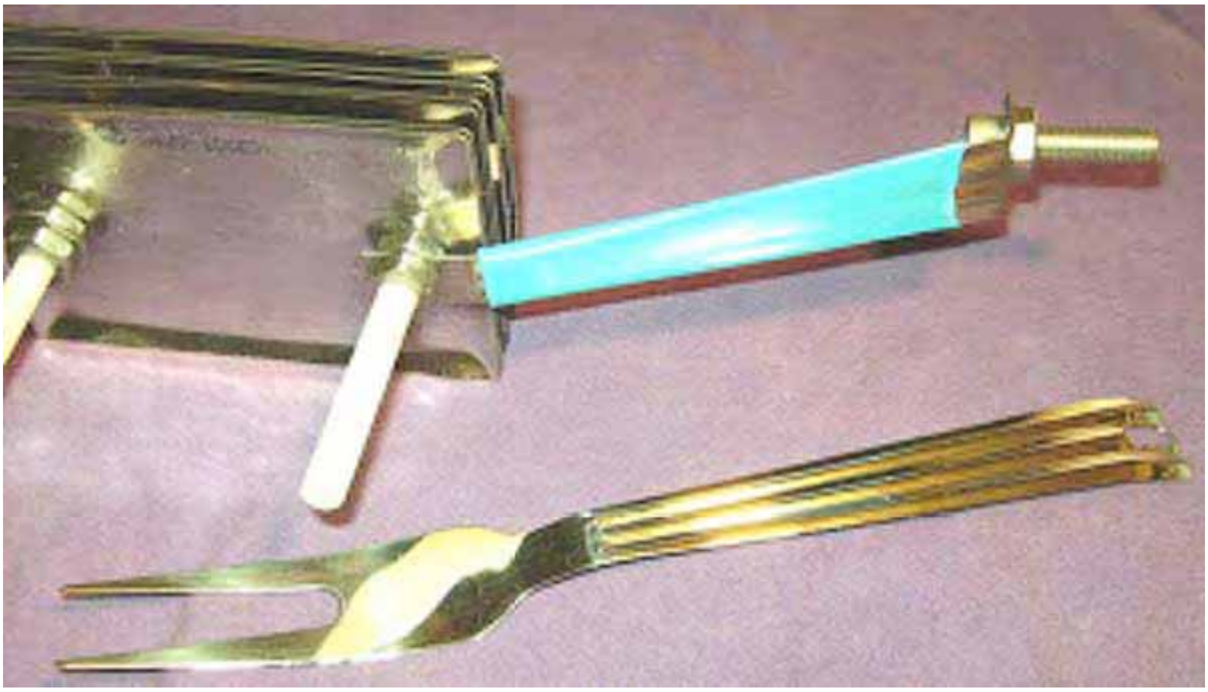
The Design

The booster is made from a length of 4-inch diameter PVC pipe, two caps, several metal plates, a couple of metal straps and some other minor bits and pieces:

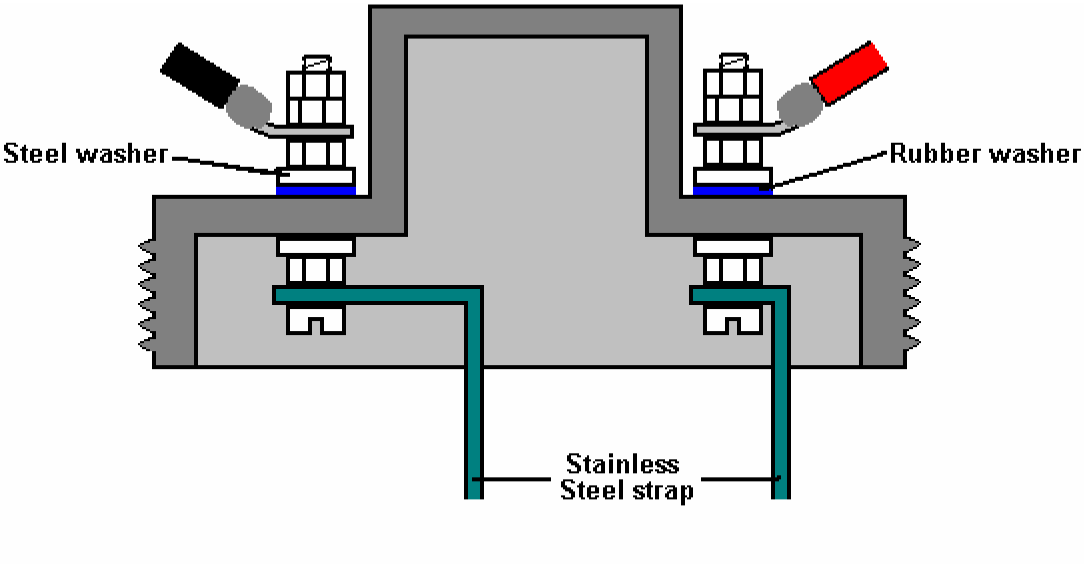
This is not rocket science, and this booster can be built by anybody. A clever extra feature is the transparent plastic tube added to the side of the booster, to show the level of the liquid inside the booster without having to unscrew the cap. Another neat feature is the very compact transparent bubbler which is actually attached to the booster and which shows the gas flow coming from the booster. The main PVC booster pipe length can be adjusted to suit the available space beside the engine.

Bubbler connections close up:

This booster uses cheap, standard electrical stainless steel wall switch covers from the local hardware store and stainless steel straps cut from the handles of a wide range of food-preparation cutlery.



The electrical cover plates are clamped together in an array of eight closely-spaced pairs of covers. These are suspended inside a container made from 4-inch (100 mm) diameter PVC or ABS pipe. The pipe is converted to a container by using PVC glue to attach an end-cap on one end and a screw-cap fitting on the other. The container then has the gas-supply pipe fitting attached to the cap, which is drilled with two holes to allow the connecting straps for the plate array to be bolted to the cap, as shown here:



CROSS-SECTION THROUGH CAP

In order to ensure that the stainless steel straps are tightly connected to the electric wiring, the cap bolts are both located on the robust, horizontal surface of the cap, and clamped securely both inside and out. A rubber washer or rubber gasket is used to enhance the seal on the outside of the cap. If available, a steel washer with integral rubber facing can be used.

As the stainless steel strap which connects the booster plates to the negative side of the electrical supply connects to the central section of the plate array, it is necessary to kink it inwards. The angle used for this is in no way important, but the strap should be perfectly vertical when it reaches the plates as shown here:

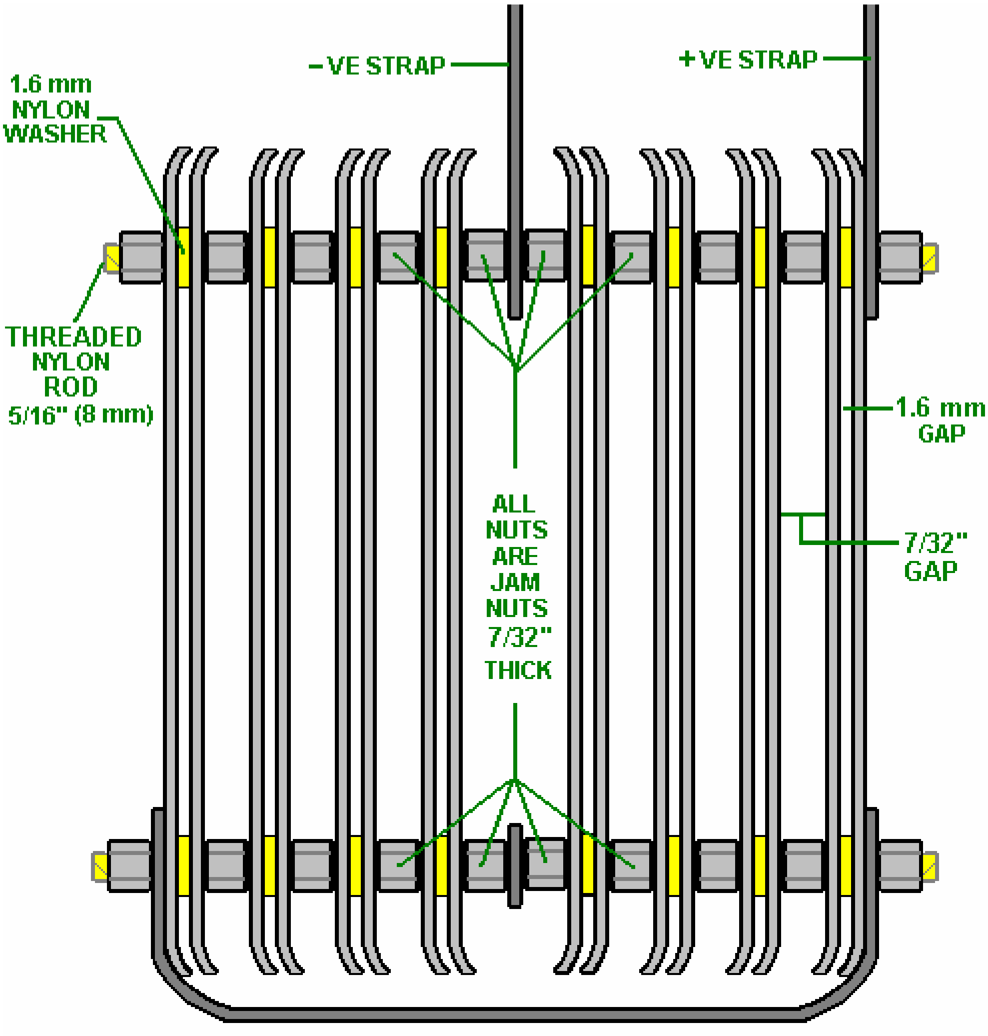
The picture above shows clearly the wall plates being used and how the bubbler is attached to the body of the booster with super-glue. It also shows the various pipe connections. The stainless steel switch-cover plates are 2.75 inch x 4.5 inch (70 mm x 115 mm) in size and their existing mounting holes are drilled out to 5/16 inch (8 mm) diameter in order to take the plastic bolts used to hold the plates together to make an array. After a year of continuous use, these plates are still shiny and not corroded in any way.

Two stainless steel straps are used to attach the plate array to the screw cap of the booster. These straps are taken from the handles of cooking utensils and they connect to three of the plates. An extra outside strap runs across the bottom of the plate array, clear of the plates, and connects to both outside plates as can be seen in both the above photographs and the diagram below.

The plates are held in position by two plastic bolts which run through the original mounting holes in the plates. The arrangement is to have a small 1.6 mm gap between each of eight pairs of plates. These gaps are produced by putting plastic washers on the plastic bolts between each pair of plates.

The most important spacing here is the 1.6 mm gap between the plates as this spacing has been found to be very effective in the electrolysis process. The way that the battery is connected is unusual in that it leaves most of the plates apparently unconnected. These plate pairs are called “floaters” and they do produce gas in spite of looking as if they are not electrically connected.

Stainless steel nuts are used between each pair of plates and these form an electrical connection between adjacent plates. The plate array made in this way is cheap, easy to construct and both compact and robust. The electrical straps are bolted to the screw cap at the top of the unit and this both positions the plate array securely and provides electrical connection bolts on the outside of the cap while maintaining an airtight seal for the holes in the cap.



SIDE VIEW OF PLATE ARRAY

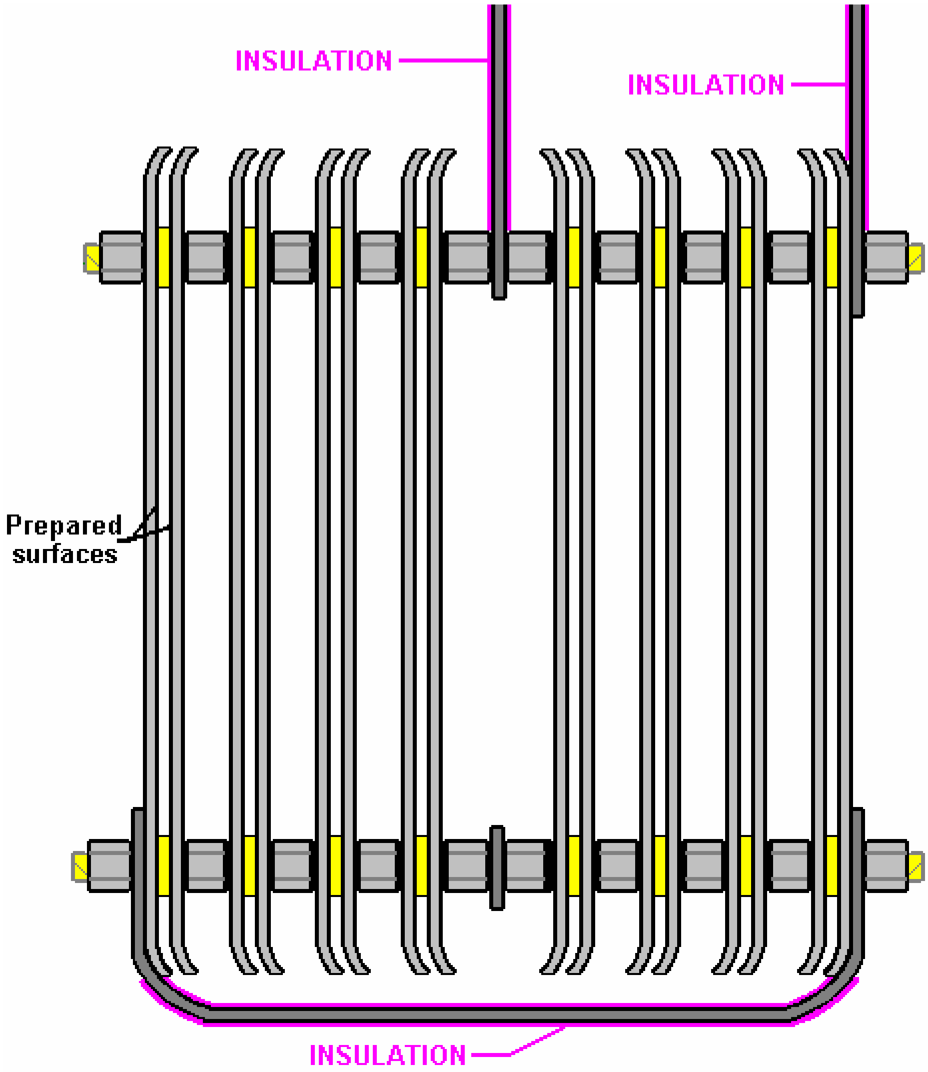
The plates are held in a vise when being drilled:

The active surfaces of the plates - that is, the surfaces which are 1.6 mm apart from each other, need to be prepared carefully. To do this, these surfaces are scored in an X-pattern using 36-grade coarse sandpaper. Doing this creates miniature sharp-crested bumps covering the entire surface of each of these plates. This type of surface helps the hydroxy bubbles break away from the surface as soon as they are formed. It also increases the effective surface area of the plate by about 40%.

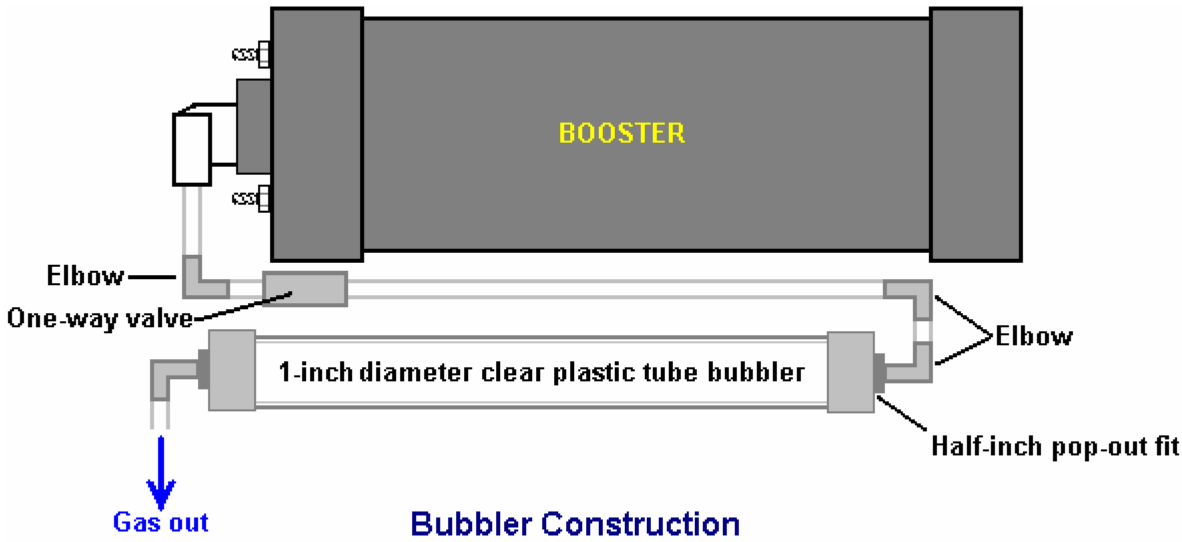
Shown above are typical hand tools used to create the indentations on the plates. The active plate surfaces – that is, the surfaces which are 1.6 mm apart – are indented as well as being sanded.

I know that it may seem a little fussy, but it has been found that fingerprints on the plates of any electrolyzer seriously hinder the gas production because they reduce the working area of the plate quite substantially. It is important then, to either avoid all fingerprints (by wearing clean rubber gloves) or finish the plates by cleaning all grease and dirt off the working surfaces with a good solvent, which is washed off afterwards with distilled water. Wearing clean rubber gloves is by far the better option as cleaning chemicals are not a good thing to be applying to these important surfaces.

Another very practical point is that the stainless steel straps running from the screw cap to the plate array, need to be insulated so that current does not leak directly between them through the electrolyte. The same applies to the strap which runs underneath the plates. This insulating is best done with shrink-wrap. Alternatively, good quality tool dip (McMaster Carr part number 9560t71) is an effective method, but if neither of these methods can be used, then the insulating can be done by wrapping the straps in electrical insulating tape. Using that method, the tape is wrapped tightly around the straps, being stretched slightly as it is wrapped. The strap running underneath the covers is insulated before the array is assembled.



The PVC housing for the booster has two small-diameter angle pipe fittings attached to it and a piece of clear plastic tubing placed between them so that the level of the electrolyte can be checked without removing the screw cap. The white tube on the other side of the booster is a compact bubbler which is glued directly to the body of the booster using super-glue in order to produce a single combined booster/bubbler unit. The bubbler arrangement is shown here, spread out before gluing in place as this makes the method of connection easier to see.



The elbows at the ends of the one-inch diameter bubbler tube have their threads coated with silicone before being pushed into place. This allows both of them to act as pressure-relief pop-out fittings in the unlikely event of the gas being ignited. This is an added safety feature of the design.

This booster is operated with a solution of Potassium Hydroxide also called KOH or Caustic Potash which can be bought from Summer Bee Meadow at http://www.summerbeemeadow.com/ via their "Soapmaking Supplies" button. To get the right amount in the booster, I fill the booster to its normal liquid level with distilled water and add the Hydroxide a little at a time, until the current through the booster is about 4 amps below the chosen working current of 20 amps. This allows for the unit heating up when it is working and drawing more current because the electrolyte is hot. The amount of KOH is typically 2 teaspoonfulls. It is very important to use distilled water as tap water has impurities in it which make a mess which will clog up the booster. Also, be very careful handling potassium hydroxide as it is highly caustic. If any gets on you, wash it off immediately with large amounts of water, and if necessary, use some vinegar which is acidic and will offset the caustic splashes.

The completed booster usually looks like this:

But, it can be built using different materials to give it a cool look:

And attached to a cool bike:

The final important thing is how the booster gets connected to the engine. The normal mounting for the booster is close to the carb or throttle body so that a short length of piping can be used to connect the booster to the intake of the engine. The connection can be to the air box which houses the filter, or into the intake tube. The closer to the butterfly valve the better, because for safety reasons, we want to reduce the volume of hydroxy gas hanging around in the intake system. You can drill and tap a 1/4" (6 mm) NPT fitting into the plastic inlet tubing with a barbed end for connecting the 1/4" (6 mm) hose.

The shorter the run of tubing to the air ductwork of the engine, the better. Again, for safety reasons, we want to limit the amount of unprotected hydroxy gas. If a long run of 3 feet (1 metre) or more must be used due to space constraints, then it would be a good idea to add another bubbler at the end of the tube, for additional protection. If you do this, then it is better to use a larger diameter outlet hose, say 3/8" or 5/16" (10 mm or 12 mm).

If you don't have the necessary tools or workspace, then you can buy one ready-made. You can see the details on the web site **http://www.smacksboosters.110mb.com**

Powering your Booster

Use wire and electrical hardware capable of handling 20 amps DC, no less. Overkill is OK in this situation, so I recommend using components that can handle 30 amps. Run your power through your ignition circuit, so that it only runs when the vehicle is on. A 30 amp relay should be used to prevent damaging the ignition circuit which may not be designed for an extra 20 amp draw. Make sure to use a properly rated fuse, 30 amps is ideal. You can use a toggle switch if you like for further control. As an added safety feature, some like to run an oil pressure switch to the relay as well, so the unit operates only when the engine is actually running. It is very important that all electrical connections be solid and secure. Soldering is better than crimping. Any loose connections will cause heat and possibly a fire, so it is up to you to make sure those connections are of high quality. They must be clean and tight, and should be checked from time to time as you operate the unit just to be sure the system is secure.

Adjusting the Electrolyte

Fill your booster with distilled water and NaOH (sodium hydroxide) or KOH (potassium hydroxide) **only**. No tap water, salt water or rainwater! **No table salt or baking soda!** These materials will permanently damage the booster!

First, fill the booster with distilled water about 2" from the top. Add a teaspoon of KOH or NaOH to the water and then slide the top into place. Do not tighten it for now, but leave the top loose and resting in place. Connect your 12V power supply to the leads and monitor the current draw of the unit. You want 16 amps flowing when the booster is cold. As the water heats up over time, the current draw will increase by around 4 amps until it reaches about 20 amps, and this is why you are aiming for only 16 amps with a cold system.

If the current is too high, dump out some electrolyte and add just distilled water. If the current is too low, add a pinch or two at a time of your catalyst until the 16 amps is reached. Overfilling your booster will cause some of the electrolyte to be forced up the output tube, so a liquid level tube was added to monitor electrolyte level.

The booster generally needs to be topped off once a week, depending on how long it is in operation. Add distilled water, then check your current draw again. You may observe a drop in current over the course of a few refills, and this is normal. Some of the catalyst escapes the cell suspended in water vapor droplets, so from time to time you may need to add a pinch or two. The water in the bubbler acts to scrub this contaminant out of the gas as well. I highly recommend installing an ammeter to monitor current draw as you operate your booster.

Mounting the Booster

Choose a well ventilated area in the engine compartment to mount your booster. Since every vehicle design is different, I leave it up to you to figure out the best method to mount it. It must be mounted with the top orientated upwards. Large 5" diameter hose clamps work well, but do not over tighten them or the PVC may deform. I recommend mounting the booster behind the front bumper in the area usually present between it and the radiator. Support the weight of the unit from the bottom with a bracket of your design, then use two hose clamps to secure the unit, one near the top and one near the bottom. Never install the unit in the passenger compartment for safety reasons.

Output hose and Bubbler

The bubbler on the side of the unit should be filled about 1/3 to 1/2 full of water - tap water is fine for the bubbler. The check valve before the bubbler is there to prevent the bubbler water from being sucked back into the booster when it cools and the gases inside contract. **Make sure the bubbler level is maintained at all times**. **Failure to do so could result in an unwanted backfire explosion**. That water inside the bubbler is your physical shield between the stored hydroxy volume in the generator and the intake of your engine. Install the output hose as close to the carburetor/throttle body as close as possible by making a connection into the intake tube/air cleaner. Try to make the hose as short as possible to reduce the amount of gas volume it contains. I recommend using the same type of 1/4" poly hose that is used on the unit.

Here is a list of the parts needed to construct the booster and bubbler if you decide to build it yourself rather than buying a ready-made unit:

The Main Parts Needed

Part	Quantity	Comment
4-inch diameter PVC pipe 12-inches long	1	Forms the body of the booster
4-inch diameter PVC pipe end-cap	1	Closes the bottom of the booster
4-inch diameter PVC pipe screw cap	1	The top of the booster
90-degree Quick Connect Outlet fitting	1	3/8" O.D. Tube x 1/4" NPT from Hardware store
Level indicator Nylon barbed tube fitting	2	1/4" Tube x 1/8" NPT Part Number 2974K153 or from your local hardware store
Quarter-inch I.D. Poly sight tube	8”	Water-level indicator tubing - Hardware store
Stainless steel switch covers	16	The plate array components
Stainless steel straps 12-inches long	2	The electrical connections to the plates
3/4" Inside Diameter Clear poly tube	12-inch	From your local hardware store
5/16” stainless steel bolts 1.25” long	2	Electrical strap connection to the top cap
5/16” stainless steel nuts & washers	6 each	To fit the steel bolts in the cap
5/16” diameter nylon threaded rod	8” min.	Nylon Threaded Rod 5/16"-18 Thread. McMaster Carr Part No 98831a030
5/16” inch nylon washers 1.6 mm thick	1-pack	Nylon 6/6 Flat Washer 5/16", Pack of 100 McMaster Carr Part No 90295a160
5/16”-18 s/s jam nuts (7/32" thick)	20	McMaster Carr Part No 91841A030
90 degree Bubbler Fittings	2	1/4" Barbed Tube 1/2" NPT. McMaster Carr Part No 2974K156
Check valve	1	1/4" tube, McMaster Carr Part No 47245K27 or from your local Hardware store
PVC glue	1 tube	Same color as the PVC pipe if possible
5/16" Neoprene sealing washer	2	McMaster Carr Part No 94709A318 or from your local Hardware store
Tool dip – 14.5 oz	1	McMaster Carr Part No 9560t71
Optional: Light Emitting Diode	1	10 mm diameter, red, with panel-mounting clip
Quarter-watt resistor	1	470 ohm (code bands: Yellow, Purple, Brown)

Now, having shown how this very effective booster and bubbler are constructed, it should be pointed out that if you use it with a vehicle fitted with an Electronic Control Unit which monitors fuel injection into the engine, then the fuel-computer section will offset the gains and benefits of using this, or any other, booster. The solution is not difficult, as the fuel-computer can be controlled by adding in a little circuit board to adjust the sensor signal fed to the computer from the oxygen sensor built into the exhaust of the vehicle. Ready-built units are available for this or you can make your own from the details shown later on in this document.

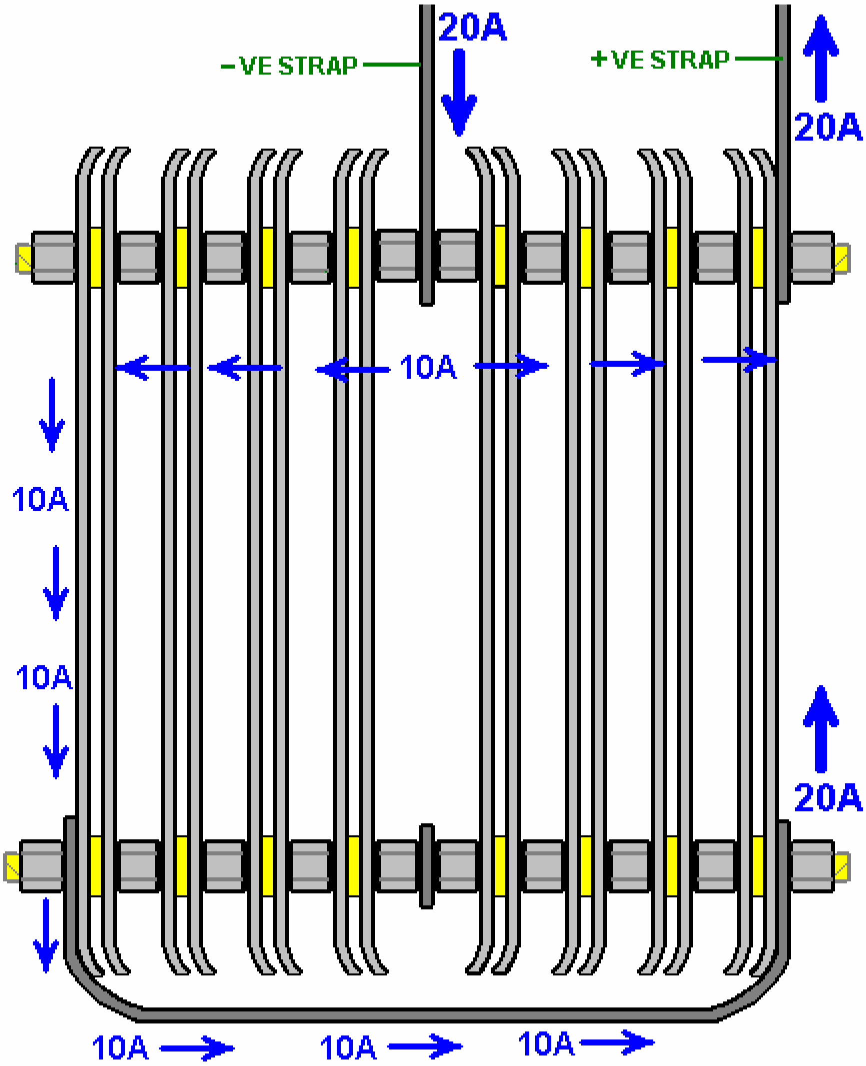
Enjoy using this booster and do your part in cutting greenhouse gas emissions.

Eletrik

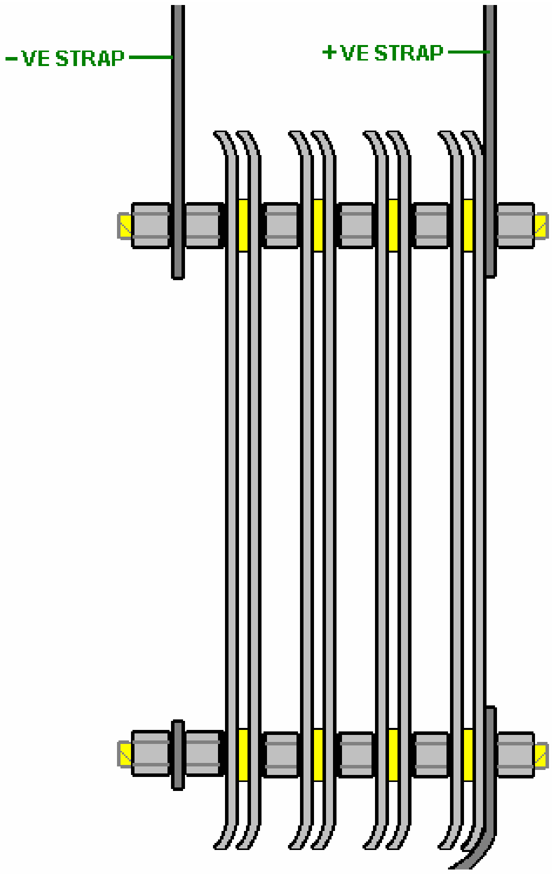
Background Information

Many people find the plate arrangement of the Smack’s Booster, rather difficult to understand, so this additional section is just to try to explain the operation of the cell. This has nothing to do with actually building or using a Smack’s Booster, so you can just skip this section without missing anything.

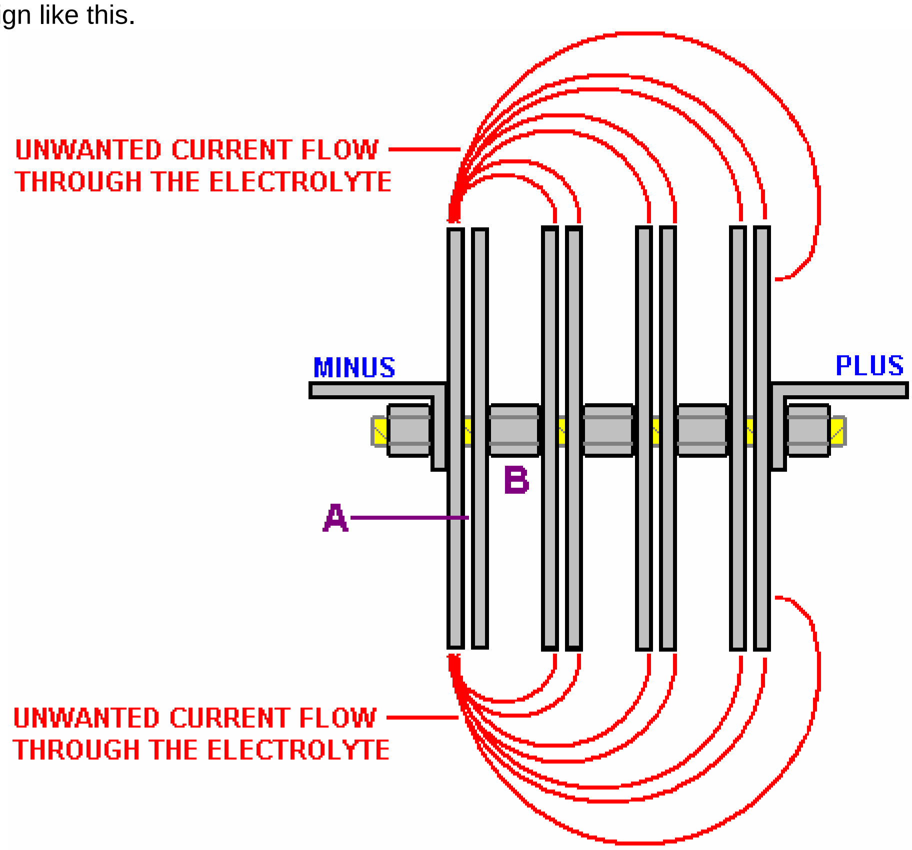
The Smack's Booster plate arrangement does look confusing. This is mainly because Eletrik has squeezed two identical sets of plates into one container as shown here:



This arrangement is two identical sets of plates positioned back-to-back. To make it easier to understand the operation, let's just consider just one of the two sets of plates:



Here, you have just the electrical Plus linked to the electrical Minus by a set of four pairs of plates in a daisy chain (the technical term is: connected "in series" or "series-connected"). Easily the most electrically efficient way for doing this is to exclude all possible current flow paths through the electrolyte by closing off around the edges of all the plates and forcing the current to flow through the plates and only through the plates, but this is not possible in an open-bath design like this.



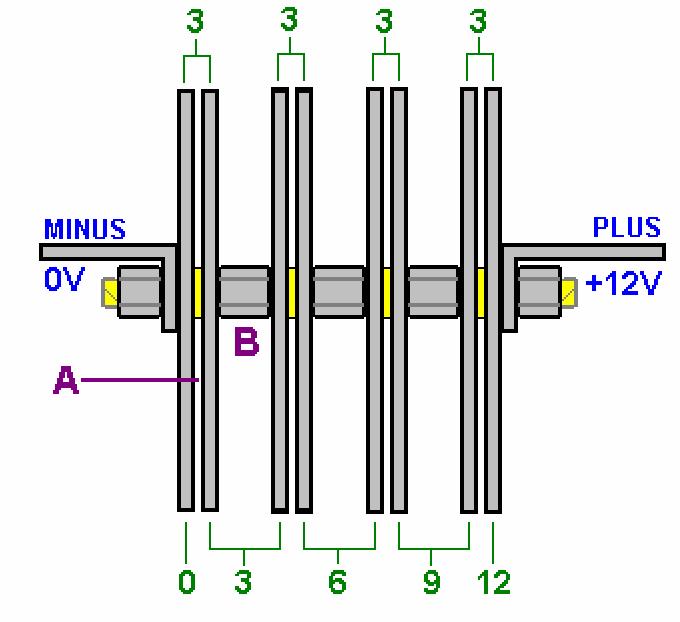
This diagram shows the way that the plates are connected. The red lines show paths of unwanted current flow which do not produce much gas. This wasted current flow is opposed by the useful current flow across gap "**A**" in the diagram.

To favour the flow across the 1.6 mm gap "**A**", an attempt is made to make the waste flows as long as possible by comparison. This is done by the gap "**B**" being made as large as possible.

The voltage applied to the cell (13.8 volts when the engine is running) divides equally across the four plate pairs, so there will be one quarter of that voltage (3.45 volts) across each plate pair, and this has been found to be the best arrangement for this design.

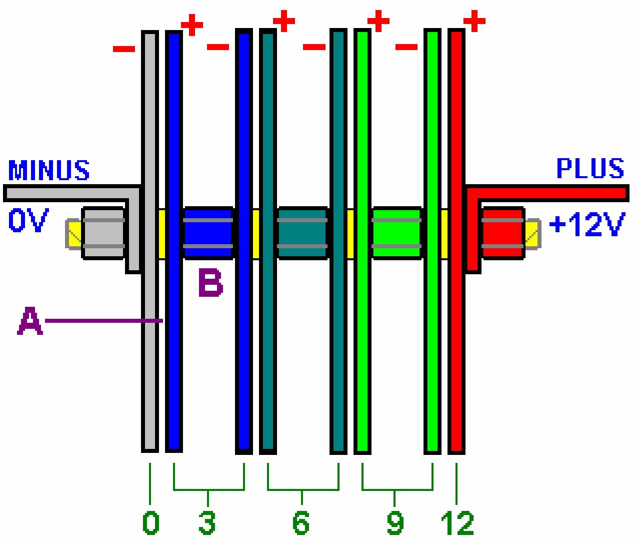
If you look again at the original diagram, you will see that there are two of these sets of four plate pairs, positioned back-to-back in the container. Each of these acts separately, except for the fact that there are additional current leakage paths through the electrolyte between the plates of one set and the plates of the second set.

There is a steady voltage drop progressively across the array of plates. Remember that they are connected in pairs in the middle due to the metal-to-metal connection created by the steel nuts between the plates:



VOLTAGE DROPS FOR A 12-VOLT SUPPLY

It is often difficult for people to get the hang of how the voltage drops across a chain of resistors (or matrix of plates). The voltages are relative to each other, so each plate pair thinks that it has a negative electrical connection on one plate and a positive connection on the other plate.



For example, if I am standing at the bottom of a hill and my friend is standing ten feet up the hill, then he is ten feet above me.

If we both climb a hundred feet up the mountain and he is at a height of 110 feet and I am at a height of 100 feet, he is still ten feet above me.

If we both climb another hundred feet up the mountain and he is at a height of 210 feet and I am at a height of 200 feet, he is still ten feet above me. From his point of view, I am always ten feet below him.

The same thing applies to these plate voltages. If one plate is at a voltage of +3 volts and the plate 1.6 mm away from it is at a voltage of +6 volts, then the 6 volt plate is 3 volts more positive than the 3 volt plate, and there is a 3 volt difference across the gap between the two plates. The first plate looks to be 3 volts negative to the 6 volt plate when it "looks" back at it.

You can also say that the +3 volt plate is 3 volts lower than the +6 volt plate, so from the point of view of the +6 volt plate, the +3 volt plate is 3 volts lower down than it, and it therefore "sees" the other plate as being at -3 volts relative to it.

In the same way, my friend sees me as being at -10 feet relative to him, no matter what height we are on the mountain. It is all a matter of being "higher up" whether in terms of height above sea level on a mountain or in terms of higher up in voltage inside a booster.

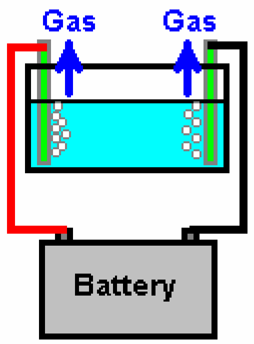
Now, having shown how this booster and bubbler are constructed, it should be pointed out that if you use it with a vehicle fitted with an Electronic Control Unit which monitors fuel injection into the engine, then the fuel-computer section will offset the mpg gains of using this, or any other, booster. The solution is not difficult, as the fuel-computer can be controlled by adding in a little circuit board to adjust the sensor signal fed to the computer from the oxygen sensor built into the exhaust of the vehicle. Ready-built units are available for this or you can make your own.

Newcomers to boosting frequently decide that they want to experiment with other plate configurations inside the Smack's Booster housing. Please be aware that Eletrik spent a whole year experimenting and testing different configurations and the arrangement shown above is his best, so it is unlikely that other arrangements will prove to be better.

Other Boosters. The principles involved here are not at all difficult to understand. If a small amount of hydroxy gas is added to the air being drawn into the engine, the resulting mix burns very much better than it would if no hydroxy gas were added. This extracts a higher percentage of energy from the fossil fuel being burnt in the engine, giving more power and smoother running. With reasonable amounts of hydroxy gas added, the burn quality is so high that a catalytic converter is not needed. Normally, unburnt fuel coming out of the engine is burnt in the catalytic converter. With a good booster connected, there is no unburnt fuel reaching the catalytic converter, so although you leave it in place, it never wears out as it is not being used.

You have just seen the details of the Smack's booster, which is a very usable design, but naturally, there are many other designs. It would be advisable then if you understood the basic principles of booster design as you can then assess the capabilities of any new design.

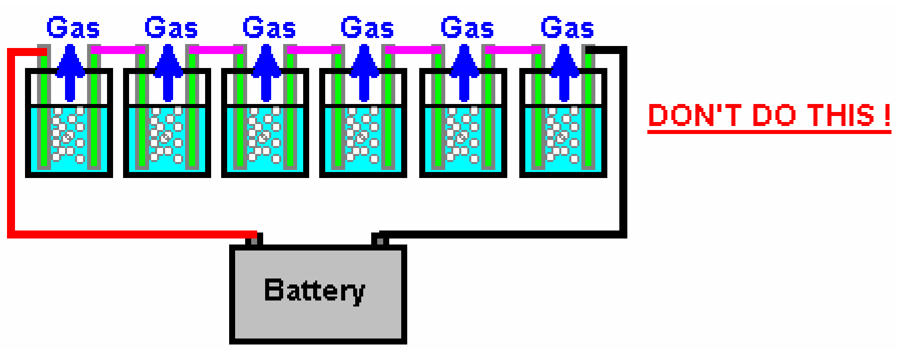
Electrolysis has been known for a very long time and it appears very simple. Michael Faraday described the method and determined the gas output for what seemed to be 100% efficiency of the process. Bob Boyce of the 'watercar' Group has designed a DC electrolysis cell which achieves twice Faraday's theoretical maximum output per watt of input power. Straight DC electrolysis works like this:



Here, a current flows through the liquid inside the electrolysis cell, moving from one plate to the other. The current breaks the bonding of the water molecules, converting the H_2O into hydrogen H and oxygen O. There are various forms of hydrogen and oxygen and mixtures of the two. H atoms on their own are called "monatomic" hydrogen, and given the chance, it will join with another H to form H_2 which is called "diatomic" hydrogen. The same goes for the oxygen atoms. The monatomic variety of hydrogen has four times the energy and about 1% of it mixed with air, is capable of powering an engine without using any fossil fuel oil at all.

If the liquid in the electrolyser is distilled water, then almost no current will flow and almost no gas will be produced. If you add two or three drops of battery acid to the water, the current and gas production increase enormously. Putting acid in the water is a bad idea as it gets used in the process, the acidity of the water keeps changing, the current keeps changing, the acid attacks the electrodes and unwanted gasses are given off. Putting salt in the water, or using seawater, has nearly the same effect with poisonous chlorine gas being given off. Baking soda is also a bad choice as it gives off carbon monoxide which is a seriously toxic gas, it damages the electrodes and ends up as sodium hydroxide. Instead of using these additives, it is much better to use a "catalyst" which promotes the electrolysis without actually taking part in the chemical process. The best of these are Sodium Hydroxide ("Red Devil lye" in the USA, "caustic soda" in the UK) and even better still, Potassium Hydroxide ("Caustic Potash").

The process of electrolysis is most unusual. As the voltage applied to the plates is increased, the rate of gas production increases (no surprise there). But once the voltage reaches 1.24 volts across the electrolyte between the electrodes, there is no further increase in gas production with increase in voltage. If the electrolysis cell produces 1 litre of hydroxy gas per hour with 1.24 volts applied to the electrolyte, then it will produce exactly 1 litre of hydroxy gas per hour with 12 volts applied to the electrolyte. Even though the input power has been increased nearly 10 times, the gas output remains unchanged. So it is much more effective to keep the voltage across the electrolyte to 1.24 volts or some value near that. As there is a small voltage drop due to the material from which the electrodes are made, in practice the voltage per cell is usually set to about 2 volts for the very best electrode metal which is 316L-grade stainless steel.

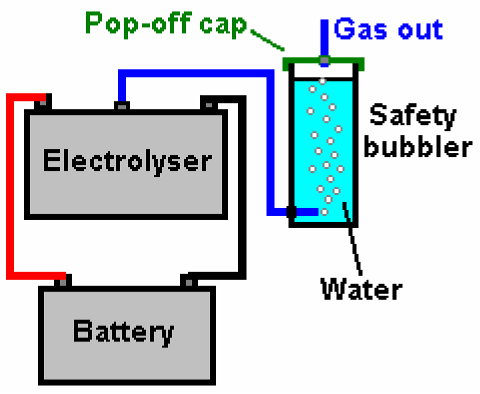


The electrolyser shown here produces six times as much gas for exactly the same input power. This is a serious gain in efficiency. As all of the cells of this electrolyser are identical, each has approximately 2 volts across it when a 12 volt battery is used. The amount of gas produced depends directly on the amount of current passing through the cells. As they are "in series" (connected in a chain), the same current passes through all of them. For any given battery voltage and electrode spacing, the current is controlled by the amount of catalyst added to the water. The liquid in the electrolyser cells is called the 'electrolyte'. In practice, there is a distinct advantage in having a large surface area for each electrode, and a small spacing between the electrodes of about 3 mm or 1/8". Do not allow the hydroxy gas produced to escape upwards as shown above, unless you are outdoors as it will collect on the ceiling and form an explosive mix there.

There is a strong tendency for bubbles of gas to remain on the surface of the electrodes and impede the electrolysis process. If there were enough bubbles on an electrode, it would not actually touch the electrolyte and electrolysis would stop altogether. Many methods have been used to minimise this problem. The electrode plates are normally made from 16 gauge 316L-grade stainless steel and it is recommended that there be between 2 and 4 square inches of plate area on every face of every electrode for each amp of current passing through the cell. Some people place an ultrasonic transducer underneath the plates to vibrate the bubbles off the plate surfaces. Archie Blue and Charles Garrett made the engine suck its input air through the electrolyser and relied on the air drawn through the electrolyte to dislodge the bubbles. Pulling air through the electrolyte is a very bad idea as the air contaminates the electrolyte. Some people use piezo electric crystals attached to the plates to vibrate the plates and shake the bubbles free, others use magnetic fields, usually from permanent magnets. The best method is to treat the electrode plates with cross-hatch scouring, an extensive cleansing process and an extensive conditioning process. After that treatment, a catalytic layer builds up on the electrodes, doubling their efficiency and bubbles no longer stick to the electrodes but break away immediately without the need for any form of additional help.

As indicated in the drawing above, you **MUST NOT** perform electrolysis with the gas escaping freely, unless you are out of doors with very good ventilation. Hydrogen and especially hydrogen/oxygen mix gasses are HIGHLY dangerous, easily ignited and can easily injure or kill you. They must be treated with a high degree of respect. Most people have a great urge to ignite hydroxy gas bubbles coming from their new bubbler. Please **don't**. One cupful of hydroxy gas produces a ban loud enough to damage your hearing permanently, not to mention having the neighbours calling the police to investigate.

You need to keep the amount of gas held at the top of each cell to a minimum, and **ALWAYS** use at least one bubbler as shown here:



The deep water in the bubbler stops any flashback reaching the electrolyser and should the gas at the top of the bubbler be ignited by some accident, then the tightly-fitting cap should blow off harmlessly. If equipment of this nature is being installed in any vehicle, NO component containing "hydroxy" gas must ever be placed inside the passenger compartment. The engine compartment should be used to house this equipment or, if you really must, the boot ("trunk") and no pipe containing gas should run through any part of the passenger area. Staying alive and uninjured is much more important than reducing emissions or fuel consumption.

The least efficient method of producing hydroxy gas is to put a single cell across the whole voltage of a vehicle's electrical system, which produces about 14 volts when the vehicle is being driven. However, the simplicity of a single simple cell can make it a very attractive proposition. To illustrate this, consider the following booster design.

Here are the full step-by-step instructions for making a very simple single-cell booster design from "HoTsAbI" - a member of the Yahoo 'watercar' forum. This is a very neat and simple electrolysis booster unit which has raised his average mpg from 18 to 27 (50% increase) on his 5-litre 1992 Chevy Caprice.

The unit draws only 10 amps which is easily handled by the existing alternator. The construction uses ABS plastic with Sodium Hydroxide ("Red Devil" lye, 1 teaspoon to 8 litres of distilled water) and the gas-mix is fed directly into the air intake filter of the car engine. The electrodes are stainless steel with the negative electrode forming a cylinder around the positive electrode.

The circuit is wired so that it is only powered up when the car ignition switch is closed. A relay feeds power to the electrolyser which is three inches (75 mm) in diameter and about 10 inches (250 mm) tall. The electrolyser circuit is protected by a 30-amp circuit breaker. The electrolyser has several stainless steel wire mesh screens above the water surface.

The output of the electrolyser is fed to a steam trap, also fitted with several stainless steel wire mesh screens, and then on via a one-way valve and into a safety bubbler. The bubbler also has stainless steel wire mesh screens which the gas has to pass through before it exits the bubbler. The gas is then passed through an air-compressor style water trap to remove any remaining moisture, and is injected into the air intake of the vehicle. Although not shown in the diagram, the containers are protected by pop-out fittings which provide extra protection in the extremely unlikely event of any of the small volumes of gas being ignited by any means whatsoever.

The ammeter is used to indicate when water should be added to the electrolyser, which is typically, after about 80 hours of driving and is done through a plastic screw cap on the top of the electrolyser cap (shown clearly in one photograph). This unit used to be available commercially but the designer is now too busy to make them up, so he has generously published the plans free as shown here:

The "E-CELL" by HOTSABI

Please read all of these instructions carefully and completely before starting your project.

Important Note: If you decide to construct an electrolyser from these instructions, you do so entirely at your own risk. Please pay especial attention to the safety instructions in this document as your life and health may depend on sensible precautions which you must take.

This project is the construction of an electrolyzer unit which is intended to improve the running of a vehicle by adding gases produced by the electrolysis of water, to the air drawn into the engine when running.

ELECTROLYZER PARTS LIST

1. One 7" long x 3" ABS tubing cut square - de-burr edges
2. One 3" ABS (Acrylonitrile Butadiene Styrene) Plug - clean out threaded cap
3. One Threaded adaptor DWV 3" HXFPT   ("DWV" and "HXFPT" are male and female threaded sewer type plastic caps)
4. One 3" ABS cap
5. One 4" Stainless steel cap screw 1/4 20
6. Two stainless steel 1" 1/4 20 cap screw
7. One 10/32 x 1/4" stainless steel screw
8. Five washers and Eight stainless steel nuts 1/4 20
9. One piece of stainless steel shimstock 11" x 6" 0.003" thick
10. One piece of stainless steel 14 gauge wire mesh 8" x 3"
11. One 3/8" nylon plug
12. One 1/4" x 1/4" NPT (National Pipe Tap) barbed fitting
13. Plumbers tape

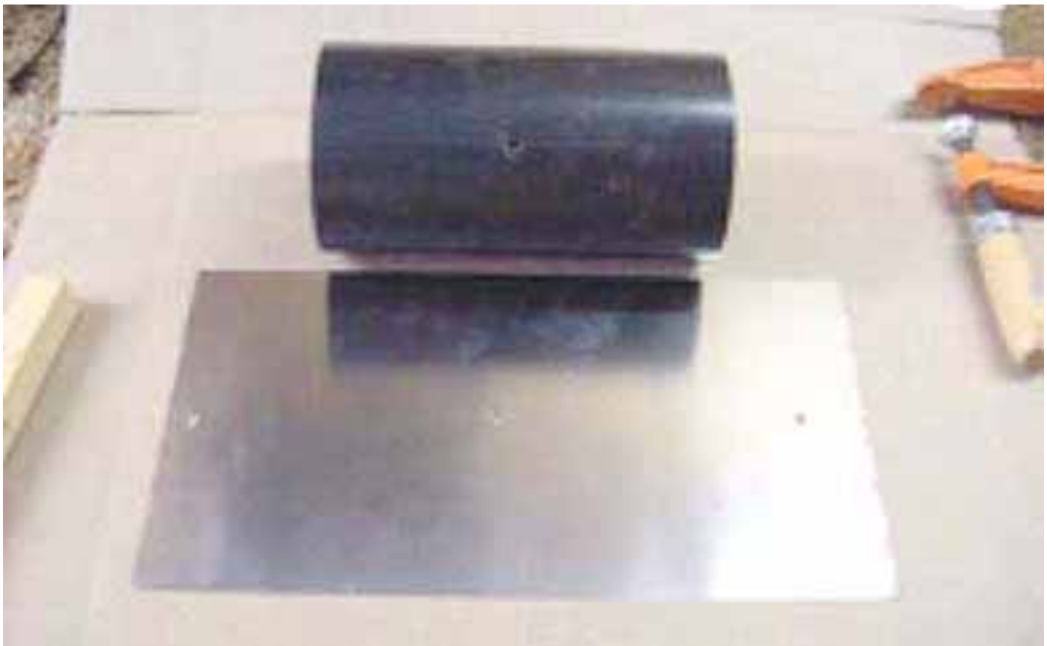
TOOLS LIST

1. Hand drill
2. Cutters (for mesh and shimstock)
3. 1/4" NPT tap and 5/16" drill bit
4. 3/8" NPT tap and 1/2" drill bit
5. 10/32" tap and 1/8" drill bit
6. Clamp and 1" x 1" wood strip
7. Hex key "T-handle" wrench to fit capscrew
8. Philips screwdriver
9. Small adjustable wrench

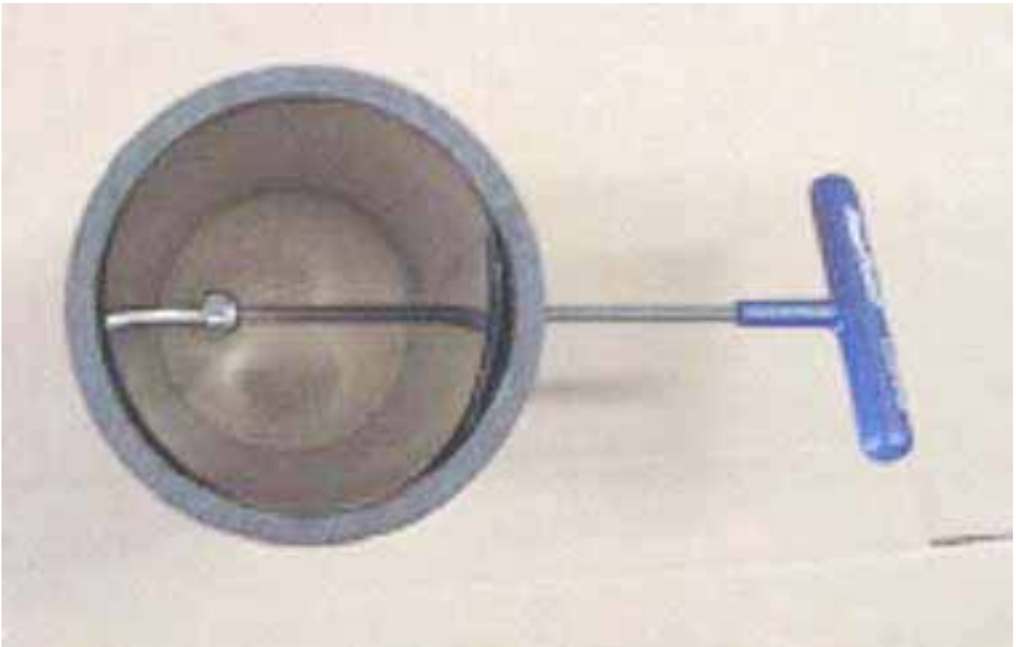
Cut and fit shimstock into ABS tubing, 11" works well as this gives a 1" overlap.

For drilling, use a strip of wood.
Be sure shimstock is flush with at least one edge of the tube.
Use the flush edge as the bottom of the electrolyzer.

Clamp securely and drill two 0.165” holes, one on either side, perpendicular to each other, as best you can.
These holes will be tapped 1/4” 20



The shimstock holes need to be reamed to accept the capscrew.



Note: This is why 2 holes are drilled (to facilitate assembly)
Next, attach the electrode inside the barrel.
It is **important** to us a stainless steel nut inside to seat the capscrew.

Note that the shimstock is flush with the bottom of the tube. Final assembly for the electrodes. Note that the capscrews each have stainless steel nuts inside the barrel to seat to the shimstock. The screw on the left will be used as the Negative battery connection to the cell while the screw on the right merely seats the shimstock.

The upper component is Threaded adaptor DWV 3" HXFPT
The lower component is 3" ABS Plug, clean out threaded cap.
Prepare the top cap and plug:
Drill and tap a 3/8" NPT in the centre of the threaded cap (main filling plug)
Drill and tap a 1/4" NPT on the side (barbed fitting).

Prepare the bottom cap:
Drill and tap 1/4" 20 hole in the centre.
Install capscrew with stainless steel nut. Tighten and install washer and stainless steel nut outside.

This is the Positive battery connection.

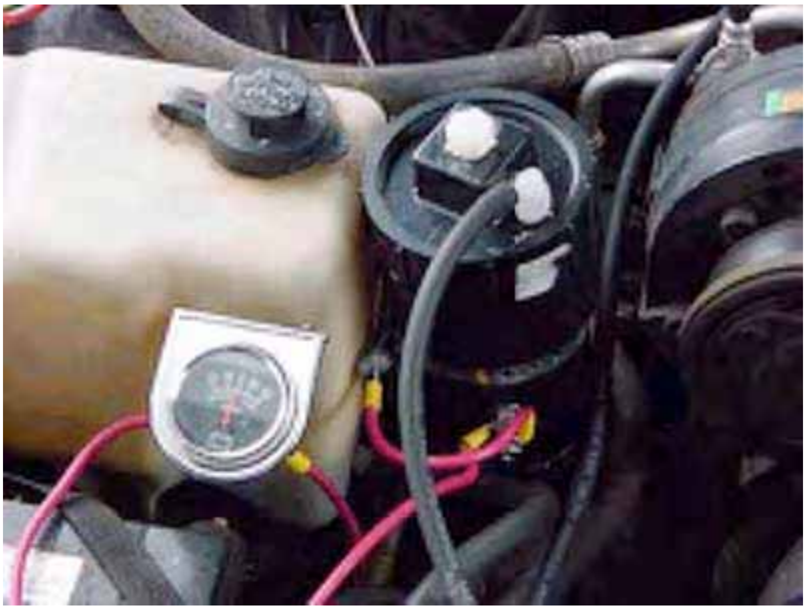
This is the finished e-cell shown here upside down.
Assemble the unit using ABS glue.

Next, prepare the stainless steel mesh. Cut it carefully to fit inside the threaded cap. Use at least 3 pieces.

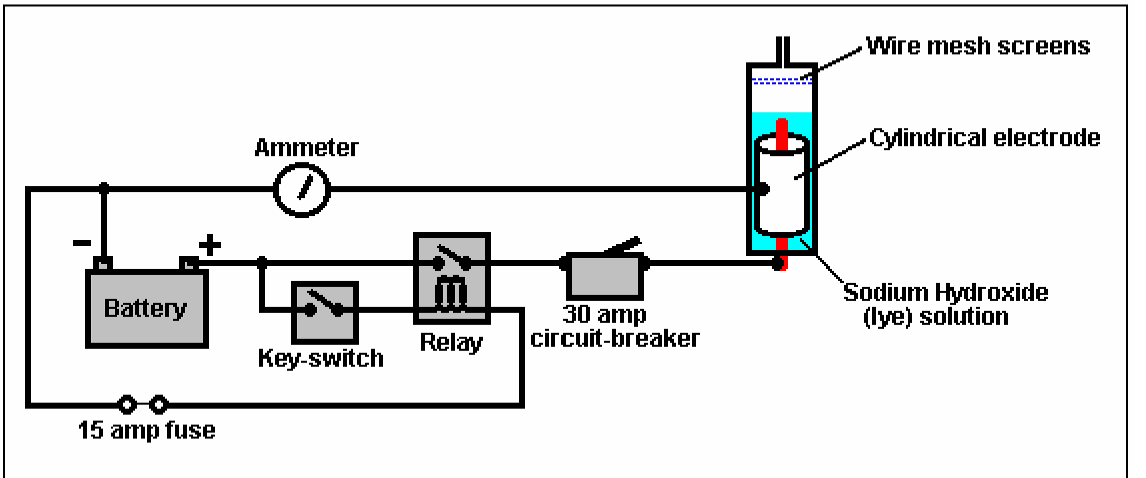
After fitting the mesh tightly into the cap, mount it with a 10/32 stainless steel screw on the opposite side to the 1/4" tapped hole for the barbed fitting. This is a flame arrestor, so make CERTAIN that the entire inside is covered tightly. Note that the sides wrap up. Turn each layer to cross the grain of the mesh.


Use white "plumber's tape" on all threaded fittings.

This unit has raised the average mpg on my 1992 5-litre Chevy Caprice from 18 to 27 mpg which is a 50% increase. It allows a very neat, professional-looking installation which works very well:



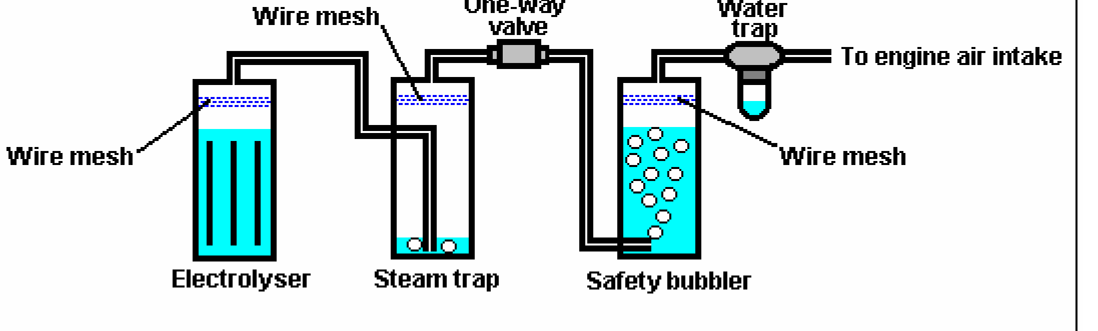
The unit draws only 15 amps which is easily handled by the existing alternator. The construction uses ABS plastic with Sodium Hydroxide ("Red Devil" lye, 1 teaspoon to 8 litres of distilled water) and the gas-mix is fed directly into the air intake filter of the car engine. The electrodes are stainless steel with the negative electrode forming a cylinder around the positive electrode:



Electrical Circuit

The circuit is wired so that it is only powered up when the car ignition switch is closed. A relay feeds power to the electrolyser which is three inches (75 mm) in diameter and about 10 inches (250 mm) tall. The electrolyser circuit is protected by a 30-amp circuit breaker. The electrolyser has several stainless steel wire mesh screens above the water surface.

The output of the electrolyser is fed to a steam trap, fitted with several stainless steel wire mesh screens, and then on via a one-way valve into a safety bubbler:



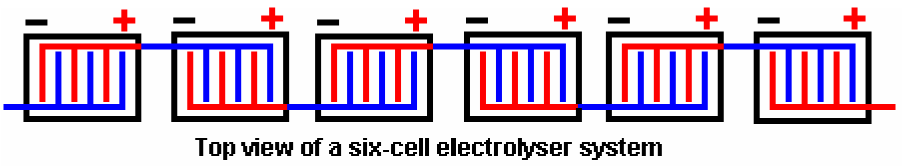
Electrolysis Connections

The bubbler also has stainless steel wire mesh screens which the gas has to pass through before it exits the bubbler. The gas is then passed through a compressor-style water trap to remove any remaining moisture, and is injected into the air intake of the vehicle. Although not shown in the diagram, the containers are protected by pop-out fittings which provide extra protection in the extremely unlikely event of any of the small volumes of gas being ignited by any means whatsoever.

The ammeter is used to indicate when water should be added to the electrolyser, which is typically, after about 80 hours of driving and is done through the plastic screw cap on the top of the electrolyser cap.

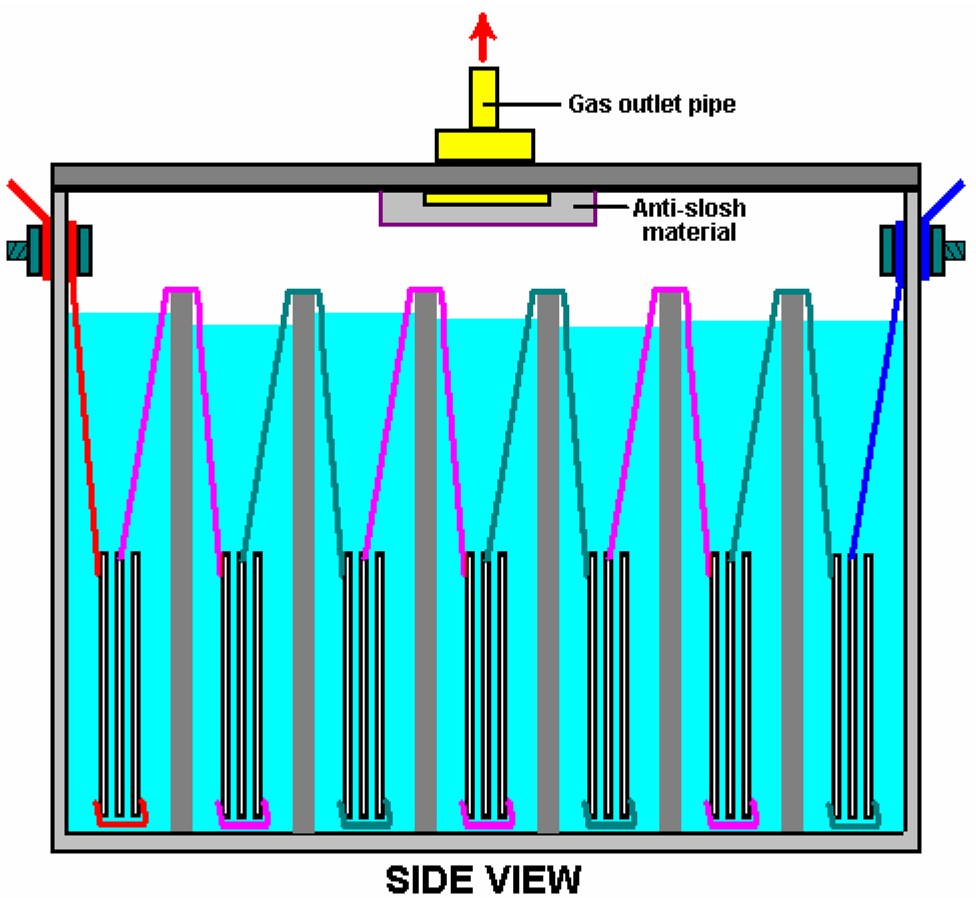
All of the 3/8" plastic fittings including one way valves, come from Ryanherco and are made of Kynar to withstand heat. The water trap is from an air compressor. The 3/16" tubing or hose is also high-heat type from an automatic transmission coolant lines. I use Direct Current and limited with a thermal breaker and LYE mixture adjustment.
Booster Contact: hotsabi@gmail.com (please put "e-cell" in the title of the e-mail).

There are many different ways of constructing electrolysis equipment. A fairly conventional electrical set-up is shown here:



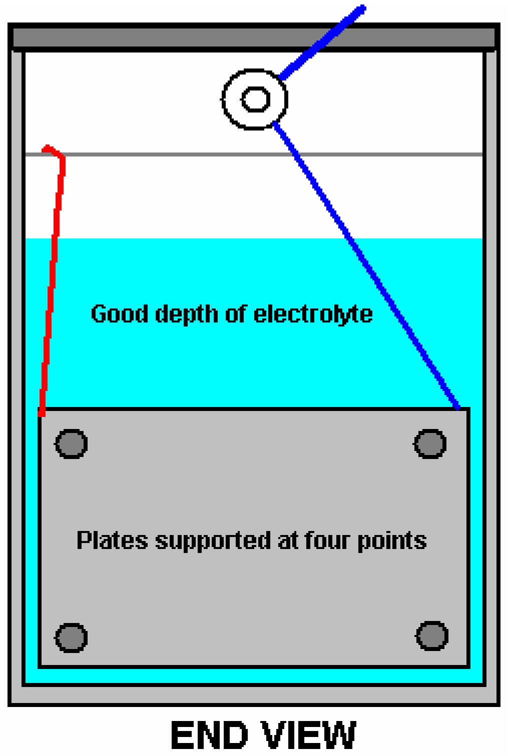
Three plates are used for each electrode and the cells are connected in series. This is a perfectly good arrangement and it has the advantage that the plates can be submerged deeply in the electrolyte, the cells are fully isolated from each other and they can be positioned in convenient locations scattered around the engine compartment. Also, the gas from each cell can be drawn through the electrolyte of the other cells, and this helps to dislodge gas bubbles and improve the operating efficiency of the system.

It is not necessary to have these containers as separate units. A single, much more compact, housing can contain all of the plates needed to make a very efficient "series" electrolyser, as shown here:



A design of this type looks so simple that it is tempting to think of it as being a unit of very minor performance, but is definitely not the case. A unit of this type is capable of producing enough hydroxy gas to power a 250 cc scooter up to 60 mph if a 12 volt car battery is carried and charged between trips. It has the advantage of being capable of being constructed in any convenient size, and with a large amount of electrolyte in each cell, there is no need for a complicated automated water-filling system. The stainless steel plates can be solid or mesh and construction accuracy does not need to be particularly high, though obviously, the case needs to be completely airtight, or to be more precise, hydrogen-tight. A well constructed unit of this type is capable of producing 3 lpm of hydroxy gas on just 15 amps of current, which should give a very respectable mpg improvement when used as a car booster, provided the oxygen sensor signal is controlled as described later in this chapter.

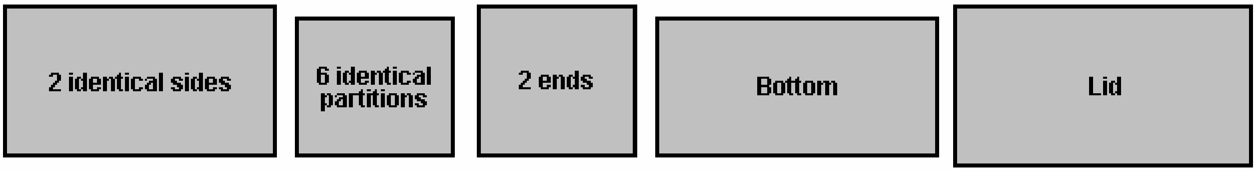
This design has twice the electrical efficiency of the Smack's Booster because all of the current is forced to flow through all seven sets of plates. This produces a gas output from every one of those sets of plates. In the case of an open-bath electrolyser like the Smack's Booster, the current has the option of bypassing the central plates and jumping direct to the final plate. This produces very little gas as the gap is large and there is only one area of gas generation instead of seven separate gas-producing areas. Also, the Smack's Booster has only four pairs of plates which means that at least 65% of the power fed to the unit, ends up just heating the electrolyte. In the case of a 7-cell, isolated cell design, only 38% of the power goes to heat the electrolyte. So, the gas-producing efficiency is doubled and the wasted energy is halved. However, the big appeal of the Smack's Booster is it's ease of construction.



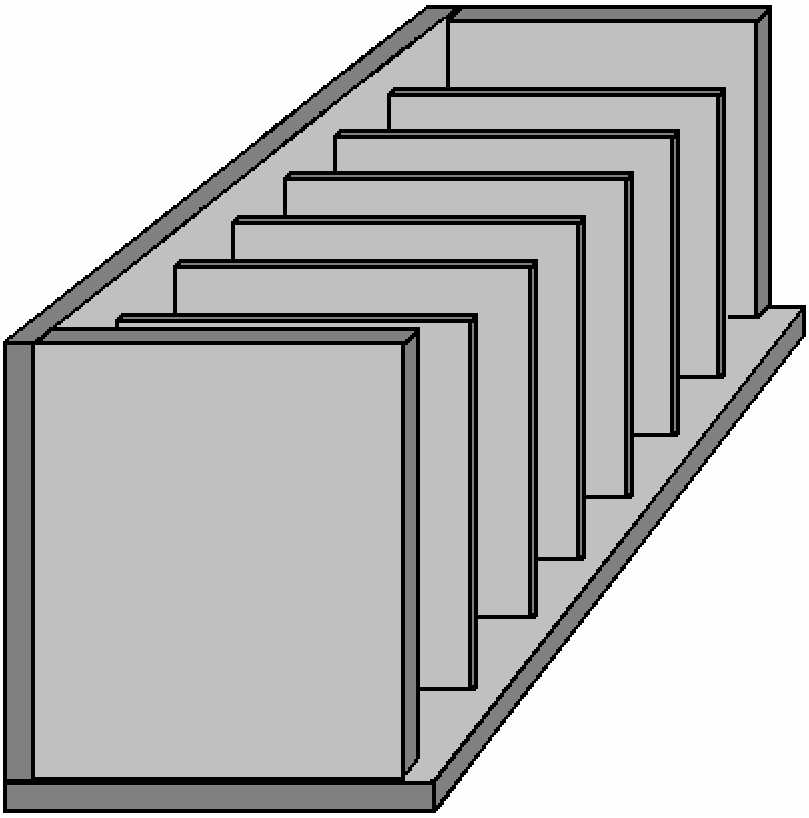
The design shown above has several advantages, and it could be built with a small footprint. The level of electrolyte in each compartment is not critical, so a considerable volume of electrolyte can be held above the plates. This means that topping up with water need only be done very occasionally, and so there is no need for a complicated filling mechanism. The method of construction is very simple. The unit is fairly compact. The electrode plate area can be made a big as you wish. The cell has seven compartments as when a vehicle engine is running, the alternator produces nearly 14 volts in order to charge the 12 volt vehicle battery. This means that there will be about 2 volts across each of the seven cells and gas production will be seven times that of a single cell.

As peak electrical efficiency is being aimed for, it should be realised that while reducing the electrolyte concentration will lower the current, it does so at the expense of increased resistance to current flow through the cell which creates power loss and additional heating. So, for optimum performance, the electrolyte should be the maximum concentration of 28% KOH by weight and the current through the unit being controlled by using a Pulse-Width Modulator ("PWM") circuit. A ready-made PWM circuit and a suitable ammeter to monitor the current are both available from The Hydrogen Garage http://stores.homestead.com/hydrogengarage/StoreFront.bok.

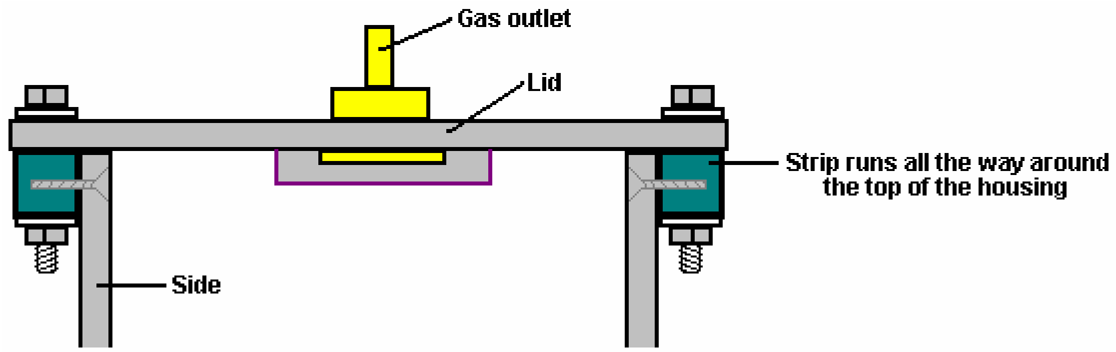
Construction of a housing is not difficult. Pieces are cut out for two sides, one base, one lid and eight absolutely identical partitions. These partitions (which include two housing end pieces) must be exactly the same so that there is no tendency for leaks to develop.



The Bottom piece is the same length as the Sides, and it is the width of the Partitions plus twice the thickness of the material being used to build the housing. If acrylic plastic is being used for the construction, then the supplier can also provide an “adhesive” which effectively “welds” the pieces together making the different pieces appear to have been made from a single piece. The case would be assembled like this:

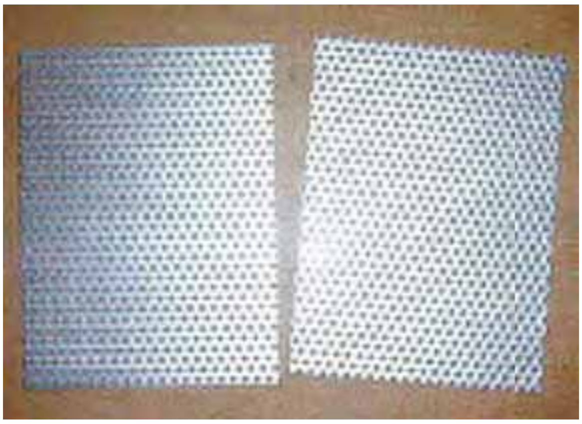


Here, the partitions are fixed in place one at a time, and finally, the second side is attached and will mate exactly as the partitions and ends are all exactly the same width. A simple construction for the Lid is to attach a strip all the way around the top of the unit and have the lid overlap the sides as shown here:

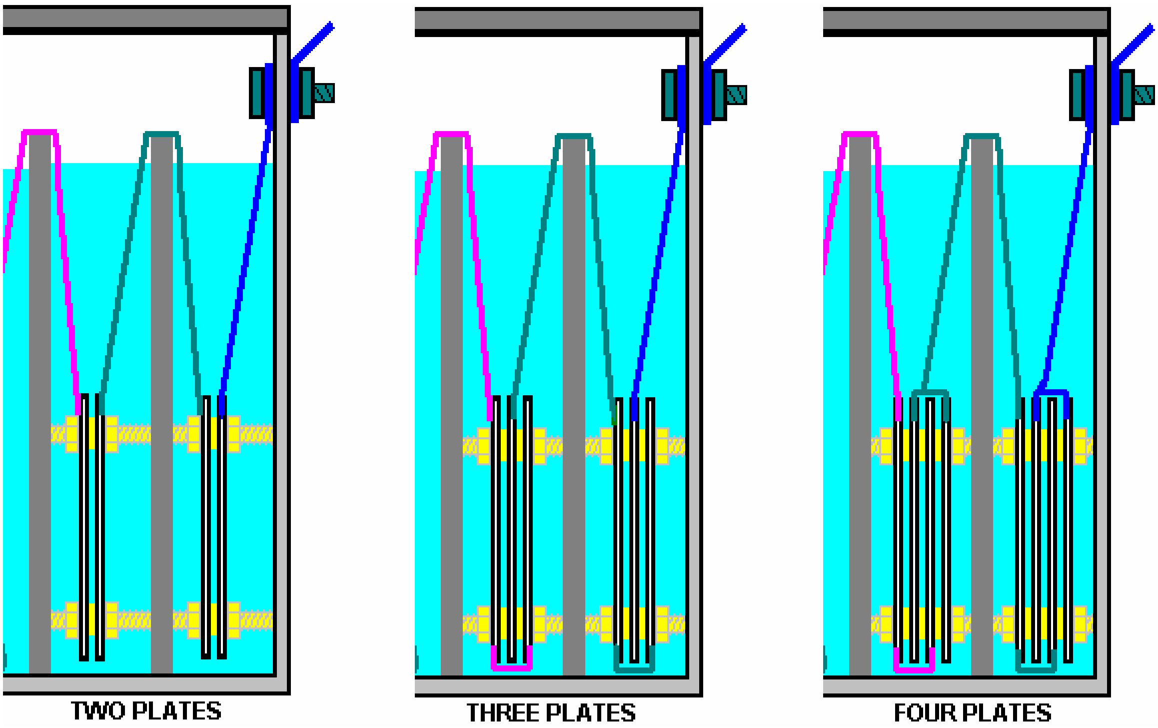


A gasket placed between the sides and the lid would assist in making a good seal when the lid is bolted down. The gas outlet pipe is located in the centre of the lid which is a position which is not affected if the unit is tilted when the vehicle is on a steep hill.

The electrode plates for this design can be made from stainless steel mesh as this material can be cut by hand using a pair of tin snips. If the mesh is particularly flexible, then it may be necessary to support it to prevent one mesh electrode from short-circuiting to the next one. Generally speaking, most meshes are rigid enough not to have flexing problems.



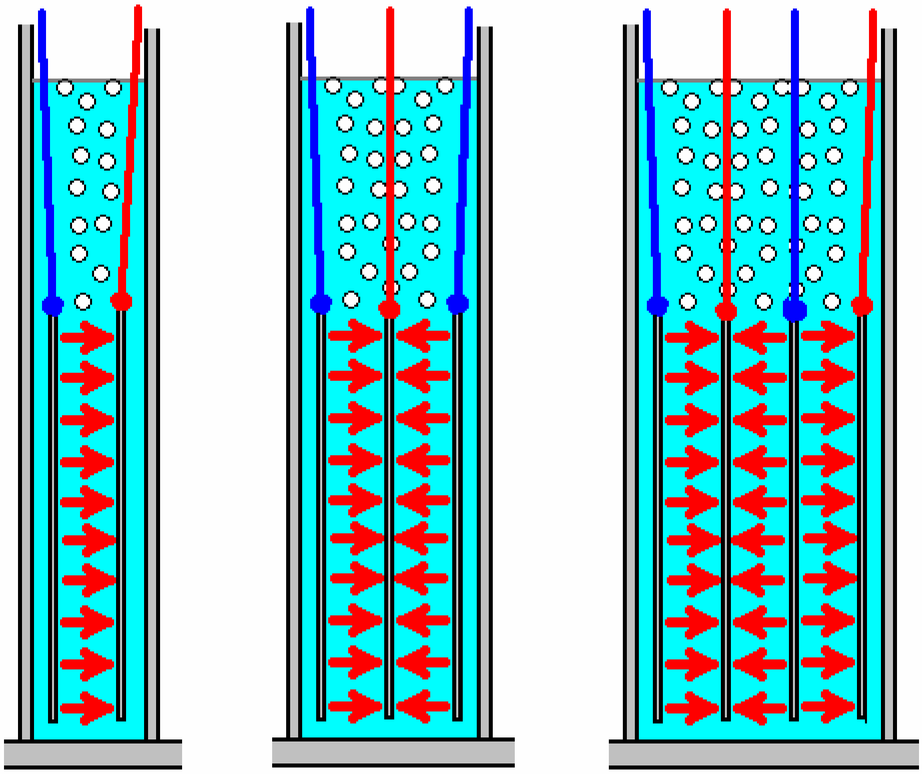
These plates should be held 3 mm (1/8 inch) apart for the best gas-producing performance. This can be done by using plastic threaded rod and bolts positioned at each corner of the sheets. The sheets are spaced accurately by placing plastic washers on the threaded rod between the plates. If the threaded rods are cut to just the right length, they can be a push-fit between the partitions and that holds the plates securely in position inside the cell. There are various ways of connecting the plates which are placed in each compartment of this cell. The connection method depends on the number of plates in each set. The most simple arrangement is just two plates per compartment, but there can just as easily be, three, four, five or whatever number suits you:



The electrolysis takes place in the gaps between the plates, so with two plates, there is just one area of electrolysis. With three plates, there are two inter-plate spaces and electrolysis takes place on both sides of the central plate in each compartment. With four plates, there are three inter-plates spaces and electrolysis takes place on both faces of the two inner plates in each compartment.

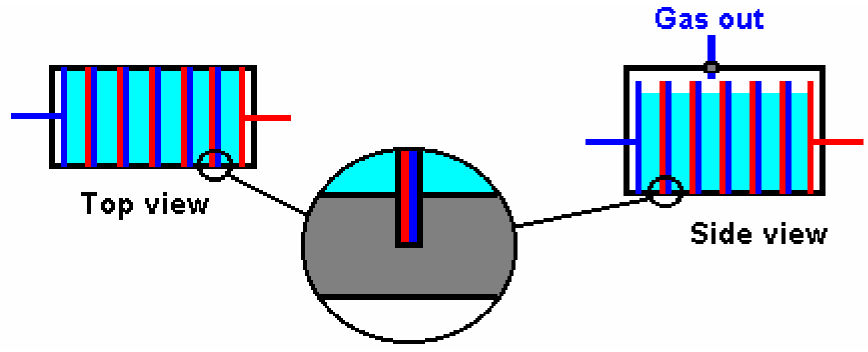
If each plate is, say, 5” x 4” with 20 square inches of area on each face, then with two plates, the electrolysis area is 20 square inches allowing up to 10 amps of current. With the three plate arrangement, the electrolysis area is 40 square inches, allowing a current of up to 20 amps through the electrolyser. With the four plate arrangement, the electrolysis area of the electrode plates is 60 square inches, allowing up to 30 amps to be passed through the cell. The higher currents are not a problem with this design because with seven cells in series, there is little heating of the electrolyte and the cell operation remains stable.

To show this more clearly, here is a diagram for each of these three arrangements, showing how the current flows between the plates:

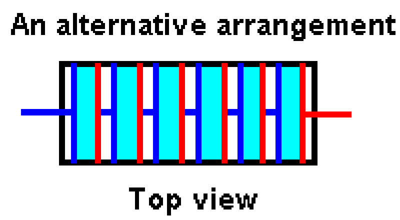


Properly built, with cleansed and conditioned plates, an electrolyser of this type is capable of producing 2 lpm of hydroxy gas with just 10 amps of current, 3 lpm at 15 amps, 4 lpm at 20 amps and 5 lpm at 25 amps. However, as the 'hotsabi' booster which is the least efficient possible design, running at just 10 amps, gives its designer a 50% improvement in mpg. it should be realised that large volumes of hydroxy gas are not necessarily the optimum for any particular engine – all engines being different and having different states of tuning.

There are many different styles of cell. It is possible to dispense with the partitions shown above, if you are willing to sacrifice the large volume of electrolyte above the electrode plates. This style of design is necessary if instead of having just seven partitions in the cell, there are to be seventy or more. This leads to the style of construction shown here:



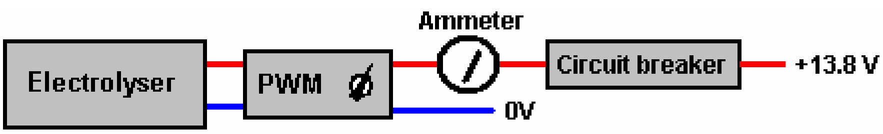
Here, the outer casing is slotted to receive the electrode plates. The build accuracy needs to be high as the electrode plates are expected to form a watertight seal to create separate cells inside the housing. In this diagram, the central electrode plates are shown in red for positive and blue for negative voltage connections. The plates are just single sheets of stainless steel and to a quick glance, it looks as if the central plates do nothing. This is not so. Because the electrolyte is not free to move between compartments, it produces the same electrical effect as the arrangement shown here:



While this is the same electrically, it requires the production and slotting of five additional plates. Each extra plate is effectively redundant because the space between the internal pairs is empty (wasted space) and one steel plate is just wired directly to the next one. As the plates are wired together in pairs, there is no need to have two plates and a connecting wire - a single plate will do. The reason for pointing this out in detail is because it is quite difficult to see how the standard arrangement is connected electrically with the opposite sides of a single plate forming part of two adjacent cells and in addition, the electrical connection between those two cells.

When straight DC electrolysis is being used, the rate of gas production is proportional to the current flowing through the cells. With 12 volt systems, the current can be controlled by the concentration of the electrolyte and it's temperature, though having insufficient plate area or the wrong plate material does require the voltage to be pushed up to reach the required current and this extra voltage has a strong heating effect. When an electrolyser is first started, it usually has a fairly low temperature. As time goes by, the various inefficiencies of the electrolysis process raises the temperature of the electrolyte. This increases the current flowing through the electrolyser, which in turn, heats the electrolyte even more. This causes two problems. Firstly, the gas production rate at start-up is lower than expected as the electrolyte is not as hot as it will become. Secondly, when the electrolyser has been going for some time, a temperature runaway effect is created where the current gets out of hand. Also, the raised temperature causes the production of excessive amounts of water vapour or steam, neither of which are desirable as they just take up space in the cylinder which could have been used for useful fuel.

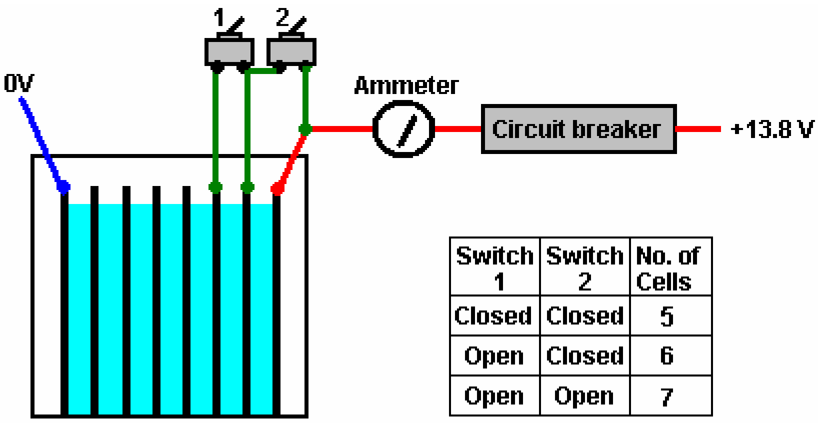
There are various solutions to this situation. One is to accept that the gas production will be low in the early stages of each run, and adjust the concentration of the electrolyte so that the maximum running temperature gives exactly the design current through the electrolyser. This is not a popular solution, especially with people who make a lot of short journeys between long trips. The best solution is to use the highest concentration of electrolyte and an electronic "Pulse-Width Modulator" circuit to control the current. This rather impressive name just means a circuit which switches the power to the electrolyser ON and OFF many times each second, and is the DC version of a dimmer switch used to control lighting levels in the home. Using this solution, an ammeter to show the current, and a PWM control knob, are mounted on the dashboard of the vehicle, and the driver lowers the current manually if it starts to get too high.



If using a PWM circuit, when buying it, pick a 30-amp variety as one like that will be able to handle the normal current range commonly chosen for use with boosters – typically 15 to 22 amps. Your ammeter should also be able to display 30-amps as well, and the best types are very cheap.

Another, very effective, but not popular alternative is to add in extra electrolysis cells. As well as controlling the current, this raises the efficiency of the gas production. This can be achieved in various ways. One option is to install extra cells with a heavy duty 12V switch across them. When the switch is closed, the cell is starved of current and effectively is not operational at all. Heavy duty switches of this kind can be bought in ship chandlers at reasonable cost as they are used extensively in boating for switching engine and lighting circuits in power boats and sailing yachts. An alternative is to used a high powered semiconductor to replace the switch and either use cheap, low power switches to control the semiconductors or add in a circuit which does it automatically.

Using switches, the arrangement could be like this:



Switch 1	Switch 2	No. of Cells
Closed	Closed	5
Open	Closed	6
Open	Open	7

Here, the arrangement is very simple with two switches allowing one or two additional cells to be added in.

If connecting electrical items like this seems rather complicated to you, then you would probably find that reading some of the Electronics Tutorial in Chapter 12 to be helpful. The tutorial explains the basics of circuits and the components used in them, and while there is no need for you to start building circuits, understanding something about them would be helpful.

Dealing with the Oxygen Sensor.

The hydroxy boosters mentioned above, are intended for use with the vehicle's existing fuel supply. The Smack's booster produces about 1.7 litres per minute ("1.7 lpm") and that is enough to improve the quality of the fuel burn inside the engine and clean up both the emissions and any old carbon deposits inside the engine.

Zach West has recently built an interesting design of electrolyser for his 6-volt, 250 cc motorcycle. He reckons that it produces 17 lpm of hydroxy and can run his bike directly off water. His design is shown in detail, later in this chapter.

Bob Boyce has recently stated that he has run a 650 cc twin-cylinder, two-stroke, marine engine on 60 lpm of hydroxy produced by one of his own designs of sophisticated electrolyser. That engine produced a measured 114 horsepower output during short-duration powerboat racing where the engine was being driven to its absolute maximum stress on a deliberately over-rich hydroxy/air mix. A 101-plate version of Bob's design, if accurately built, properly conditioned and tuned, can produce 50 lpm continuously and 100 lpm in short bursts which can run a small car engine, directly from water without any fossil fuel.

It is normal for hydroxy gas to be used inside an IC engine with anything from a 1% to a 4% (1:25) concentration of hydroxy gas in air. The air is needed as it expands with the heat of combustion and raises the pressure inside the cylinder to drive the piston downwards. It is beneficial to have water droplets like those produced by a pond "fogger" device, inside the cylinder as they convert instantly to flash-steam which provides a powerful driving force. Steam and water vapour do not expand further and so they are a hindrance as they just waste space inside the cylinder - space which could have been used for active components.

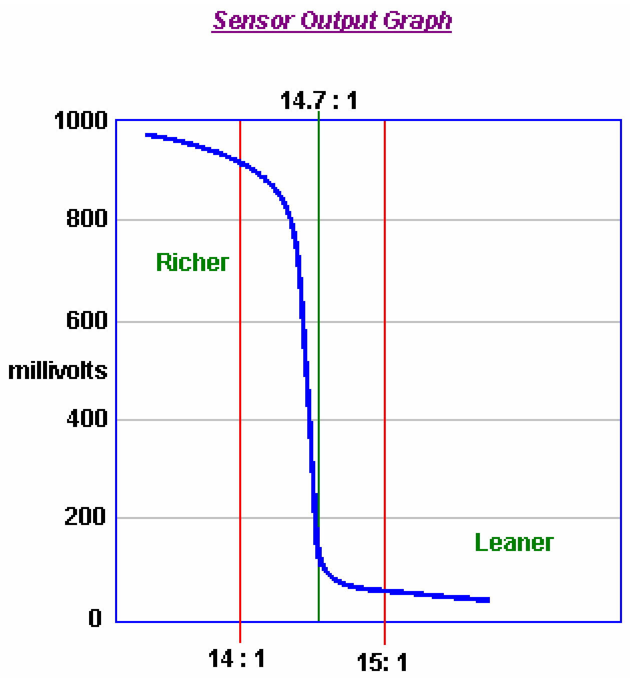
It is not possible to say with certainty how much hydroxy gas would be needed to power any given engine as engines of the same capacity vary drastically in their performance, so no hard and fast figures can ever be quoted, especially since engine condition and tuning are also major factors. However, to see how much hydroxy might be needed to power an engine, consider a 1,600 cc engine running at 2,500 rpm:

Firstly, engine efficiencies vary so much that the question is almost meaningless. However, to determine a possible ball-park figure, the 1.6 litre engine capacity is drawn into the engine when two revolutions are completed. So, 1.6 litres will be taken 1,250 times per minute. That is exactly 2,000 lpm. But only 1% of that volume needs to be hydroxy gas and the remaining 99% can be air. So, the amount of hydroxy gas needed per minute is 2,000 / 100 which is 20 lpm of hydroxy. However, this figure does not take into account the increased fuel needed for loaded engine conditions, low-efficiency engines and a host of other practical issues, so it would be wise to assume some much larger flow rate – say 80 lpm perhaps.

I am not an automotive expert, but people who state that they are professional automotive people, say that an engine running at speed, only succeeds in replacing, typically, 85% of the cylinder contents on the exhaust and intake strokes. If that is correct, then only 85% of that 80 lpm will be needed to run a 1,600 cc engine and that works out to be 68 lpm, which is no small amount of hydroxy gas. If you visualise a 2-litre soft drinks bottle turned upside down and filled with water, and the hydroxy gas output of your electrolyser bubbling up into that bottle, pushing the water out. Then that entire bottle needs to be completely filled with hydroxy gas in less than two seconds, and that is a spectacular rate. Bob Boyce's 101-plate design approaches that, and full details of it are given later in this chapter. However, gas volume calculations like this are almost meaningless as engines of the same capacity can vary enormously in the amount of power needed to make them run correctly.

But to return to our 1.7 lpm booster which is capable of giving such good results in cutting harmful vehicle emissions. A booster will not give any improvement in fuel economy on a modern vehicle, because of the feedback coming from the oxygen sensor (or sensors). The fuel computer of the vehicle will detect the very much reduced emissions from the engine, and will immediately believe that there is not enough fuel going into the engine, and it will promptly start pumping more fuel into the engine. For that reason, and that reason alone, adding a booster on its own can actually make the fuel economy slightly worse. The remedy is to adjust the signal coming from the oxygen sensor to the fuel computer, so that it stays on track with the hydroxy gas being added to the fuel mix. This is not as difficult as it sounds. If you are not familiar with electronics, then now might be a good time to take a run through the Electronics Tutorial in chapter twelve, so that you can understand exactly what is being said about controlling the oxygen sensor.

In the most simple terms, most vehicles which have an Electronic Control Unit ("ECU") to control the fuel flow are fitted with one of two types of exhaust sensor. The majority have a "narrowband" sensor while the remainder have a "wideband" sensor. The ideal mix of air to fuel is considered to be 14.7 to 1. A narrowband sensor only responds to mixtures from about 14.2 to 1 through 14.9 to 1. The sensor operates by comparing the amount of oxygen in the exhaust gas to the amount of oxygen in the air outside the vehicle and it generates an output voltage which moves rapidly between 0.2 volts where the mixture is too lean, and 0.8 volts when it passes below the 14.7 to 1 air/fuel mix point where the mixture is too rich (as indicated by the graph shown below). The ECU increases the fuel feed when the signal level is 0.2 volts and decreases it when the signal voltage is 0.8 volts. This causes the signal voltage to switch regularly from high to low and back to high again as the computer attempts to match the amount of "too lean" time to the amount of "too rich" time.



A simple control circuit board can be added to alter the sensor signal and nudge the fuel computer into producing slightly better air/fuel mixes. Unfortunately, there is a severe downside to doing this. If, for any reason, the fuel mix is set too high for an extended period, then the excess fuel being burnt in the catalytic converter can raise the temperature there high enough to melt the internal components of the converter. On the other hand, if the circuit board is switched to a mix which is too lean, then the engine temperature can be pushed high enough to damage the valves, which is an expensive mistake.

Over-lean running can occur at different speeds and loads. Joe Hanson recommends that if any device for making the mix leaner is fitted to the vehicle, then the following procedure should be carried out. Buy a “type K” thermocouple with a 3-inch stainless steel threaded shank, custom built by ThermX Southwest of San Diego. This temperature sensor can measure temperatures up to 1,800 degrees Fahrenheit (980 degrees Centigrade). Mount the thermocouple on the exhaust pipe by drilling and tapping the pipe close to the exhaust manifold, just next to the flange gasket. Take a cable from the thermocouple into the driver’s area and use a multimeter to show the temperature.

Drive the vehicle long enough to reach normal running temperature and then drive at full speed on a highway. Note the temperature reading at this speed. When a leaner mix is used, make sure that the temperature reading under exactly the same conditions does not exceed 180 degrees Fahrenheit (100 degrees Centigrade) above the pre-modification temperature.

David Andruczyk recommends an alternative method of avoiding engine damage through over-lean fuel/air mixtures, namely, replacing the narrowband oxygen sensor with a wideband sensor and controller. A wideband oxygen sensor reads a very wide range of Air/Fuel ratios, from about 9 to 1 through 28 to 1. A normal car engine can run from about 10 to 1 (very rich) to about 17.5 to 1 (pretty lean). Maximum engine power is developed at a mix ratio of about 12.5 to 1. Complete fuel combustion takes place with a mix of about 14.7 to 1, while the mix which gives minimum exhaust emissions is slightly leaner than that.

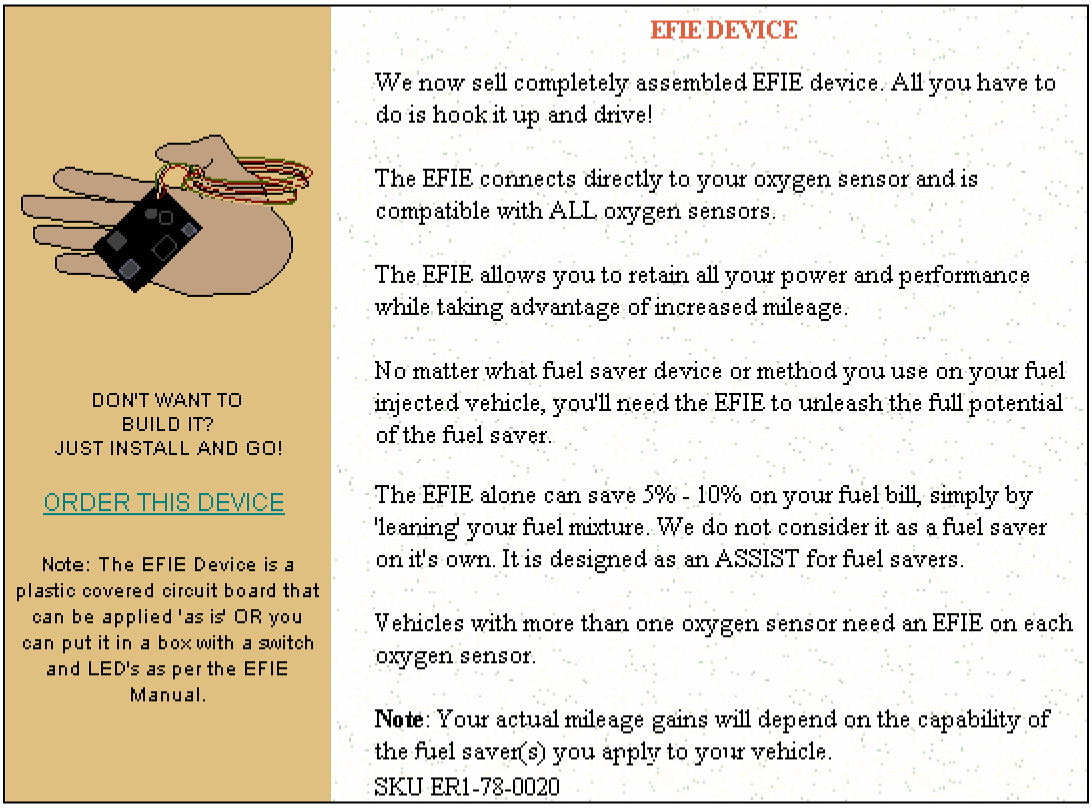
Unlike narrowband sensors, wideband sensors need their own controller in order to function. There are many of these units being offered for sale for retro-fitting to existing vehicles which have just narrowband oxygen sensor systems. David’s personal recommendation is the Innovate Motorsports LC-1 which is small, and uses the very reasonably priced LSU-4 sensor. This wideband controller can be programmed. Most controllers have the ability to output two signals, the wideband signal suitable for running to a gauge or new ECU, plus a synthesised narrowband signal which can feed an existing ECU. The trick is to install a wideband sensor, with the LC-1 controller and then reprogram it to **shift** the narrowband output to achieve a leaner mix as shown here:

Actual Air/Fuel Mix	Wideband Output	Original Narrowband Output	Shifted Narrowband Output
9 to 1	9 to 1	Mix is too Rich	Mix is too Rich
10 to 1	10 to 1	Mix is too Rich	Mix is too Rich
11 to 1	11 to 1	Mix is too Rich	Mix is too Rich

12 to 1	12 to 1	Mix is too Rich	Mix is too Rich
13 to 1	13 to 1	Mix is too Rich	Mix is too Rich
14 to 1	14 to 1	Mix is too Rich	Mix is too Rich
14.6 to 1	14.6 to 1	Mix is too Rich	Mix is too Rich
14.8 to 1	14.8 to 1	Mix is too Lean	Mix is too Rich
15 to 1	15 to 1	Mix is too Lean	Mix is too Rich
15.5 to 1	15.5 to 1	Mix is too Lean	Mix is too Lean
16 to 1	16 to 1	Mix is too Lean	Mix is too Lean
18 to 1	18 to 1	Mix is too Lean	Mix is too Lean

This system allows you to set the narrowband "toggle point" very precisely on an exact chosen air/fuel ratio. This is something which it is nearly impossible to do accurately with a circuit board which just shifts a narrowband oxygen signal as you just do not know what the air/fuel ratio really is with a narrowband sensor.

However, for anyone who wants to try adding a circuit board to alter a narrowband sensor signal to produce a leaner mix on a vehicle, the following description may be of help. It is possible to buy a ready-made circuit board, although using a completely different operating technique, from the very reputable Eagle Research, via their website: http://www.eagle-research.com/products/pfuels.html where the relevant item is shown like this:


DON'T WANT TO
BUILD IT?
JUST INSTALL AND GO!

ORDER THIS DEVICE

Note: The EFIE Device is a plastic covered circuit board that can be applied 'as is' OR you can put it in a box with a switch and LED's as per the EFIE Manual.

EFIE DEVICE

We now sell completely assembled EFIE device. All you have to do is hook it up and drive!

The EFIE connects directly to your oxygen sensor and is compatible with ALL oxygen sensors.

The EFIE allows you to retain all your power and performance while taking advantage of increased mileage.

No matter what fuel saver device or method you use on your fuel injected vehicle, you'll need the EFIE to unleash the full potential of the fuel saver.

The EFIE alone can save 5% - 10% on your fuel bill, simply by 'leaning' your fuel mixture. We do not consider it as a fuel saver on it's own. It is designed as an ASSIST for fuel savers.

Vehicles with more than one oxygen sensor need an EFIE on each oxygen sensor.

Note: Your actual mileage gains will depend on the capability of the fuel saver(s) you apply to your vehicle.
SKU ER1-78-0020

This unit generates a small voltage, using a 555 timer chip as an oscillator, rectifying the output to give a small adjustable voltage which is then added to whatever voltage is being generated by the oxygen sensor. This voltage is adjusted at installation time and is then left permanently at that setting. Eagle Research also offer for sale, a booklet which shows you how to build this unit from scratch if you would prefer to do that.

I understand that at the present time, the purchase price of this device is approximately US $50, but that needs to be checked if you decide to buy one. Alternatively, instructions for building a suitable equivalent circuit board are provided later on in this document.

If you wish to use a circuit board with a narrowband oxygen sensor, then please be aware that there are several versions of this type of sensor. The version is indicated by the number of connecting wires:

Those with **1** wire, where the wire carries the signal and the case is ground (zero volts)
Those with **2** wires, where one wire carries the signal and the other wire is ground.
Those with **3** wires, where 2 (typically slightly thicker) wires are for a sensor heater, and

1 for the signal while the case is ground.

Those with **4** wires (the most common on current model cars), where there are

2 (slightly heavier) for the sensor heater,

1 for the signal , and

1 for the signal ground.

(Sensors with **5** wires are normally wideband devices.)

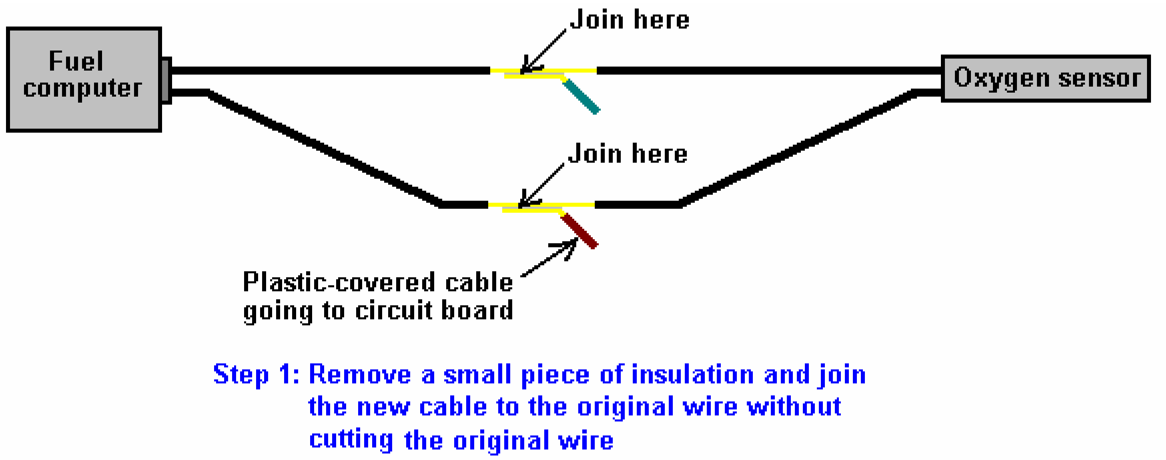
Look in the engine compartment and locate the oxygen sensor. If you have difficulty in finding it, get a copy of the Clymer or Haynes Maintenance Manual for your vehicle as that will show you the position. We need to identify the sensor wire which carries the control signal to the fuel control computer. To do this, make sure that the car is switched off, then

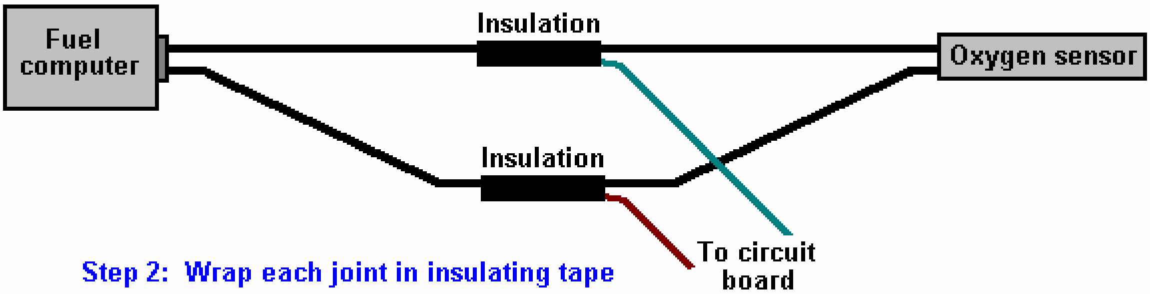
For **3** and **4** wire sensors:

Disconnect the oxygen sensor wiring harness,
Set a multimeter to a DC voltage measurement range of at least 15 volts,
Turn on the ignition and probe the socket looking for the two wires that provide 12 volts.
These are the heater wires, so make a note of which they are,
Shut the ignition off, and reconnect the oxygen sensor.

The two remaining wires can now be treated the same as the wires from a 2-wire sensor, one will carry the sensor signal and one will be the signal ground (for a single wire sensor, the signal ground will be the engine block). Jesper Ingerslev points out that the Ford Mustang built since 1996 has 2 oxygen sensors per catalytic converter, one before the converter and one after. Some other vehicles also have this arrangement. With a vehicle of this type, the circuit board described here should be attached to the sensor closest to the engine.

Find a convenient place along the wires. Don't cut these wires, you will cut the sensor wire here at a later time, but not now. Instead, strip back a small amount of the insulation on each wire. Be careful to avoid the wires short-circuiting to each other or to the body of the vehicle. Connect the DC voltmeter to the wires (the non- heater wires). Start the engine and watch the meter readings. When the engine is warmed up, if the oxygen sensor is performing as it should (i.e. no engine check lights on), the voltage on the meter should begin toggling between a low value near zero volts and a high value of about 1 volt. If the meter reading is going negative, then reverse the leads. The black multimeter lead is connected to the signal 'ground' (zero volts) and the red lead will be connected to the wire which carries the signal from the sensor. Connect a piece of insulated wire to the stripped point of the sensor wire and take the wire to the input of your mixture controller circuit board. Connect a second insulated wire between the signal 'ground' wire, or in the case of a 1-wire sensor, the engine block, and the circuit board zero-volts line. Insulate all of the stripped cables to prevent any possibility of a short-circuit:





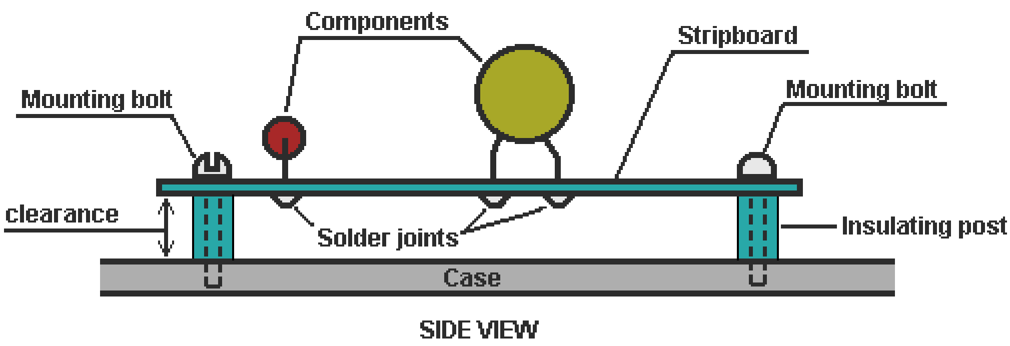
Construction

If you wish to build an oxygen sensor controller circuit, then here is a suggestion as to how you might do it. This description assumes very little knowledge on the part of the reader, so I offer my apologies to those of you who are already expert in these matters. There are many different ways to design and construct any electronic circuit and each electronics expert will have his own preferred way. In my opinion, the way shown here is the easiest for a newcomer to understand and build with the minimum of tools and materials.

The circuit shown here, is taken from the website http://better-mileage.com/memberadx.html, and is discussed here in greater detail. This circuit can be constructed on a printed circuit board or it can be built on a simple single-sided strip-board as shown here:

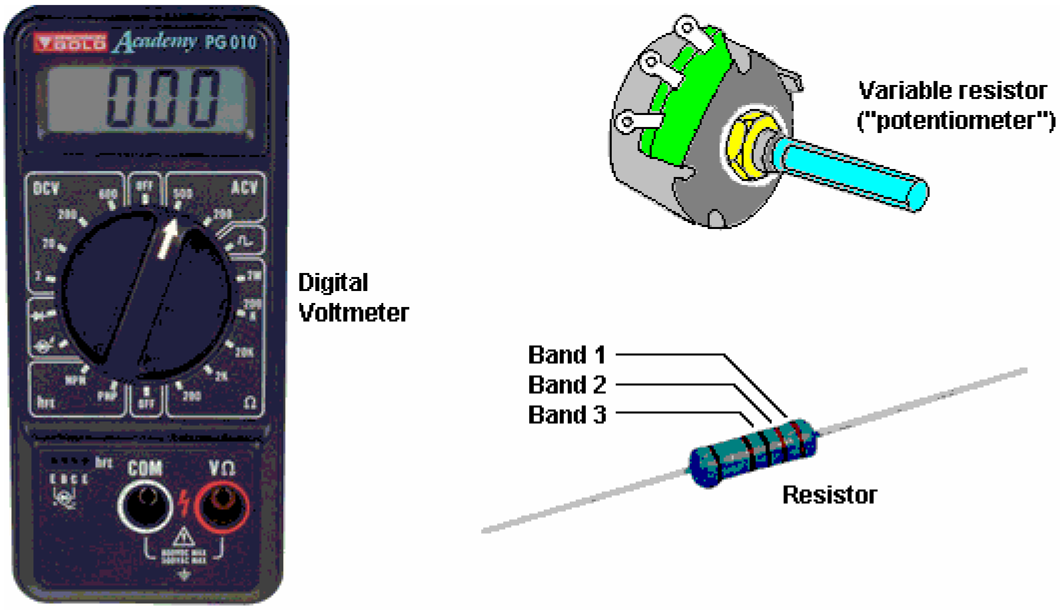
Strip-board (often called "Veroboard"), has copper strips attached to one side of the board. The copper strips can be broken where it is convenient for building the circuit. Component leads are cut to length, cleaned, inserted from the side of the board which does not have the copper strips, and the leads attached to the copper strips using a solder joint. Soldering is not a difficult skill to learn and the method is described later in this document.

When all of the components have been attached to the strip-board and the circuit tested, then the board is mounted in a small plastic case as shown here:



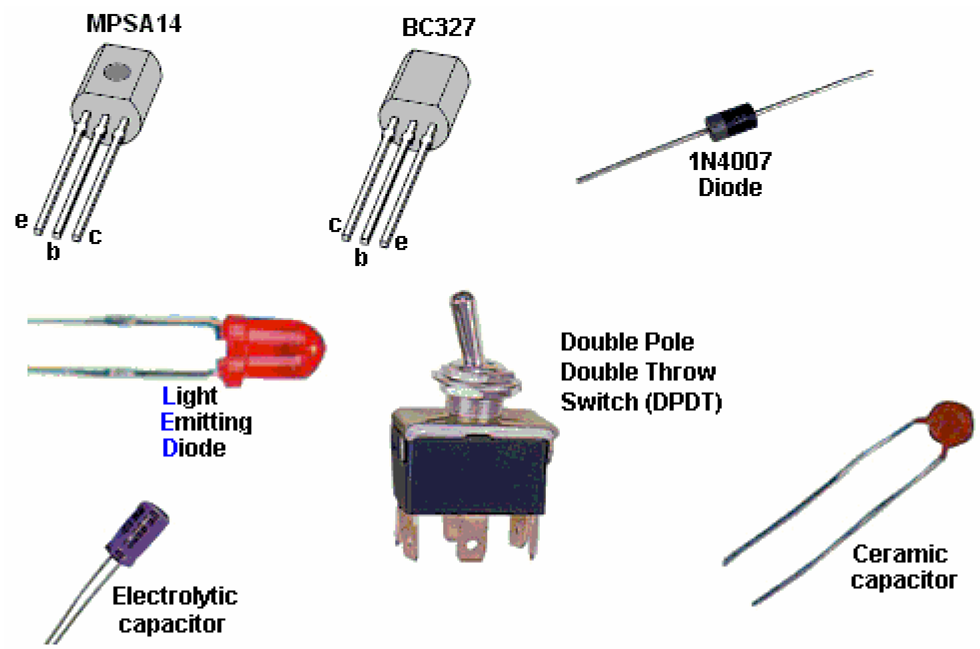
Insulating posts can be made from a short pieces of plastic rod with a hole drilled through its length. The mounting bolt can self-tap into a hole drilled in the case, if the hole is slightly smaller than the diameter of the bolt threads. Alternatively, the holes can be drilled slightly larger and the bolt heads located outside the case with nuts used to hold the board in place. This style of mounting holds the circuit board securely in place and gives some clearance between the board and the case.

You will need building equipment, namely, a soldering iron, a 12 volt power supply such as a battery pack and an accurate digital volt meter for this project. If the 12 volt supply is a main-powered unit, then it needs to be a well-filtered, voltage-stabilised unit. Lastly, you will need a variable voltage source that can go from 0 to 1 volt to imitate the output from the vehicle's oxygen sensor when testing the completed circuit board. This is simple enough to make, using a resistor and a variable resistor.



A series of components will be needed for the circuit itself. These can be bought from a number of different suppliers and the ordering details are shown later in this document. Shown above is a resistor. The value of the resistor is indicated by a set of three colour bands at one end of the body. The reason for doing this rather than just writing the value on the resistor, is that when the resistor is soldered in place, its value can be read from any angle and from any side. The component list shows the colour bands for each of the resistors used in this circuit.

Other components which you will be using, look like this:



The MPSA14 and the BC327 devices are transistors. They each have a "Collector", a "Base" and an "Emitter" wire coming out of them. Please notice that the two packages are not identical, and take care that the right wire is placed in the correct hole in the strip-board before soldering it in place.

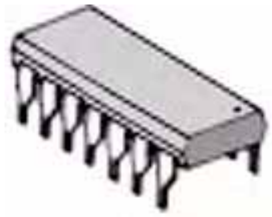
The 1N4007 diode has a ring marked at one end of the body. The ring indicates the flat bar across the symbol as shown on the circuit diagram, and in that way it identifies which way round the diode is placed on the strip-board.

The Light-Emitting Diode (the "LED") will be familiar to most people as it is used so extensively in equipment of all types.

The toggle switch has six contacts - three on each side. The centre contact is connected to one of the two outer contacts on its side, which one, depends on the position of the switch lever.

The two capacitors (which are called "condensers" in very old literature) look quite different from each other. The electrolytic capacitor has it's + wire marked on the body of the capacitor, while the ceramic has such a small value that it does not matter which way round it is connected.

The main component of the circuit, is an integrated circuit or "chip". This is a tiny package containing a whole electronic circuit inside it (resistors, capacitors, diodes, whatever, ...). Integrated circuit chips generally look like this:



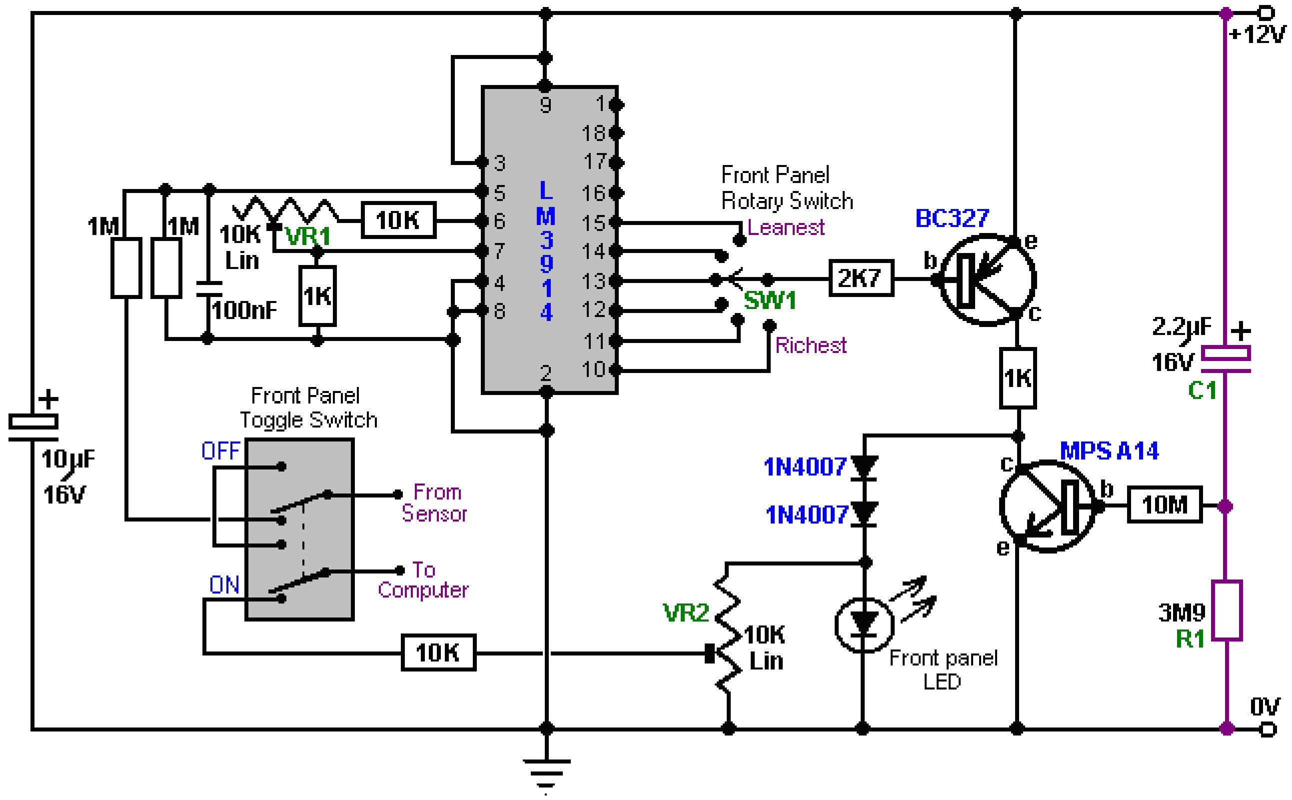
A very common version of this package has two rows of seven pins each and it goes by the grandiose name of "Dual In Line" which just means that there are two rows of pins, each row having the pins in a straight line. In our particular circuit, the chip has eighteen pins, in two rows of nine.

Now to the circuit itself. If you find it hard to follow, then take a look at the electronics tutorial on the web site as it shows the circuit diagram symbol for each component and explains how each device works.

The circuit contains three capacitors, eight resistors, two diodes, one LED, one IC chip, two transistors, one toggle switch and two types of component not yet described, namely: two preset resistors and one rotary switch.

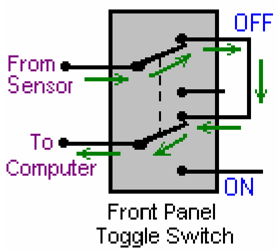
The preset resistor is very small and is adjusted using a flat bladed screwdriver. It is used for making an adjustable setting which is then left unchanged for a long time. The Rotary switch has a central contact which is connected to a row of outer contacts in turn when the shaft is rotated from position to position. The switch shaft is made of plastic and so can easily be cut to the length needed to make a neat installation, and the knob is locked in place by tightening its grub screw against the flat face of the shaft, although some knobs are designed just to push tightly on to the shaft. There is a wide range of knob styles which can be used with this switch, so the choice of knob is dictated by personal taste.

This is the circuit diagram:



Electronic circuits are normally "read" from left to right, so we will look at this circuit that way. The first component is the 10 microfarad, 16 volt electrolytic capacitor. This is put there to help iron out any little variations in the voltage supply, caused by surges in the current drawn by the circuit when it switches from one state to another.

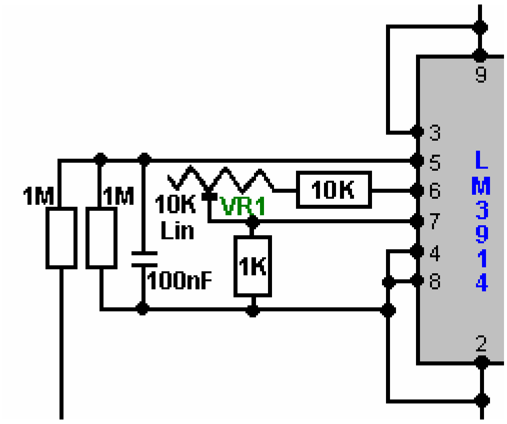
The next item is the On/Off dashboard switch. When switched to its Off position as shown here:



the connection from the oxygen sensor is passed straight through to the vehicle's fuel computer, bypassing the circuit board completely. This switch allows the whole circuit to be switched Off should you want to do this for any reason.

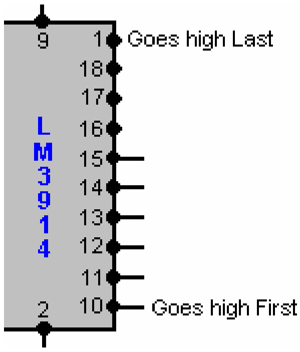
In it's On position, as shown in the circuit diagram, the varying voltage signal coming from the oxygen sensor is passed into the circuit, and the output voltage from the circuit is passed back to the fuel computer, instead of the original sensor voltage. This allows the circuit to manipulate the voltage sent to the fuel computer.

The next set of components (four resistors, one ceramic capacitor and one preset resistor) shown here:



are needed to feed the incoming sensor voltage to the Integrated Circuit chip, and make the chip operate in the way that we want, (the chip manufacturer allows more than one way for the chip to work). You can just ignore these components for now, just understand why they are there.

The Integrated Circuit chip has ten outputs, coming out through Pins 1 and 10 through 18 inclusive:



If the input voltage coming from the oxygen sensor is low, then all of these ten outputs will have low voltages on them. When the input voltage rises a little, the voltage on Pin 10 suddenly rises to a high value, while the other output pins still have low voltages.

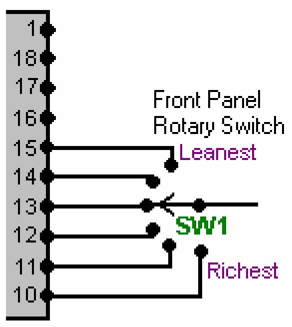
If the input voltage rises a little higher, then suddenly the voltage on Pin 11 rises to a high value. At this point, both Pin 10 and Pin 11 have high voltage on them and the other eight output pins remain at low voltage.

If the input voltage rises a little higher again, then suddenly the voltage on Pin 12 rises to a high value. At this point, Pin 10, Pin 11 and Pin 12 all have high voltage on them and the other seven output pins remain at low voltage.

The same thing happens to each of the ten output pins, with the voltage on Pin 1 being the last to get a high voltage on it. The circuit is arranged so that Pin 10 provides the output signal for the richest air/fuel mixture for the vehicle, and the mix gets progressively leaner as the output on Pins 11, 12, ... etc. are selected to be fed to the fuel computer.

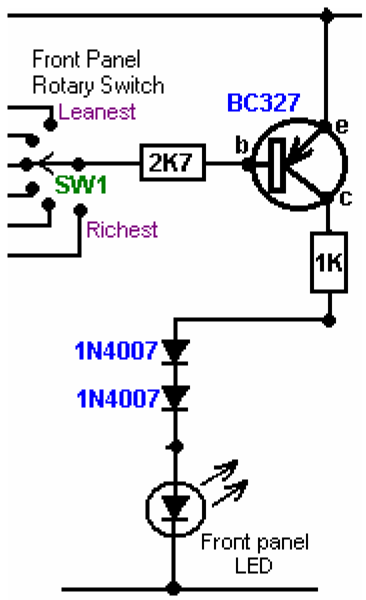
As there is the possibility of engine damage if the fuel mix is too lean, only six of the outputs are taken on into the circuit. However, if the engine is being fed hydroxy gas from an electrolyzer to improve both the miles per gallon performance and reduce emissions to zero, then it is likely that the engine will run cooler than before and engine damage is most unlikely to occur. It is quite safe to leave the remaining output pins of the Integrated Circuit chip unconnected.

The output pin to be used by the remainder of the circuit is selected by the rotary switch mounted on the dashboard:



A standard single-pole rotary wafer switch has twelve positions but the switch operation can be restricted to any lesser number of positions by placing the end-stop lug of the switch just after the last switch position required. This lug comes as standard, fits around the switch shaft like a washer, and is held in place when the locking nut is tightened on the shaft to hold the switch in place. The lug projects down into the switch mechanism and forms an end-stop to prevent the switch shaft being turned any further. With six switch positions, the circuit provides five levels of leaner air/fuel mix which can be selected. This should be more than adequate for all practical purposes.

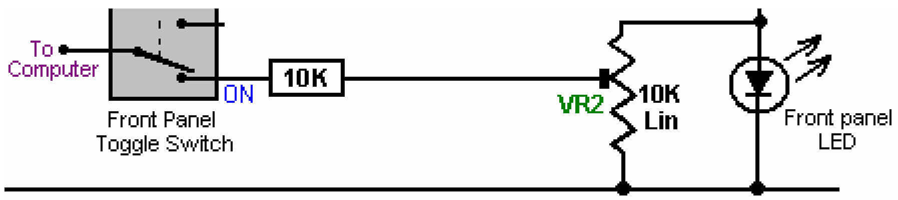
The next section of the circuit is the BC327 transistor amplifier stage which provides the output current for the fuel computer:



Here, the switch "SW1" connects to one of the output pins of the Integrated Circuit. When the voltage on that pin goes low, it causes a current to flow through the transistor Base/Emitter junction, limited by the 2.7K (2,700 ohm) resistor. This current causes the transistor to switch hard On, which in turn alters the voltage on its Collector from near 0 volts to near +12 volts. The 2.7K resistor is only there to limit the current through the transistor and to avoid excessive loading on the output pin of the IC.

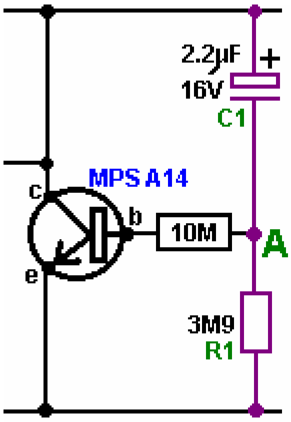
The transistor now feeds current to the LED via the two 1N4007 diodes and the 1K (1,000 ohm) resistor. This causes the Light Emitting Diode to light brightly. The 1K resistor is there to limit the amount of current flowing through this section of the circuit.

Part of the voltage across the LED is fed back to the fuel computer:



By moving the slider contact on the preset resistor "VR2", any output voltage can be fed to the fuel computer. This voltage can be anything from the whole of the voltage across the LED, down to almost zero volts. We will use VR2 to adjust the output voltage when we are setting the circuit up for use. In this circuit, VR2 is acting as a "voltage divider" and it is there to allow adjustment of the output voltage going from the circuit to the fuel computer.

The final section of the circuit is the MPSA14 transistor and its associated components:



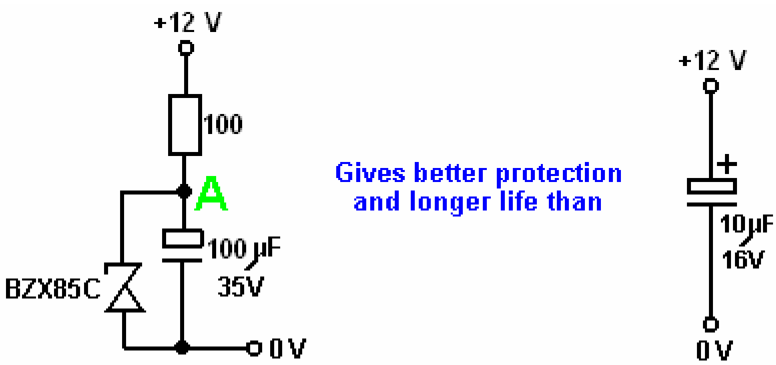
This circuit is a timer. When the circuit is first powered up (by the vehicle's ignition key being turned), the tantalum 2.2 microfarad capacitor "C1" is fully discharged (if it isn't, then the oxygen sensor will already be hot). As it is discharged and one side is connected to the +12 volt line, then the other side (point "A") looks as if it is also at +12 volts. This provides a tiny current to the Base/Emitter junction of the MPSA14 transistor, through the very high resistance 10M (10,000,000 ohm) resistor. The MPSA14 transistor has a very high gain and so this tiny current causes it to switch hard on, short-circuiting the LED and preventing any voltage developing across the LED.

As time passes, the tiny current flowing through the MPSA14 transistor, along with the tiny current through the 3.9M (3,900,000 ohm) resistor "R1", cause a voltage to build up on capacitor "C1". This in turn, forces the voltage at point "A" lower and lower. Eventually, the voltage at point "A" gets so low that the MPSA14 transistor gets starved of current and it switches off, allowing the LED to light and the circuit to start supplying an output voltage to the fuel computer. The purpose of the section of the circuit is to shut off the output to the fuel computer until the oxygen sensor has reached it's working temperature of 600 degrees Fahrenheit. It may be necessary to tailor this delay to your vehicle by altering the value of either "R1" or "C1". Increasing either or both will lengthen the delay while reducing the value of either or both, will shorten the delay.

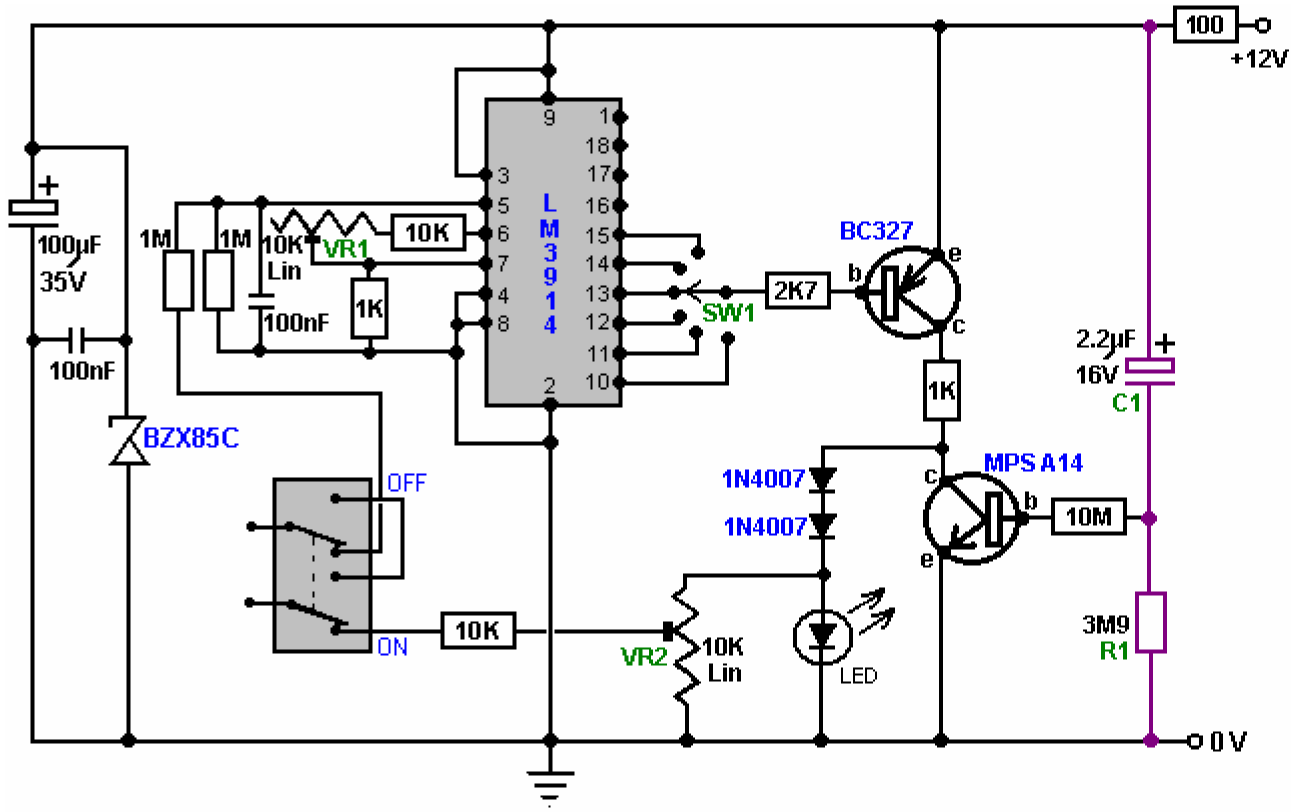
Changes:

Having examined this circuit, Nigel Duckworth has recommended some alterations. Firstly, the capacitor placed across the battery supply lines is shown as 10 microfarad, which comes from the manufacturer's specification sheet for the Integrated Circuit. While this will be sufficient for many applications, this circuit will be working in what is effectively a hostile environment, with the battery supply being liable to have severe voltage spikes and surges superimposed on it. Consequently, it would be advisable to increase the value of this capacitor to, say, 100 microfarad in order to help it cope with these difficult conditions. Also, electrolytic capacitors perform much better and have a much longer life if their voltage rating is higher than the average working voltage they are expected to encounter. For vehicle circuits, a minimum of 35 volts is recommended. This has no significant effect on the cost or size of the capacitor, so it is a good idea to increase the rating as recommended.

One other very important point is that the Integrated Circuit has an absolute maximum voltage rating of 25 volts and this can easily be exceeded in vehicle environments. To protect against this, it is worth adding a current-limiting resistor and a 24 volt zener diode as shown here:

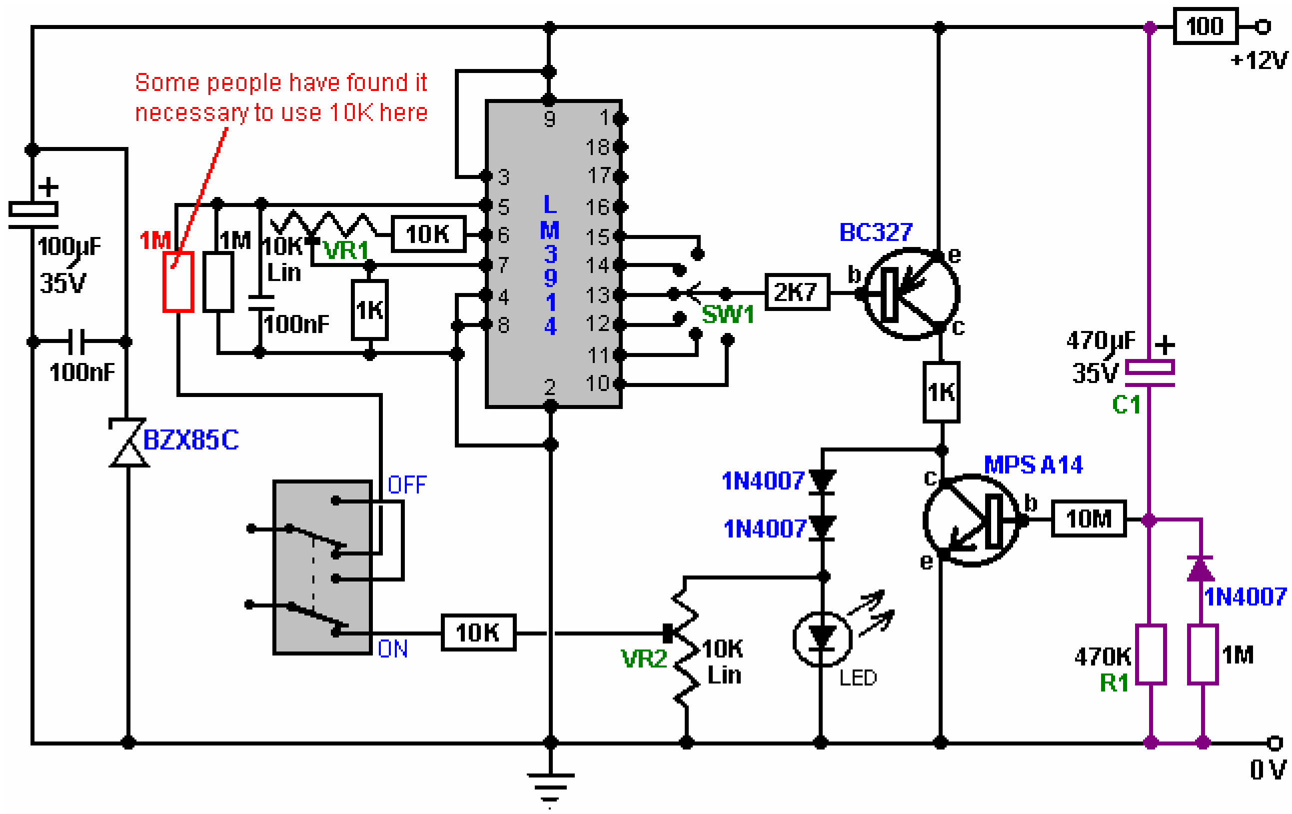


With this modification, if the nominal +12 volt supply gets a spike on it which briefly takes the voltage up to, say, 40 volts, the voltage at point “A” starts to rise rapidly. When it reaches 24 volts, the BZX85C zener diode start to conduct heavily, collapsing the spike and pinning down point “A”, preventing the voltage exceeding 24 volts. One additional protection option is to put a 0.1 microfarad capacitor across the 100 microfarad capacitor. This looks unusual if you have not seen it before, but is a standard method of trapping very sharp spikes on the supply line, as a capacitor as small as that acts like a short-circuit to high frequency spikes. Also, to make adjustment of the circuit easier, an additional 10K resistor has been inserted between VR1 and Pin 6 of the integrated circuit. This makes the circuit:



The next point of concern is the timing circuit of “C1” and “R1”. Contrary to what the website suggests, using the values shown here, capacitor C1 will charge up fully in nine seconds through R1 alone, and not the “few minutes” quoted. That neglects the current flowing through the Base/Emitter junction of the MPSA14 transistor and its 10 megohm resistor, which will shorten the nine second period quite substantially. If this part of the circuit is to generate a realistic delay period, then capacitor C1 needs to be very much larger, say a capacitor of 470 microfarad capacity. That will be an electrolytic capacitor, and they tend to have quite large leakage currents which will prevent them charging fully unless the current being fed into them is reasonably large. For that reason, we should change resistor R1 to 470K (470,000 ohms) which, with a 470 microfarad capacitor for C1, should give a delay time of about three and a half minutes.

There is another detail which needs to be checked, and that is the situation when the vehicle is parked long enough for the oxygen sensor to cool down below it’s 600 degree Fahrenheit working temperature. We want the time delay to occur if the engine is off for some time, but not to occur if the engine is switched off only briefly. For this to happen, it is suggested that a diode is placed across the timing resistor. This will have no effect when the circuit is powered up, but it will discharge the capacitor when the circuit is powered down. We can slow down the rate of discharge by putting a high-value resistor in series with the discharge diode and that would make the circuit:



Circuit Operation:

Now that we have looked at each part of the circuit separately, let us look again at the way that the circuit operates. The main component is the LM3914 integrated circuit. This device is designed to light a row of Light Emitting Diodes ("LEDs"). The number of LEDs lit is proportional to the input voltage reaching it through it's Pin 5. In this circuit, the integrated circuit is used to provide a reduced voltage to be fed to the fuel computer, rather than to light a row of LEDs. When the operating switch is set in it's ON position, the sensor voltage is fed to Pin 5 through a 1 megohm resistor.

The sensitivity of this circuit is adjusted, so that when 500 millivolts (0.5 volts) is applied to Pin 5, the output on Pin 10 is just triggered. This is done by adjusting the 10K linear preset resistor "VR1" while placing a test voltage of 500 millivolts on Pin 5. This LM3914 Integrated Circuit is normally switched so that it samples the sensor voltage. The LM3914 chip provides ten separate output voltage levels, and the circuit is arranged so that any one of several of these can be selected by the rotary switch "SW1". These output voltages range from 50 millivolts on Pin 1 to 500 millivolts on Pin 10, with each output position having a 50 millivolt greater output than it's neighbouring pin. This allows a wide range of control over the sensor feed passed to the fuel computer.

The input resistor/capacitor circuit provides filtering of the sensor signal. Because this circuit draws very little current, it is easily knocked out of correct operation through it's input line picking up stray electrical pulses produced by the engine, particularly the vehicle's ignition circuit. When the exhaust sensor heats up, the signal becomes cleaner and then the circuit starts operating correctly. The circuit includes a delay so that after start up, the output is held low for a few minutes to simulate a cold sensor. The sensor must be operating correctly before we send signals to the computer. The most common problem, if we don't have this delay, is that the output will be high simply from the noise on the signal line. The computer will think the sensor is working, because it is high, and will cut back the fuel to make the signal go low. If that were to happen, we would end up with an over-lean fuel input to the engine, producing very poor acceleration.

The front panel LED is not just to show that the device is operating, but forms a simple voltage regulator for the output signal to the computer. When the engine is warmed up and running normally, the LED is lit when the output is high, and not lit when the output is low, so this LED should be flashing on and off.

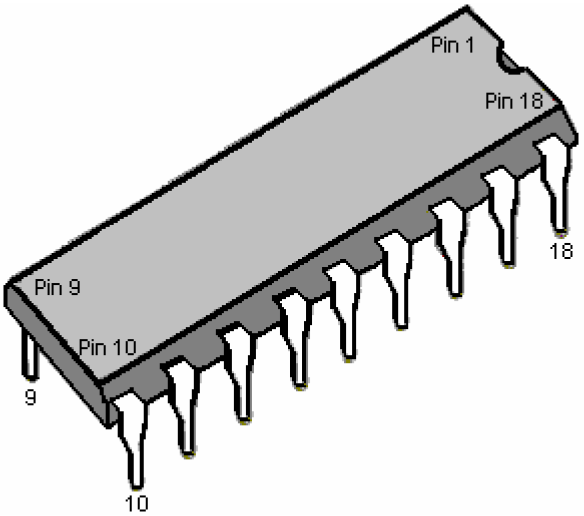
The earth connection for the oxygen sensor is the exhaust system, which is firmly bolted to the engine. The computer earth is the vehicle body. A difference of just 0.5 volts can make a large difference to the mixture. If the engine is not securely earthed to the vehicle body, then a voltage difference can exist between the two, and in this situation a voltage difference of just 0.5 volts would normally go unnoticed. We can't afford to have that sort of voltage difference when trying to control the mixture accurately, so some investigation and adjustment is needed.

To do this, start the engine, switch the headlights on to high beam, then measure the voltage between the engine and the body. Use a digital volt meter. Any more than 50 millivolts (0.05 volts) means that there is a bad earth connection which need cleaning and tightening. Modern cars usually have more than one connection so look around. If you have trouble achieving a really good connection, then earth your circuit board directly on the engine rather than connecting it to a point on the bodywork of the vehicle. The most important item is to have a good quality signal voltage coming from the sensor, since the operating range consists of quite low voltages. The components and tools needed for building this circuit are shown later, but for now, consider the setting up and testing of the unit so as to understand better what is needed.

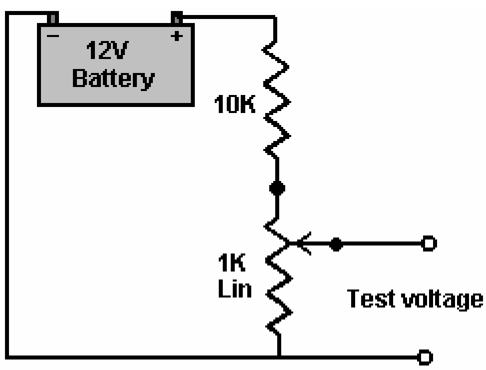
Adjusting on the Bench

When the circuit has been constructed to the testing stage, that is, with all components in place except for the timing capacitor "C1", and before the power is turned on, plug the Integrated Circuit chip into its socket mounted on the board. Be very careful doing this as the chip can be destroyed by static electricity picked up by your body. Professionals wear an electrical earth wrist strap when handling these devices, so it would be a good idea to touch a good earth point such as a metal-pipe cold water system just before handling the chip.

It is vital that you install the IC chip, the correct way round or it may be damaged. The circuit board layout shows which way round it goes. The chip has a semi-circular indentation at one end to show which end is which, so be careful that the indentation is positioned as shown on the board layout in the section which shows how the board is built. Some manufacturers use a dot rather than a semi-circular indentation to mark the end of the chip which has Pin 1 in it.



Make up the test voltage device. We need something to give us an adjustable voltage in the range 0 to 1 volt. A very easy way to get this is to use a 10K resistor and a 1K variable resistor (called a "potentiometer" by some people) and connect them across the 12 volt battery, as shown here:



This gives us a voltage in the correct range when the shaft of the variable resistor is turned. Power up the circuit board by switching the 12 volt battery through to the board. Adjust the test-voltage source to 500 millivolts (0.5 volts) and apply it to the board's input (where the sensor connection will be made when it is installed in the vehicle). Set the switch to the "Richest" position, that is, with the switch connected to Pin 10 of the chip.

Now, using a flat-blade screwdriver, adjust the sensitivity control preset resistor "VR1" so that the output LED is just lit. Leave the preset resistor in that position and adjust the test voltage lower and higher to test that the LED turns on and off in response to the varying voltage at the input to the circuit. The LED should come on at 0.5

volts, and go off just below 0.5 volts. The other outputs, which can be selected by the rotary switch "SW1", will be about 50 millivolts lower for each position of the switch away from it's "Richest" setting on Pin 10.

Now, with the output high and the LED lit, use a flat-bladed screwdriver to adjust the preset resistor "VR2" to set the output voltage being sent to the computer to about 1.0 volts. When this has been set, lower the input voltage so that the LED goes out. The output voltage should now be at zero volts. If this is what happens, then it shows that the circuit is operating correctly.

If this board is not in place, the sensor will cause the fuel computer to make the fuel mixture richer so as to maintain a 500 millivolt voltage from the sensor. With the circuit in place and set to its "Richest" setting, exactly the same thing happens. However, if the rotary switch is moved to its next position, the fuel computer will maintain the fuel feed to maintain a 450 millivolt output, which is a leaner fuel-to-air mixture. One step further around and the fuel computer will make the mix even leaner to maintain a 400 millivolt output from the circuit board, which the fuel computer thinks is coming from the exhaust oxygen sensor.

If your circuit board does not operate as described, then power it down and examine the circuit board again, looking for places where the solder connections are not perfect. There may be somewhere where the solder is bridging between two of the copper strips, or there may be a joint which looks as if it is not a good quality joint. If you find one, don't solder anywhere near the IC chip as the heat might damage the chip. If necessary, earth yourself again, remove the chip and put it back into the anti-static packaging it came in, before repairing the board. If the components are all correctly positioned, the copper tracks broken at all the right places and all solder joints looking good and well made but the board still is not working correctly, then it is likely that the IC chip is defective and needs to be replaced.

Next, install the delay capacitor "C1". Set the test voltage above 500 millivolts and turn the power on again. It should take about three minutes for the LED to come on. If you want to shorten this delay, then change the timing resistor "R1" for a resistor of a lower value. To lengthen the delay, replace the timing capacitor "C1" with a capacitor of larger value. If you find that the oxygen sensor heats up quickly, then you can reduce the length of the delay. Having too long a delay is not ideal, since the computer will be adding extra fuel to make the mixture richer.

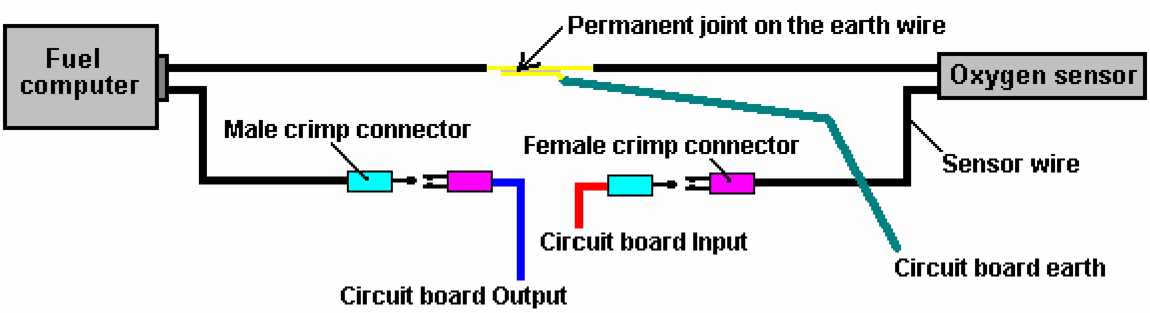
It is suggested that the rotary switch should be set to have only six switch positions (by moving it's end-stop lug washer), so initially, connect the IC chip output pins 10 through 15 to the switch. You can choose to connect the wires to the switch so that the mixture gets richer when you turn the knob clockwise, or if you prefer, you can wire it in the reverse order so that the mixture gets richer when you turn the knob counter-clockwise.

Testing in the Car

You can now test the device in the vehicle but don't install it yet. Look in the engine compartment and locate the oxygen sensor. If you have difficulty in finding it, get a copy of the Clymer or Haynes Maintenance Manual for your vehicle as that will show you the position. If your vehicle has two sensors, then select the one nearest to the engine. If your sensor has five wires running to it, then it is a "wideband" sensor which measures both the oxygen content and the amount of unburnt fuel, and unfortunately, the type of circuit described here will not control it.

Start the vehicle and allow the oxygen sensor to warm up for a couple of minutes. Remember that there is a delay built in to the circuit, so after a few minutes you should see the LED start to flash. Rev the engine and the LED will stay on. When you release the throttle, the LED will go out for a while. A flashing LED is what you want to see. The rate of flashing will be somewhere between 1 and 10 times per second, most likely around 2 per second. Confirm that the LED goes out when you switch off the circuit board On/Off switch mounted on the dashboard.

Now comes the exciting bit, cutting the oxygen sensor wire and inserting the controller. Turn the engine off and cut the wire in a convenient place. Use crimp connectors on the wire ends. Use a matching pair on the wire which you just cut, in case you need to reconnect it, as shown here:



When set up like this, the male connector furthest on the left could be plugged into the female connector furthest on the right and the circuit board removed. Be sure to insulate the sensor and fuel computer plug/socket connections to make quite sure that neither of them can short-circuit to any part of the body. There is no need to insulate the earth connection as it is already connected to the body of the vehicle. Although not shown in the diagram, you could also put a male and female crimp connector pair on the earth cable. If your sensor has only one wire coming from it, then you best earth connection is to a solder-tag connector placed under a bolt on the engine. If you do that, be sure to clean all grease, dirt, rust, etc. off the underside of the bolt head and the area around the bolt hole. Push a paper towel into the bolt hole before doing this to make sure that no unwanted material ends up in the bolt hole and use wet-and-dry paper to really clean the surfaces. The objective here is to make sure that there is a very good electrical connection with shiny metal faces clamped firmly together.

Installing the Controller

Now, install the circuit board in the vehicle. For the 12 volt supply, find a connection which is switched on and off by the vehicle's ignition switch. Don't drive the car yet, do this test in the driveway. With the front panel switch in it's "Off" position, start the car and check that it runs normally. Set the front panel rotary switch to the Richest position (connected to the IC's Pin 10) and switch the circuit board toggle switch to it's "On" position. The car is now running with a modified oxygen sensor signal although the mixture is still the same. The vehicle performance should be completely normal. Drive the vehicle with this setting for a while to prove that the system is working reliably before changing to any of the lower settings. When you are satisfied that everything is in order, try the next leanest setting on the rotary switch and see how it runs.

It is important that there should be no hesitation in the engine performance and no knocking or "pinking" as that is an indication that the mix is too lean and the engine is liable to overheat. This circuit is intended for use with an electrolyzer, so your electrolyzer should be set up and working for these tests. The electrolyzer will tend to make the engine run cooler and offset any tendency towards overheating.

Building the Circuit Board

Although the above information has been presented as if the board has already been built, the actual construction details have been left until now, so that you will already have an understanding of what the circuit is intended to do and how it is used.

It is likely that you will know somebody (neighbour, friend, relative,...) who has the necessary equipment and skills. If so, borrow the equipment, or better still, recruit the person to help with the construction. It is very likely that anybody owning the equipment would be very interested in your project and more than willing to help out.

However, the rest of this document will be written on the assumption that you cannot find anybody to help and have had to buy all of the necessary equipment. This project is not difficult to build, so you will almost certainly be successful straight off.

The tools which you will need, are:

1. A soldering iron with a fine conical tapering tip (probably 15 watts power rating)
2. Some "Multicore" resin solder. This is special solder for electronics construction work and is quite different from plumber's solder which is not suitable for this job.
3. A pair of long-nosed pliers (for holding component wires when soldering them in place)
4. Something for cutting and cleaning wires and stripping off insulation coverings. I personally prefer a pair of "nail" scissors for this job. Others prefer a pair of wire cutters and some sandpaper. You get whatever you feel would be the best tool for doing these tasks.
5. A 1/8 inch (3 mm) drill bit (for making bolt holes in the strip-board and for breaking the copper strips where needed) and a 3/8 inch (9 mm) drill and bit for mounting the switches on the plastic box.
6. A coping-saw or similar small saw for cutting the rotary switch shaft to the optimum length.
7. A small screwdriver (for tightening knob grub screws).

8. A crimping tool and some crimp connectors.
9. A multimeter (preferably a digital one) with a DC voltage measuring range of 0 to 15 volts or so.
10. (Optional) a magnifying glass of x4 or higher magnification (for very close examination of the soldering)

Soldering

Many electronic components can be damaged by the high temperatures they are subjected to when being soldered in place. I personally prefer to use a pair of long-nosed pliers to grip the component leads on the upper side of the board while making the solder joint on the underside of the board. The heat running up the component lead then gets diverted into the large volume of metal in the pair of pliers and the component is protected from excessive heat. On the same principle, I always use an Integrated Circuit socket when soldering a circuit board, that way, the heat has dissipated fully before the IC is plugged into the socket. It also has the advantage that the IC can be replaced without any difficulty should it become damaged.

If you are using CMOS integrated circuits in any construction, you need to avoid static electricity. Very high levels of voltage build up on your clothes through brushing against objects. This voltage is in the thousands of volts range. It can supply so little current that it does not bother you and you probably do not notice it. CMOS devices operate on such low amounts of current that they can very easily be damaged by your static electricity. Computer hardware professionals wear an earthing lead strapped to their wrists when handling CMOS circuitry. There is no need for you to go that far. CMOS devices are supplied with their leads embedded in a conducting material. Leave them in the material until you are ready to plug them into the circuit and then only hold the plastic body of the case and do not touch any of the pins. Once in place in the circuit, the circuit components will prevent the build up of static charges on the chip.

Soldering is an easily-acquired skill. Multi-cored solder is used for electronic circuit soldering. This solder wire has flux resin contained within it and when melted on a metal surface, the flux removes the oxide layer on the metal, allowing a proper electrical and mechanical joint to be made. Consequently, it is important that the solder is placed on the joint area and the soldering iron placed on it when it is already in position. If this is done, the flux can clean the joint area and the joint will be good. If the solder is placed on the soldering iron and then the iron moved to the joint, the flux will have burnt away before the joint area is reached and the resulting joint will not be good.

A good solder joint will have a smooth shiny surface and pulling any wire going into the joint will have no effect as the wire is now solidly incorporated into the joint. Making a good solder joint takes about half a second and certainly not more than one second. You want to remove the soldering iron from the joint before an excessive amount of heat is run into the joint. It is recommended that a good mechanical joint be made before soldering when connecting a wire to some form of terminal (this is often not possible).

The technique which I use, is to stand the solder up on the workbench and bend the end so that it is sloping downwards towards me. The lead of the component to be soldered is placed in the hole in the strip-board and gripped just above the board with long-nosed pliers. The board is turned upside down and the left thumb used to clamp the board against the pliers. The board and pliers are then moved underneath the solder and positioned so that the solder lies on the copper strip, touching the component lead. The right hand is now used to place the soldering iron briefly on the solder. This melts the solder on the joint, allowing the flux to clean the area and producing a good joint. After the joint is made, the board is still held with the pliers until the joint has cooled down.

Nowadays, the holes in the strip-board are only 1/10 inch (2.5 mm) apart and so the gaps between adjacent copper strips is very small indeed. If you solder carefully, there should be no problem. However, I would recommend that when the circuit board is completed, that you use a magnifying glass to examine the strip side of the board to make quite sure that everything is perfectly ok and that solder does not bridge between the copper strips anywhere. Before powering up the circuit, double-check that all of the breaks in the copper strips have been made correctly. Here is a possible layout for the components on the strip-board: