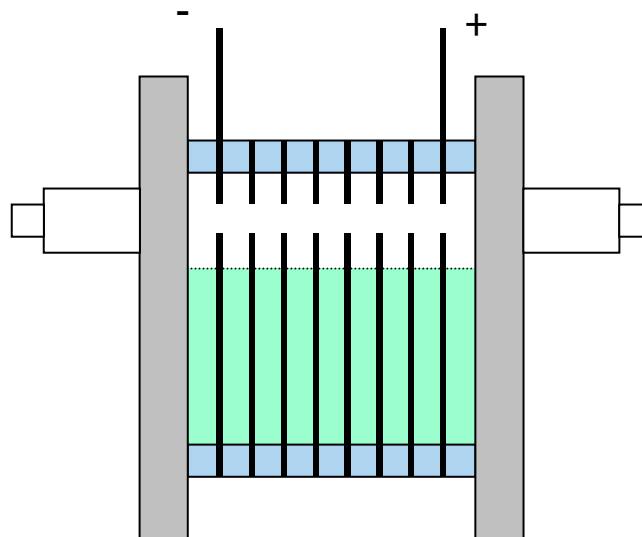


# High-efficiency series-cell electrolyzer

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## Electrolyzer

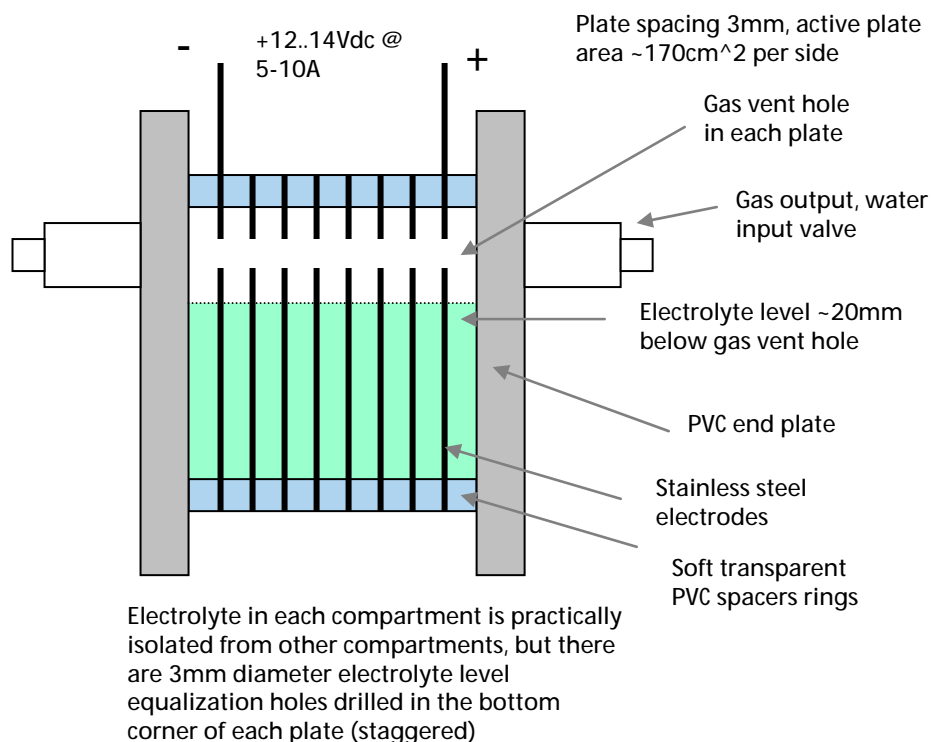
The electrolyzer shown in Figure 1 is based on the common-duct series-cell electrolyzer concept originally developed and patented by William Rhodes, Ernest Spirig, Yull Brown and later refined by Bob Boyce, George Wiseman, etc... It uses an alkaline (NaOH, KOH) electrolyte to split distilled water into hydrogen and oxygen components very efficiently.

The produced hydrogen and oxygen gasses are not separated to separate containers, but kept mixed. The produced oxyhydrogen gas is a stoichiometric mixture of hydrogen (2 parts vol.) and oxygen (1 part vol.) and can be combusted in vacuum.

The combination of series-cell topology is very efficient, because it allows the cells to operate as close to their optimal cell voltage (1.47V) as possible. The electrolyzer runs fairly cool, at about 30-50 C depending on the current and electrolyte.

The electrolyzer shown in this report has about 80-90% total efficiency when all things are considered (ambient temperature, ambient pressure, accurate measurement of gas volume and current) when powered by straight DC. Pulsing (PWM) or modulation of the input voltage waveform could increase the performance further, as it is known that in the beginning of each pulse larger current flows than in the steady state condition, thus lowering the cell voltage needed to push thru a certain amount of current and increasing the efficiency slightly. There are also claims of various resonance phenomena (Boyce, Meyer, etc.) that supposedly dramatically increase the gas production rate vs. input current when the electrolyzer is driven with a certain type of PWM rich in harmonics. However, this author has not been able to replicate any resonance modes in any sort of electrolyzer.

The electrolyzer has 7 cells with a target input voltage of about 12.9-14.1Vdc depending on temperature. This makes the cell voltage about 1.85-2.0V.



**Figure 1. Series cell electrolyzer cross-section**

## Electrolyzer construction

The eight electrolyzer plates (Figure 2) are about 0.8mm thick 160mm x 200 mm stainless steel (304 grade). A 10mm gas vent hole is drilled in each plate. The electrolyte level is always about 25mm below the gas vent hole. There are 3mm diameter liquid level equalization holes drilled in the bottom corner of each plate (not shown) in such a way that adjacent plates have holes in opposite corners. Staggering and using small holes minimizes any efficiency loss due to current leakage between cells, but makes electrolyte refilling and level equalization significantly easier. The two end plates have a small SS piece welded for electrical contact. After taking the picture the plates were sanded with an orbital sander to expose clear metal and then cross-hatch pattern was “engraved” on the plates with a rough file attached to a wooden block. This is to increase the active surface area of the plates and seems necessary for ultra high efficiency. Other methods to increase plate area exist as well.



**Figure 2. Stainless steel electrolyzer plates (8 total)**

Nine spacers (Figure 3) were cut out of 3mm thick soft and transparent PVC sheet with a knife. The wall thickness is 12mm. The PVC sheet is originally designed for door material for large room-size refrigerators. The small square PVC blocks were meant to keep proper distance between SS plate centers, but they turned out to be unnecessary and were not used.



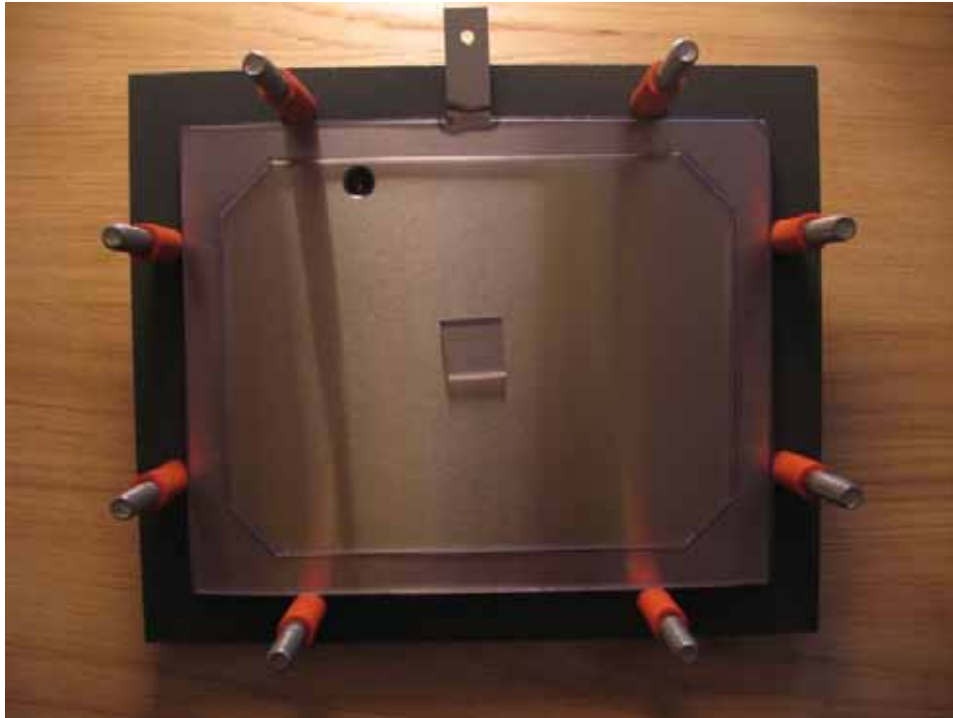
**Figure 3. Soft PVC spacers rings**

The end plates (Figure 4) were cut out of 12mm thick PVC plate. The size of the plates was 200mm x 240mm. Eight 8mm holes were drilled for M8 size stainless steel through-bolts. A ¼" pipe thread was tapped in a 11.8mm gas vent hole. A valve and gas hose connector was epoxy glued to the ¼" tapped hole in both plates. Other thread sealants may not be compatible with the electrolyte so it's best to use epoxy or teflon tape. The valve was lined up with gas vent hole in SS plates. NOTE: When the electrolyzer stack is tightened up the PVC end plates tend to bend and bulge. Some form of metallic bracing should be used to prevent bending or the end plates made out of thick stainless steel plate.



**Figure 4. PVC end plates with gas valves attached**

The first stainless steel plate and one PVC spacer ring are shown in Figure 5. There is a PVC spacer ring also between the PVC end plate and first SS plate. A 35mm piece of 8mm ID 12mm OD rubber hose is slid over the bolts to isolate the bolts from the plates and hold the plates in place. Note that it would have made more sense to drill the gas vent hole to the upper left corner of the plates, so that draining the all of the electrolyte out of the electrolyzer would have been easier.



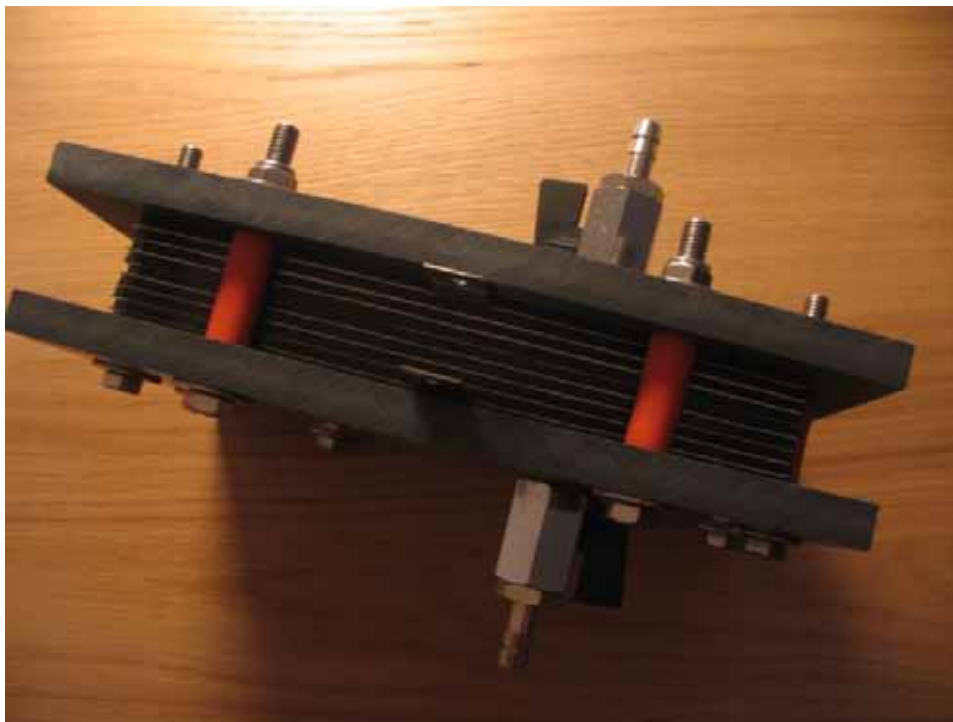
**Figure 5. First SS plate in place with the PVC spacer shown**

A side view of the cell stack with several SS plates and PVC spacer rings in place is shown in Figure 6. Note the soft PVC sheet material in the background with the cut outline drawn with a permanent overhead transparent marker pen.



**Figure 6. Partly assembled cell stack**

The finished electrolyzer is shown in Figure 7. The two PVC end plates are clamped together with 70mm long M8 stainless steel bolts with Nyloc nuts. After initial tightening the electrolyzer was submerged in hot tap water (about 60 C) with the gas vent valves closed. This softened the PVC gaskets and allowed the stack to be tightened up even further to provide an excellent seal. Note that the 12mm PVC plates are quite soft and some bulging is visible. Two additional bolts would have been useful to equalize the bolt forces more evenly around the plates.



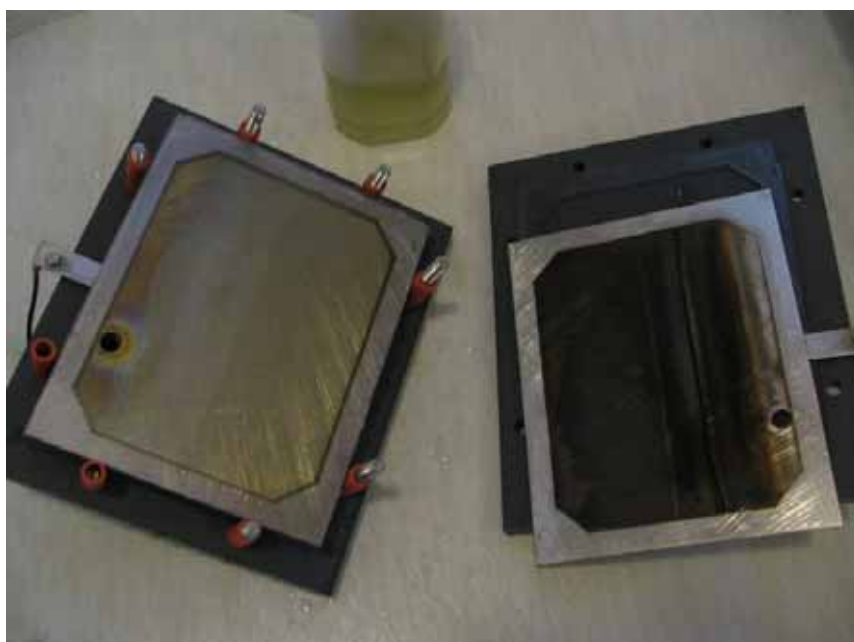
**Figure 7. Assembled stack**

The finished electrolyzer equipped with a bubbler is shown in Figure 8. The bubbler is absolutely essential to prevent backfires from blowing up the electrolyzer. The electrolyzer may be filled with slightly acidic water (use vinegar) to neutralize any residual NaOH vapors in the output gas. It would be wise to use a non-return valve between the electrolyzer and bubbler to prevent bubbler water being pushed back into the electrolyzer in case of backfire.



**Figure 8. Finished electrolyzer with bubbler**

Figure 9 shows the electrode plates after the electrolyzer had been used for some time. The chemical reactions occurring in the electrolyzer have slightly darkened the electrolyte. The use of 316 SS electrodes would probably have prevented this. Note how the other side of the plate is relatively clean, while the other side has a darker deposit. Note also the sanded and crosshatched electrode surface.



**Figure 9. Electrode discoloration due to chemical reactions (NaOH & 304 SS)**

## Electrolyzer tips

- 1) Gas production is directly proportional to the current draw only. At STP conditions (0 deg C, 1 atm) you need approximately 1.594 Amps for each LPH per one cell, while you need less if you measure the gas volume at room temperature.
- 2) The ideal cell voltage would be about 1.48V, and anything above it is wasted efficiency. The lowest practical cell voltage seems to be around 1.8V-2.0V. The voltage is only needed to push the current thru the cell, it has no relation on the amount of gas produced. The cell overvoltage (above 1.48V) is determined by electrode materials, current density, electrode spacing and conductivity of electrolyte.
- 3) Power or total efficiency is defined as the amount of watts needed to produce one LPH. Series-cell designs seem to have the best efficiency in the range of 2.5-3 Watts per LPH. The most efficient electrolyzer would have a large number (100) of cells in series with narrow cell spacing (3mm) at a low current (10A).
- 4) Many people build simple single-cell car hydro-booster type electrolyzers and control the amperage by using weak electrolyte. The cell voltage is often around 13V, and they put just enough electrolyte to pass 5A or so. 5A creates only 3.5 LPH of gas, so the efficiency is very bad at 18.5 Watts per LPH. Properly designed 7-cell series electrolyzer would produce 7 times that amount or 24.5 LPH gas at the same input power.
- 5) The cell voltage is also dependent on the current density (current / electrode area). Smaller cell area is less efficient because it requires higher voltage to pass the same amount of amps. Good practical current density is around 0.5A/Sq.inch or 0.1A/cm<sup>2</sup>. The electrolyzer shown in this report had an effective plate area of about 170cm<sup>2</sup>, with a target current of about 20A.
- 6) The higher the current thru the cell (higher current density) the higher the cell voltage. Power efficiency decreases as the current increases if the plate area is kept the same. To keep the power efficiency the same increase the plate area in proportion with the current (keep current density the same).
- 7) The smaller the electrode spacing the lower the cell voltage. In practice 3mm electrode spacing is good up to about 10A. At higher currents the electrolyte starts foaming and crawling up the plates (reduces efficiency) and the electrolyzer starts spitting electrolyte foam out. For 10-40A use 5mm-8mm spacing.
- 8) Best electrolyte is NaOH (1 part NaOH 4 parts water by weight) or KOH (28% by wt). These give the lowest practical cell voltage.
- 9) The best electrode material would be nickel, but nickel plates are very expensive. Nickel plated steel plates would also work. The most practical electrode material is stainless steel. The electrode surface conditioning is very important at minimizing the cell voltage. Best to sand (crosshatch pattern) the electrode plates to create lots of fine sharp points.
- 10) Bubbler is absolutely essential to prevent backfires from blowing up the electrolyzer. Bubbling the gas thru a water bath is the only safe way to prevent backfires, provided that the bubbler is strong enough to contain any backfires and that the water level in the bubbler is high enough. Alternatively the bubbler can have a pop-off lid or a rupture disk.
- 11) The electrolyzer as shown will not be able to take any pressure without leaking. For pressurized operation use a pressure-proof shell (metallic). If you need to store oxyhydrogen gas for a short period of time, put a large balloon on the bubbler lid. The balloon will store the gas at atmospheric pressure and will not be very dangerous if it explodes due to a backfire. Remember to wear hearing and eye protection.



## Faraday's First Law of Electrolysis:

$$V = \frac{R \cdot I \cdot T \cdot t}{F \cdot p \cdot z}$$

where V = volume of the gas [L], R = ideal gas constant = 0.0820577 L\*atm/(mol\*K), I = current [A], T = temperature [K], t = time [s], F = Faraday's constant = 96485.31 As/mol, p = ambient pressure [atm], z = number of excess electrons (2 for H<sub>2</sub>, 4 for O<sub>2</sub>).

Assume that you have STP (Standard Temperature and Pressure) conditions and the electrolyzer runs at one Amp for one hour:

$$T = 0 \text{ }^{\circ}\text{C} = 273.15 \text{ K}$$

$$p = 1 \text{ atm}$$

$$t = 3600 \text{ s}$$

$$I = 1 \text{ A}$$

Total oxyhydrogen volume is hydrogen volume + oxygen volume:

$$V_{H_2} + V_{O_2} = \frac{0.0820577 \cdot 1 \cdot 273.15 \cdot 3600}{96485.13 \cdot 1 \cdot 2} + \frac{0.0820577 \cdot 1 \cdot 273.15 \cdot 3600}{96485.13 \cdot 1 \cdot 4} = 0.418151L + 0.209075L = 0.627226L$$

This corresponds to about 0.627 LPH/Amp or 1.594A/LPH per cell.

If for example you have 7 cells in series and put 11A through the electrolyzer, according to Faraday's Law you would produce 0.627 LPH/A\*11A\*7 = ~48.3 Liters per hour at STP conditions.

It is impossible for an electrolyzer to be anything else than 100% Faraday efficient, unless there are significant leakage currents between cells. Passing one Amp thru a single cell will always produce gas at a rate of 0.627LPH when reduced to STP conditions, no matter how the one electrolyzer cell is constructed.

This however applies only at STP (0 deg C and 1 atm ambient pressure). At room temperature (25 deg C) the same amount of gas has higher apparent volume. Substituting T=25 deg C gives the efficiency as 0.684 LPH/A. Stated the other way the Faraday efficiency would appear to be about 109.5% if the gas volume was measured at room temperature, unless the correct efficiency value for room temperature (0.684LPH/Amp per cell) was used.

The thermoneutral cell voltage is ~1.48 V, which means the voltage at which all input energy for the electrolysis process comes from the electrical input energy. At 1.23 V (reversible cell potential) part of the energy comes from ambient heat and electrolyzer is about 120% voltage efficient. Note that 100% efficient hydrogen oxygen fuel cell would produce 1.23V. The thermoneutral voltage of ~1.48V is considered to be the 100% voltage and power efficient electrolysis. Combusting the produced gas will release exactly the same amount of energy that was used in making the gas.

The 100% power or wattage efficient electrolyzer would consume 1.48 V \* 1.594 Ah/l = 2.36 W/LPH when gas volume is measured at STP. At room temperature the 100% efficiency is 2.16W/LPH.

In the literature the electrolyzer efficiency is usually defined as the ratio of the thermoneutral voltage (1.48V) to the cell voltage. At 2.0V cell voltage it would imply a total efficiency of 74%. This also shows the inefficiency of single-cell hydro-booster type electrolyzers operating at automotive voltages (~12-14V), leading to a total efficiency of about 10%.

## Series-cell electrolyzer voltage and current measurements

The current thru the series-cell electrolyzer is extremely sensitive to the voltage across it. This is because the electrolyzer acts as a very non-linear resistance, with pn-junction like characteristics. It takes a certain cell voltage until the current starts flowing (“knee voltage”) and increasing the cell voltage above this voltage will increase the current exponentially. Figure 10 shows measured and modelled electrolyzer current vs. voltage graph for the 7-cell series electrolyzer. Note how increasing the electrolyzer voltage from 13.2V to 13.9V (5%) will cause a five-fold (500%) increase in current (from 2A to 10A).

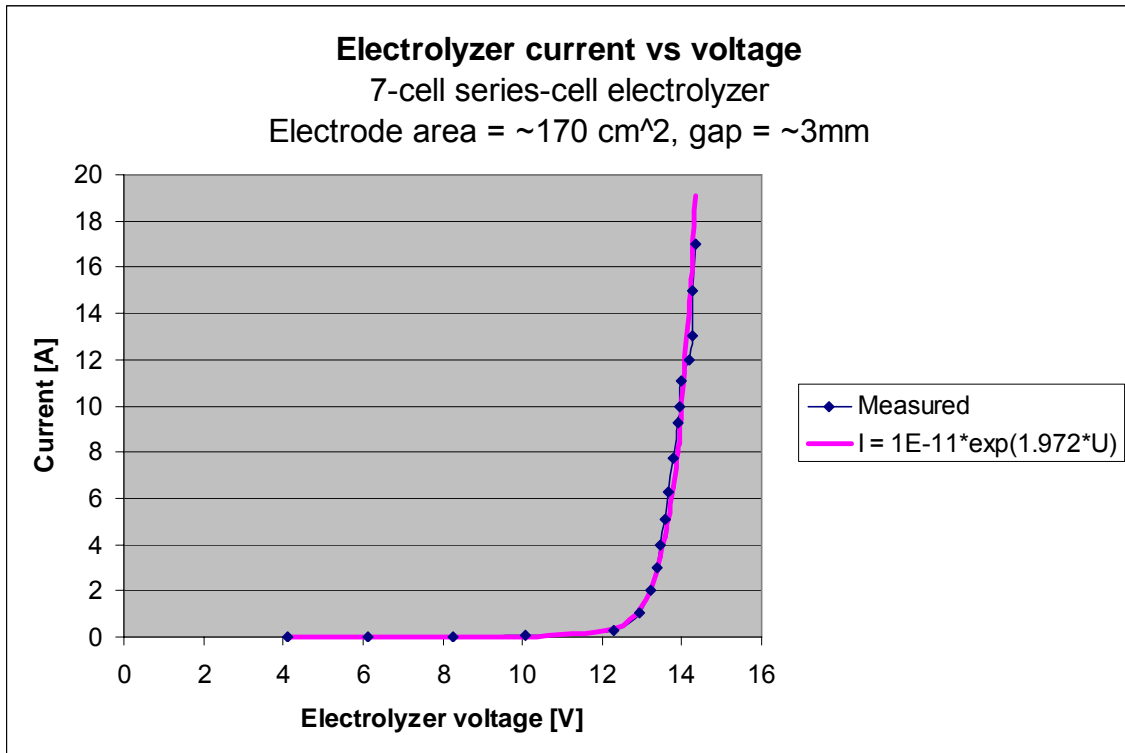
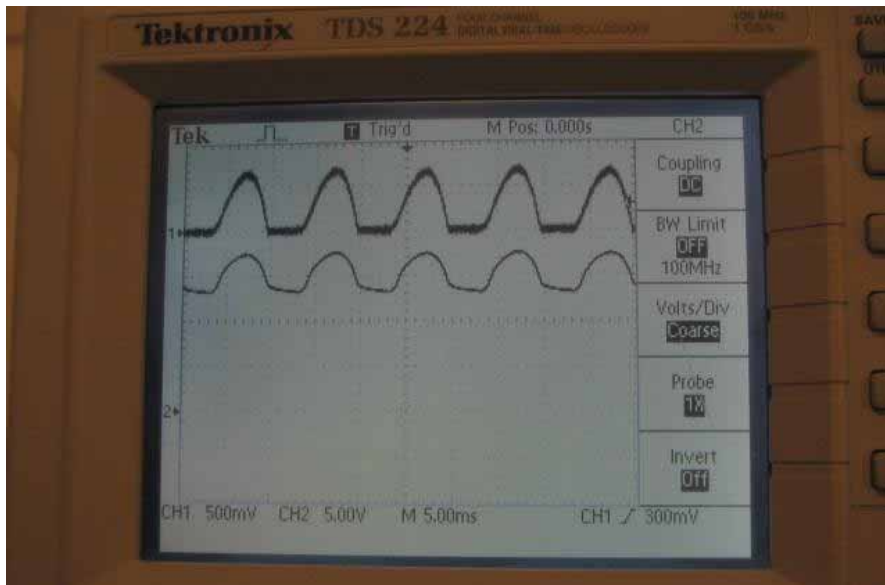


Figure 10. 7-cell series electrolyzer current vs. voltage

Note that even the insertion of a current meter in series with the electrolyzer may cause high enough voltage drop that significantly reduces the electrolyzer current. Thus it is absolutely essential that the current meter is in place when the electrolyzer gas output rate is measured.

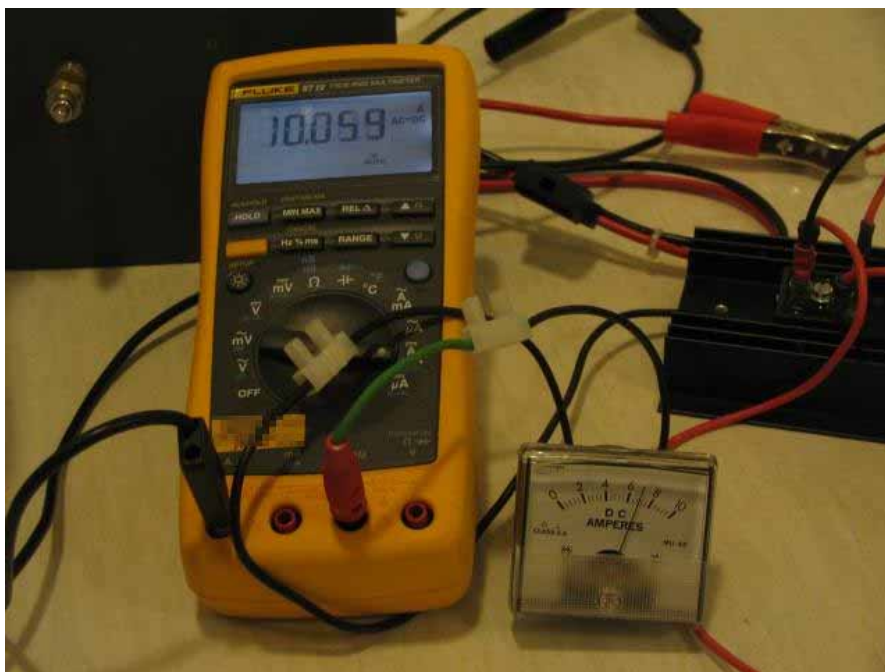
This extremely non-linear resistance of the electrolyzer also causes the current thru the electrolyzer to be modulated very strongly with any small changes in the electrolyzer voltage. This is especially true if the electrolyzer is powered by rectified AC, for example from a transformer based battery charger or power supply.

The oscilloscope pictures of the 7-cell electrolyzer voltage and current waveforms are shown in Figure 11. The power supply was a mains transformer followed by a bridge rectifier and a large filtering capacitor. Note how the electrolyzer voltage (trace 2) has a small ripple on top of it, which causes the electrolyzer current to be modulated between zero and peak current (trace 1), with appearance similar to half-wave rectified AC. The current draw waveform may be easily measured with oscilloscope by connecting the oscilloscope probe across the multimeter terminals wired in series with the electrolyzer in the current measuring mode. Thus the oscilloscope shows the voltage drop across the multimeter current shunt resistor.



**Figure 11. Series-cell electrolyzer voltage and current waveforms**

The pulsed current waveform causes significant measurement inaccuracies if normal digital multimeters or analog current meters are used. Normal current meters respond to either straight DC or perfectly sinusoidal AC waveshapes correctly, but show significantly lower current values for pulsed DC type waveforms. True-RMS multimeter is required to measure pulsed waveforms correctly (the RMS value represents the equivalent “heating value” of any current or voltage waveform). Figure 12 shows comparison between current readings of an analog current meter and a Fluke True-RMS multimeter, while measuring current draw of the 7-cell electrolyzer powered by a transformer-based power supply (actual current waveform as shown in Figure 11). The analog current meter shows approximately 7A while the correct RMS value is 10A, which would cause the electrolyzer to appear 143% efficient based on the analog current meter reading which is not true!



**Figure 12. Comparison between current meter readings for pulsed electrolyzer current**

For the most accurate measurements straight DC should be used, preferably from a battery which is not connected to a battery charger. If any other power supply is used, True-RMS measurement equipment is needed for accurate results.

## Series-cell electrolyzer current limiting

As the series-cell electrolyzer has very non-linear voltage vs current characteristic, it is important that some form of current limiting is used to prevent current runaway. While the electrolyzer is operating it will get hot and heat will decrease the required cell voltage to pass a certain number of Amps, thus increasing the electrolyzer current draw if the electrolyzer voltage remains the same. This is likely to increase the current draw very significantly, which may cause electrolyte boiling and other problems.

### PWM current limiting

The best way to limit the current is to use PWM or pulsed DC and to adjust the duty cycle to maintain the average current. A fairly straight forward way is to use a Hall effect current transducer (such as LEM LTS25-NP), which outputs a voltage proportional to the current and use this as a feedback to a PWM controller chip (TL494) to adjust the PWM duty cycle. For the switch FET IRFZ44 (N-channel 17.5mΩ 49A, placed between electrolyzer negative and ground, switched on with positive voltage) or IRF9Z34 (P-channel 140mΩ 18A, placed between electrolyzer positive and battery positive, switched on with negative voltage) may be used.

For the PWM controller a ready made DC motor speed control unit will do fine. It usually has a potentiometer to adjust the duty cycle, which can be replaced by circuitry to automatically adjust the duty cycle based on measured current draw. If automatic set-and-forget operation is not required, the PWM controller may be used to control the electrolyzer current draw manually.

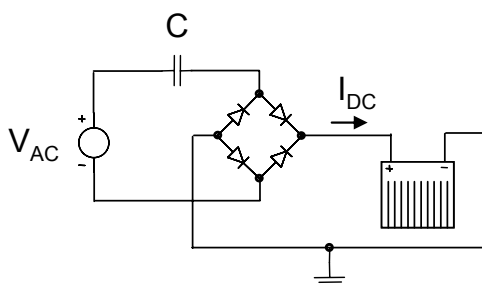
For most accurate current limiting the RMS current value may be calculated with for example MX536A or AD536A True RMS-to-DC converter chips.

For minimum parts count a microcontroller (e.g. Atmel AVR series) may be used with the Hall effect transducer output routed to the AD converter input and the duty cycle adjustment and RMS current calculation performed in software. The switch FET may be directly driven with the microcontroller.

### Capacitive current limiting

Capacitive current limiting (Figure 13) may be used for electrolyzers powered by rectified AC. It is based on putting a capacitor in series between the AC source and the bridge rectifier. The reactance of the capacitor will limit the current to a certain value, but will not dissipate any power like a current limiting resistor.

The capacitor must be suitable for AC use (not an electrolytic capacitor). For mains-powered operation power-factor correction capacitors are the best. This is best suited for welders operating on mains power (no heavy transformer needed) or hydroboosters running on modified alternators (diodes removed). You can use any number of cells (even one), but you need to figure about 2.0V per cell minimum. For 230VAC 50Hz you need about 14uF for each Amp.



$$I_{DC} \approx \frac{V_{AC}}{X_C} = V_{AC} \cdot 2\pi f \cdot C$$

$$I_{DC} \approx V_{AC} \cdot 2\pi f \cdot C = 230V \cdot 2\pi \cdot 50Hz \cdot 100\mu F \approx 7.2A$$

Figure 13. Capacitive current limiting

## Output measurements:

Run #7: (3<sup>rd</sup> Aug 2005)

Electrolyte drain-cleaner grade 93% pure Potassium Hydroxide or KOH pellets in medical grade purified water. Concentration 28% KOH and 72% water by weight. 500 grams of electrolyte (about 450ml volume) was mixed and poured into the electrolyzer. The electrolyzer was allowed to run without collecting gasses for a few hours. During this time the electrolyte temperature stabilized at 45C while the ambient temperature was 17C.

The gas production rate was measured by collecting the gas in a 0.5L coke bottle filled with water. The weight of the bottle with water was measured. The bottle filled with water was turned upside down while partly submerged in a cold water bath. The gas was allowed to bubble through the water bath to the bottle and the time was measured. After removing the gas hose and stopping the timer the cap of the bottle was screwed on while still under water and the weight of the bottle filled partly with water and partly with gas was measured. The weight difference between start and end weights was recorded, as the weight difference in grams corresponds to the volume of produced gas in milliliters. The production rate was found to be 475ml in 30 seconds, which corresponds to 57 LPH (liters per hour).

The cell was powered by a current limited (11A limit) battery charger. The voltage and current across the electrolyzer were measured to be 12.9 V and 11 A during the gas collection. Thus the input power was 141.9 W.

At room temperature the Faraday efficiency would be 0.684 LPH/A per cell. This electrolyzer should produce about  $0.684\text{LPH/A} \times 11\text{A} \times 7 = 52.6$  LPH, but it produces about 57LPH. This difference is most likely explained by the gas volume or current measurement inaccuracy.

The power efficiency was determined by dividing the total power consumption by the amount of gas produced. This is  $141.9\text{W} / 57 \text{ LPH} = \sim 2.49 \text{ W/LPH}$ . The 100% efficient electrolyzer (gas volume measured at room temperature) would be about  $1.48\text{V}/0.684\text{LPH/A} = 2.16\text{W/LPH}$ . Thus this electrolyzer has about 86.7% efficiency.

However, the cell voltage was  $12.9\text{V}/7 = 1.84\text{V}$ . Thus the actual total efficiency is  $1.48\text{V}/1.84\text{V} = \sim 80\%$ .

## Running internal combustion engines on oxyhydrogen

The amount of oxyhydrogen needed to run an internal combustion engine is spectacular. Idling a small engine (e.g. 5hp) would require 500-1000 LPH (liters per hour), while idling a car engine would probably consume about 3000LPH of oxyhydrogen. Driving down the highway would probably consume 20000-30000 LPH of oxyhydrogen. The electrolyzer shown in this report produced approximately 57LPH at 11A, which is not enough to idle even the smallest 4-stroke engine (at least 300-400LPH would be required to idle a small 1hp brush cutter 4-stroke).

One liter of gasoline contains approximately 30MJ of energy, while oxyhydrogen gas would contain approximately 7-8kJ per liter. This means that you would need approximately 4000 liters oxyhydrogen for each liter of gasoline your engine currently uses, assuming the engine efficiencies are approximately the same on oxyhydrogen than on gasoline.

Thus if your car uses 6 liters of gasoline per hour while driving down the highway, prepare for 24000 LPH oxyhydrogen consumption. Assuming a super-efficient series cell electrolyzer (2.5 W per LPH) you would need 60kW of electrical energy to run the electrolyzer. This corresponds to about 80hp, which is significantly more than the amount of engine power used at highway speeds (~20hp). Figuring in the alternator efficiency (~50%) you would actually need 160hp on the engine shaft to produce 24000LPH of oxyhydrogen gas.

How about a 100cc scooter powered by a 60-cell series electrolyzer running off an inverter and bridge rectifier powered by the 12V battery? Estimated gasoline consumption while riding at 70km/h would be about 1LPH gasoline, which would convert to about 4000LPH of oxyhydrogen consumption. Idling the same scooter would probably take 500-1000LPH. The 60-cell electrolyzer would produce about 40 LPH per Amp measured at room temperature. Thus you would need 100Amps thru the 60-cell to produce 4000LPH. Because the electrolyzer has 60 cells, you need to power it with about 120Vdc (assuming 2.0V cell voltage) from the inverter. Assuming 100% efficient inverter, it would draw 1000 Amps from the 12V battery to produce 120Vdc 100A. If the scooter had a fully charged 5Ah battery it would last for 18 seconds at 1000A until it would run out. The scooter's "alternator" would produce probably about 5A maximum.

A common misconception is to think that you can dilute oxyhydrogen gas with air and run the engine with very small amounts of gas. Oxyhydrogen gas is in itself a perfectly proportioned mixture of hydrogen and oxygen gasses, which combusts perfectly leaving no hydrogen or oxygen but only water vapor and heat. Adding any air will make it combust imperfectly and release less energy for same volume of gas.

An often quoted air:fuel ratio for hydrogen combustion in air is 34:1, but this is a MASS ratio. This means that you need 34 grams (=27.76 liters) of air for each gram of hydrogen (=11.1 liters). Converted to VOLUME ratio this is 2.5:1, which makes perfect sense because air contains approximately 20% of oxygen by volume and you need 0.5 liters of oxygen for each liter of hydrogen. Thus you need 2.5 liters of air for each liter of hydrogen for perfect combustion (leaving nitrogen and other atmospheric trace elements).

Assuming the engine has 100% volumetric efficiency, a 2.0L auto engine running at 2500RPM would have a total air intake flow of 150000LPH. Running this engine fully unthrottled at 2500RPM to produce the maximum power would take about 43000LPH of hydrogen gas and 107000LPH of air for stoichiometric operation. The 43000LPH of hydrogen contains about  $43\text{m}^3/\text{h} \times 2.8\text{kWh}/\text{m}^3 = \sim 120\text{kW}$  of power. Assuming 25% engine efficiency you would get about 30kW or 37hp shaft horsepower.

Figure 14 shows the experimental setup that was used for idling a 6.5hp 200cc 4-stroke Honda copy on oxyhydrogen gas. The electrolyzer did not produce enough oxyhydrogen to run the engine continuously, but the oxyhydrogen gas was first collected in a balloon and then used to run the engine. The 7-cell unit was used, powered by a current limited welding transformer running at about 40A producing approximately 200 LPH of gas. The gas was collected for 1-2 minutes which later ran the engine for some 20 seconds. Approximately 600-800LPH of gas would have been needed to idle the engine continuously. The engine timing was not changed in any way. The electrolyzer gas output tube was routed to a propane adapter bolted at the intake of the carb. The oxyhydrogen was admitted thru a narrow (1-2mm) orifice to the intake of the carburetor. The engine ran fully choked, with no outside air used at all. The engine would not run without the narrow orifice or without being fully choked.



Figure 14. 6.5hp 200cc 4-stroke running on electrolytic gas

## Implosion

There is a common misconception that when the engine runs on oxyhydrogen it operates by imploding the oxyhydrogen gas in the cylinders supposedly creating a vacuum that pulls the cylinders up, thus requiring altered engine timing.

One mole of water (~18ml) turns into 33.6 liters of oxyhydrogen gas. Thus you get about 1860 liters of oxyhydrogen for each liter of water, and correspondingly one liter of oxyhydrogen turns into  $1/1860 = 0.53$  milliliters of water.

But you only get a vacuum if the produced water vapor (steam) can condense, and you only get condensation if the combustion chamber is very cold. Steam will not condense on the hot cylinder walls of the engine and you won't get a vacuum in the cylinders as a result of oxyhydrogen combustion.

One mole of water (~18ml) will turn into 33.6 liters of oxyhydrogen at 0 deg C, but when the oxyhydrogen is combusted it will turn into 100 deg C steam. Assuming the steam is at 1 atm pressure, it will occupy a volume of about 30.6 liters (one mole of 100 deg C steam).

In reality the oxyhydrogen gas combusts in the engine just as any gas (even though the flame front proceeds quite fast), creating a rapid pressure/heat increase which then runs the engine.