

Barbecuing with Hydrogen Gas

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Barbecuing with hydrogen is cleaner than using charcoal or propane because there's no carbon in hydrogen. When hydrogen burns, it emits only water vapor and traces of nitrogen oxide. No toxic pollutants, smoke, or particulates are released by a hydrogen flame. When hydrogen is produced by renewable energy, the water-to-fuel-to-water cycle can be sustained virtually forever!



Above: The propane gas barbecue before modification

For generations, barbecue fires have been made from charcoal. Though we also have natural gas and electricity for cooking, these resources are largely based on fossil fuels and are not sustainable. PV produced hydrogen is sustainable. (See HP #39 to see how

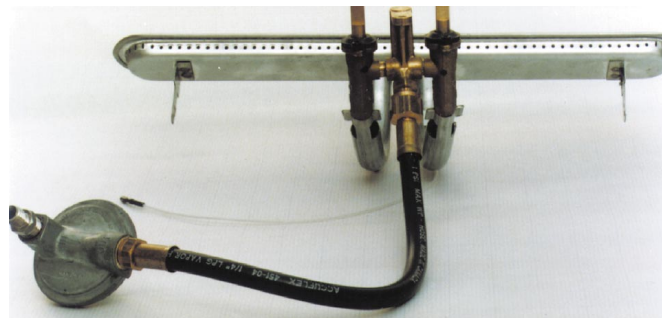
PV electrolysis is accomplished. Cooking with hydrogen also appeared in HP #33.) Air pollution from barbecues is becoming objectionable in densely populated areas. Outdoor cooking is very popular on hot summer days. Unfortunately, that's also when air quality is usually at its worst. Legislation regulating barbecuing has even been enacted in some areas.

Propane Barbecues

Propane barbecues are more convenient and produce less emissions than charcoal models. Propane also eliminates waiting while the coals get hot.



Above: By removing the cooking grill and lava rock support, you can see the stainless steel propane burner.

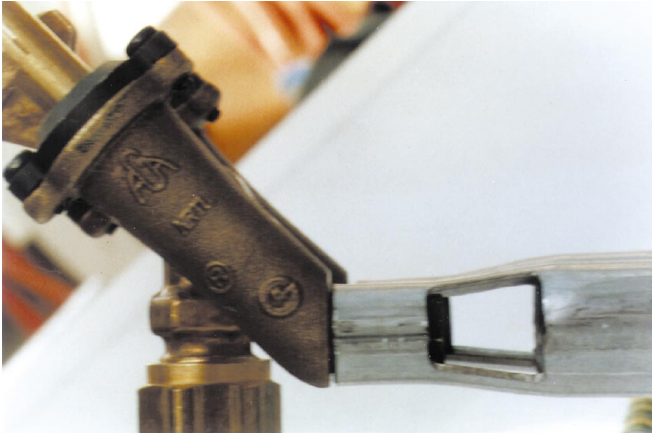


Above: The propane gas supply valves, burner, and pre-mix tubes, and pressure regulator.

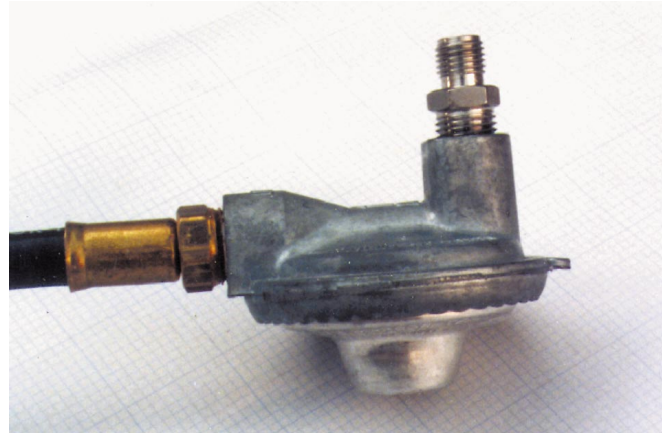
The propane burner is ignited by turning on the gas and pressing the piezo-electric igniter button. A spark ignites the fuel-air mixture escaping from the burner. The flame heats lava rocks, distributing the heat to the grill. Liquids that drip onto the lava will vaporize and burn, shielding the burner from contamination. After cooking is finished, the gas is turned off and the heat stops. The lava cools quickly to ambient temperature.

Gaseous fuel is safer than charcoal in some respects. For instance, there's no need to supervise the fire after cooking. You're less likely to start a fire when a gust of wind comes up and rekindles "dead" coals! There's also much less ash residue. Though propane flames emit carbon oxides and hydrocarbons, amounts are less than from charcoal. Better fuel-air mixing results in less smoke. Cooking time is also shorter with propane.

The propane flow to each burner is controlled by a valve and delivered to an orifice. The orifice limits the gas flow and produces a high velocity jet, which aids fuel-air mixing. The high velocity gas enters the pre-mixer, drawing air through ports on each side of the burner delivery tube.



Above: The propane burners installed in our barbecue use fuel-air pre-mixers.



Above: The gas pressure regulator with Swage lock tubing INLET pipe fitting.

Conversion of a Propane Barbecue to Hydrogen

We started with a two-burner Kenmore propane barbecue. It has 1451 square centimeters (225 square inches) of cooking area and is rated at 24,000 Btu (82 kW) per hour. Sears had it on sale for under \$100.

We converted our barbecue by changing the burners and gas delivery tubes to prevent pre-mixing of the hydrogen fuel and air. Other parts of the barbecue were usable without modification. The covers, grill plates, gas supply line, control valves, pressure regulator, and piezo-electric igniter all worked as purchased. We will use the propane tank in a future hydrogen storage experiment.

Step 1. Feeding Hydrogen to the Pressure Regulator

Remove the pressure regulator from the propane tank. Attach 0.64 cm (0.25 inch) Swage lock stainless steel tubing to a 1/4 NPT fitting. This will replace the original pipe fitting on the "INLET" side of the regulator. We used stainless tubing, but copper or brass tubing and fittings can be used as well. They may also be easier to obtain at your local hardware store.

Set the hydrogen gas supply pressure to about 1 bar (14.5 PSIG) at the pressure regulator "INLET". Most propane-type regulators are rated for 17 bar (250 PSIG) maximum inlet pressure. Do not exceed the rated value. Use safety relief-valves in the piping and storage tank so excessive pressure cannot cause an unsafe condition. A welding-type compressed hydrogen cylinder with two-stage regulator can be used to supply the pressure regulator. For safety, include a shutoff valve to isolate the hydrogen supply from the pressure regulator during idle periods.

Before we continued our hydrogen conversion, we wanted to try the barbecue on hydrogen in its

"propane" configuration. We supplied the pressure regulator inlet with 1 bar (14.5 PSIG) pressure from the hydrogen tank and checked for leaks. Donning safety glasses, we turned on the control valve and pushed the igniter button. The fuel-air mixture in the burner and supply line promptly lit with a loud "BANG" that resembled a firecracker! We weren't surprised. The pre-mixed gas and air was flammable. The velocity of a hydrogen flame is much higher than that of propane. The flame moved backwards against the hydrogen flow. It traveled from the igniter at the burner pre-mix outlets to the orifice at the mixer. The flame burned freely on the open jet of hydrogen coming out of the orifice, heating the pre-mix tube instead of the burner.

The hydrogen diffusion burner and gas distribution plate are designed to prevent the pre-mixing of hydrogen with air. In a gas diffusion burner, fuel is burned without premixing the fuel (hydrogen) with air.

Below A close-up of Hydrogen Burner Showing Gas Diffusion Ring. By coating the surface of the burner pores with a catalyst, nitrogen oxide emissions can be reduced.



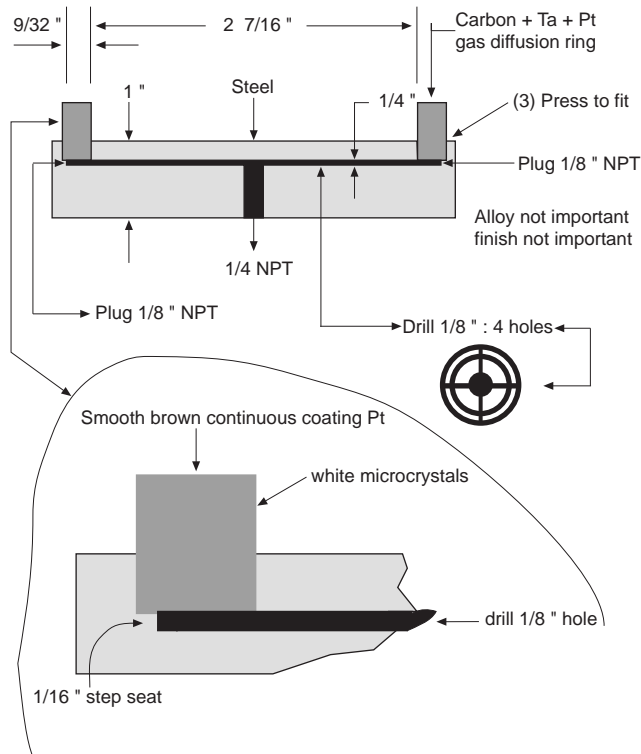
Hydrogen

Pure hydrogen fuel passes out through the porous surface of the burner. The hydrogen and oxygen from the air then mix within the outer pores of the burner. This prevents flash-backs and keeps the flame from propagating from the outer burner surface back into the fuel supply.

Step 2. Making The Burner

Machining the hydrogen gas distribution base from low carbon steel requires the following steps:

- 1) For the gas diffusion ring, cut a circular groove with a shoulder step on the outside. The step prevents the ring from being pressed all the way to the bottom of the circular groove.
- 2) Drill two long holes completely through the steel base at 90 degrees to each other. The holes will connect the gas feed fitting at the center of the burner to four different locations around the circular gas distribution groove.
- 3) Tap the outermost ends of the four holes for 1/8 NPT pipe plugs.
- 4) Tap the center gas feed point of the base to accept a 1/4 NPT-to-stainless tubing supply line fitting.



The burner gas diffusion ring is made from tantalum foam tubing. The rectangular ring segment can be cut with a table saw or chop saw. Another source of the tantalum burner-ring material is automotive air-bag deployment shell diffusers. Besides tantalum, other

high temperature foam materials are also available from Ultramet (see access).

The burner ring is plated with platinum catalyst. Attach the ring to the negative (cathode) lead of a low voltage D.C. power supply. Attach the positive (anode) power supply lead to a platinum wire. Immerse the ring and wire in an electrolyte solution. The solution is made by dissolving 1 gram of platinum in about 20 ml of aqua-regia and diluting to 100 ml with distilled water. Apply 1–2 Amps of current for several hours until the surface of the tantalum ring is coated with a thin layer of platinum.

Press the burner ring into the gas distribution base using a mechanical press. A completed burner is shown in the photo. The lava rocks have been removed from one side for clarity.



Above The burner installed in barbecue

Step 3. The Hydrogen Delivery Lines

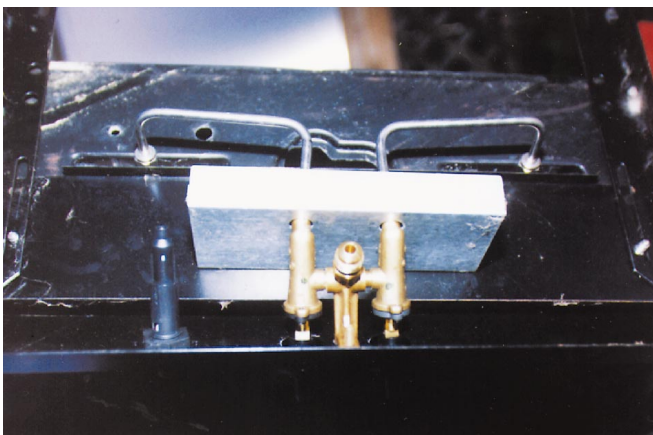
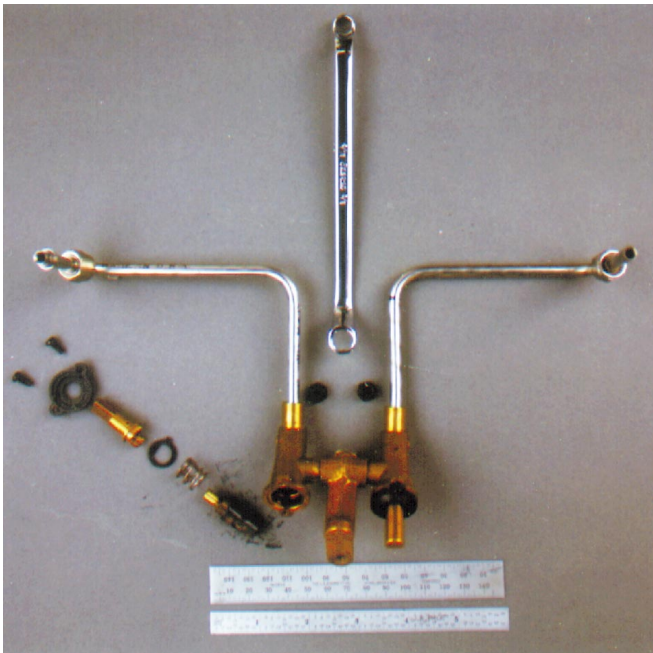
Extend the hydrogen gas delivery lines from the flow valve to the burner with two stainless steel "L" shaped 22.5 cm (9 inch, 0.25 inch diameter) lengths of tubing.

Remove the jets from the valve body using a 10 mm (3/8 inch) box end wrench. Insert the stainless tubing lengths in the former jet holes. Before soldering, disassemble the brass flow valves and remove heat sensitive components and lubricant. Position the stainless tubing sections securely and silver solder them in place. Be sure to put the sheet metal support bracket over the tubes before soldering them into the valve bodies. Also check that the bent sheet metal tabs face away from the valve bodies.

Clean the valve bodies after soldering. Reassemble the heat sensitive stem, spring, and plastic detent retainer. Use silicone stopcock grease as seal and lubricant.

Step 4. Install the Igniter

Install the piezo-electric igniter's insulator and high voltage lead near the new hydrogen gas diffusion



Above: Remove the jets and valve components, before silver-soldering stainless tubing.

Below: The barbecue's underside with burner hydrogen delivery tubes & valves.

burner. It will be used to light the burner. Bring up a ground lead alongside to position the spark gap near the burner gas diffusion ring.

A loud "POP" will occur at the moment of ignition. The hydrogen-air mixture ignites at the spark and will propagate to the burner surface. Thereafter, combustion will occur primarily in the pores of the burner ring.

Safety First!

Hydrogen gas testing should be done outside or in a well ventilated area. Only pure gas should be used or stored. Remember, though hydrogen diffuses rapidly away from a source when released, it's flammable over wider ranges of air-fuel ratios than propane. It must be

handled with respect. Hydrogen safety precautions are given in articles appearing in HP #34 and #35.

Step 5. Testing

Use a soap solution to leak test the tubing connections, pipe fittings, valves, and regulator. Test with about 1 bar (14.5 PSIG) hydrogen gas pressure.

We also tested the completed burner for heat release and nitrogen oxide emissions. A NOx meter was used to sample the burner's hot exhaust gas plume at different positions. We used a Bacharach NONOXOR II with a range of 0-2000 parts per million (ppm) NOx. These meters are used for field testing engine exhaust for emission compliance.



Above: Test setup showing barbecue, NOx meter at 50% hydrogen flow (86 ppm)

At the "LOW" gas valve setting, NOx levels varied from 60-80 ppm in the flame 5 cm (2 inches) above the burner ring. At 12 to 30 cm (5-12 inches) above the burner center, NOx varied from 2 — 6 ppm.

For "HIGH" hydrogen flows, NOx levels varied from 80-160 ppm 2.5 cm (1 inch) directly above the burner ring. At 30 cm (12 inches), the NOx dropped to 36-47 ppm. The NOx increased with increasing flow at all positions. The NOx level also increased as the probe was moved closer to the burner.

At about 50% flow, the cooking temperature was just about right. Fortunately, the heat release can be set to the proper level for cooking on the lava with no further changes to the hydrogen flow valve and valve ports. We reinstalled the rock and food grills and made a NOx measurement at the cooking grill surface above the burner and rocks. We recorded 65-90 ppm at 50% flow and 180-260 ppm at "HIGH" flow.

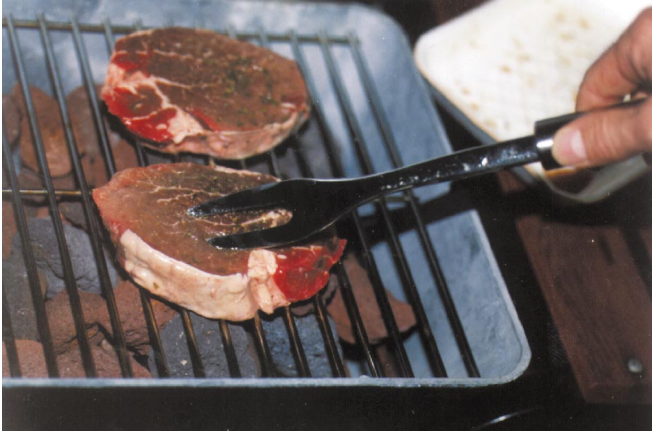
Background NOx released by the hydrogen burner exposes the cook to no more than 2 ppm. The eight hour time-weighted average set by the U.S.

Hydrogen

Occupational Safety and Health Administration (OSHA) is 25 ppm NOx. For reference purposes, our natural gas stove burner ran at mid-range with 15–25 ppm NOx at 2.5 cm. (1 inch) above the natural gas burner flame.

Cooking Tests were conducted: Hydrogen Steaks!!

We tried steaks for our first hydrogen barbecue as seen in this picture.



Above: Cooking Steaks on Hydrogen Gas Barbecue

Endurance testing is needed to determine the lifetime of the burner. Some burner ring “break-in” has occurred. After several hours of operation, the sharp edges of the gas diffusion ring have become rounded by excessive heating. Whether this will stabilize remains to be seen. Lifting the rock grill higher above the burner ring will probably reduce the reflected heat reaching the burner ring from the glowing lava.

Possible Future Improvements and Measurements

- 1) Coating the steel base to prevent rust caused by combustion water condensation at startup and “LOW” hydrogen flows.
- 2) Venting the lid to prevent the buildup of an explosive mixture. This could occur when the gas is “on”, the cover is closed, and ignition has not yet occurred. An interlock could be used to prevent hydrogen from flowing to the burner when the barbecue cover is closed and the flame has not yet been lit.
- 3) Measuring the flow rate of the hydrogen gas delivered to the burner at different valve settings.
- 4) Measuring the temperature of the burner surface at different hydrogen flow valve settings.

Acknowledgements

Ultramet, for the foam tantalum and silicon carbide tubing samples.

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Access

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Diffusion Burners for Hydrogen: Fraunhofer-Gesellschaft Institute for Solar Energy Systems Tel: (Freiberg, Germany) 49-761-4014-0 Ext. 164 or 210. FAX: 49-761-4014-100

Diffusion Ring Tubing: Ultramet, 12173 Montague Street, Pacoima, CA • 818-899-0236 FAX 818-890-1946

Chemical supplies (platinum powder and wire, aqua-regia): Aldrich Chemical Co., 1001 W St Paul Ave, Milwaukee, WI 53233 • 800-558-9160



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