A Home-Built Biomass Gasifier for Producing Wood Gas

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Intro: A Home-Built Biomass Gasifier for Producing Wood Gas

I've built a lot of alternative energy projects over the years.

I've always wanted to build a wood or biomass gasifier too. Why? Well, the internal combustion engine is really an important part of our society and the basis of a lot of our transportation and portable power technology. It isn't going to be going away any time soon. I've mastered making my own electricity from the sun and wind, but that doesn't help my truck go down the road, power the lawn mower, or run my generator on cloudy, windless days.

Those all have internal combustion engines, and they all need fuel to run. I finally decided it was time to master making my own fuel. Why pay the Arabs for it if I can make a working substitute myself?

So what is a biomass gasifier? Basically is a chemical reactor that converts wood, or other biomass substances, into a combustible gas that can be burned for heating, cooking, or for running an internal combustion engine.

Gasifiers are an old, but generally overlooked alternative energy technology. Few people these days realize that gasifiers were used extensively by both sides during WWll to power cars, trucks and buses during fuel shortages. Gasifier technology rapidly evolved and matured during the war.

Gasification is achieved by partially combusting the biomass in the reactor, and using the heat generated to pyrolyse or thermally break down the rest of the material into volatile gasses. A well built gasifier will convert wood or other cellulosic biomass into the flammable gases Carbon Monoxide and Hydrogen.

My goals here were to build a gasifier using easy to obtain materials, that would run on readily available fuels, and would produce enough gas to at least run a small generator or other machine powered by an internal combustion engine. In this step-by-step guide I am presenting the finished product (so far) that has resulted from many months of experimentation and modification.

Step 1: **How Does The Gasifier Work?**

There are no pretty pictures or informative diagrams in this step. This is the stuff you need to read before attempting to build this project. Please don't skip it.

A word of warning here. This project is dangerous. The operation of a biomass gasifier produces lots of heat, also lots of flammable and poisonous gases. Never operate the gasifier indoors. The gases produced are flammable and potentially explosive if allowed to accumulate in an enclosed space, like a building. Also, the Carbon Monoxide the gasifier produces is lethal! Only operate the gasifier outdoors and try to stay up wind of the unit when it is running.

Treat the gas coming out of the gasifier with the same respect as you would for the natural gas that you may have piped into your house. It is just as potentially explosive and deadly.

As I said in step 1, a biomass gasifier is a chemical reactor that converts wood, or other biomass substances, into a combustible gas. The formula is simple. Biomass +Heat = Pyrolysis Byproducts . Pyrolysis is a fancy-pants word that chemists use to describe the process of heat breaking down big molecules into smaller ones. In the gasifier we want to break big biomass molecules (mainly cellulose) down into smaller ones like Hydrogen and Carbon Monoxide.

Where does the heat come from? We get heat by partially combusting some of the biomass with a limited supply of Oxygen. The heat produced by the combustion then drives the pyrolysis reaction. A well built reactor will also convert combustion byproducts like CO2 and water vapor into flammable CO and H2 by passing them over a bed of hot charcoal, left over from the partial combustion, where they will get reduced.

Thus the gasifier converts most of the mass of the wood (or other biomass feedstock) into flammable gases with only some ash and unburned charcoal (bio-char) residue. That is the theory anyway. This is an extreme over-simplification of how the gasifier really works. Wood and other biomass is made of incredibly complex macromolecules like Cellulose and Lignin that break down into hundreds or thousands of different smaller molecules as the reaction proceeds. There are thousands of different complex chemical reactions going on inside the reactor. The overall result though, if the gasifier is working well, is lots of clean, flammable gas.

Ideally, the gasifier would break down biomass into nothing but Hydrogen and Carbon Monoxide. Here in the real world though, things rarely work ideally. The dirty (literally) little secret about biomass gasification is tar production. Above I said that the macro-molecules that make up biomass get broken down into smaller molecules.

Some of those smaller molecules are still pretty big though. If the gasifier is working well, these big breakdown by-products will be further "cracked" into smaller molecules. If the gasifier isn't working so well, these big molecules will wind up in the gas being produced. They will condense out of the gas as a thick, sticky, black, semi-liquid that very closely resembles roofing or road tar, but is even stinkier. Even a well-built gasifier produces a small amount of tar. Most real-world applications (like engines) can't handle much, or even any, tar. My struggle to design and build a working biomass gasifier could actually be accurately described as an ongoing battle to reduce tar production. The first few iterations of this gasifier produced more tar than gas.

Below is the most important of all chemical reactions a novice gasifier builder needs to know.

Biomass + Poorly Designed Gasifier = Tar!

I strongly recommend that anyone interested in gasifier technology do some research and read up on it. There is a lot more to this technology than I can present in this plan.

Step 2: Schematic of the Gasifier

I know, it is a busy and confusing drawing. Don't panic though. It isn't as bad as it looks. There is actually more to the finished design than this, but this is a good place to start. More complexities will be introduced in later steps. I strongly suggest you read through the entire plan before attempting to build your own gasifier.

Dimensions are not critical for most things. I do give a few dimensions here and there where it is important. However, you don't have to worry about slavishly copying my unit in every minute detail in order to make a gasifier that works. I improvised my unit from found materials and made it work by tweaking it over time. You could almost certainly do as well (maybe better) yourself with completely different materials. Feel free to experiment.

Back to the schematic. Basically, the outer shell of the gasifier is just a 5-gallon steel drum. The drum must be steel because of the extreme heat generated during the gasification process. The drum collects the gas that is generated. The gas exits through one of the drum's bungs. Ash and char produced collect in the bottom of the drum. An access door cut in the side of the drum allows for periodically cleaning out the ash and char. The solid by-products remaining in the bottom of the drum is known as bio-char. It is often used to improve poor soils.

A stainless steel tube 4 1/4 inches in diameter serves as both fuel hopper and reaction tube. There is a constriction in the tube near the bottom. A perforated stainless steel grate at the bottom of the tube prevents the contents from just spilling out the bottom. The grate can move, and is shaken periodically during operation to allow ash and char to exit the reaction tube and allow fresh fuel to fall into the reaction zone. The gases produced travel downward and exit through the shaker grate. So this type of gasifier is called a downdraft gasifier.

Six j-shaped copper tubes pipe air into the reaction zone at the base of the stainless steel tube. Since the outer drum is full of hot gas during operation, the long j-tubes also pe-heat the air before it goes into the reaction tube.

The entire core assembly consisting of the reaction tube, j-tubes, and shaker grate can be removed from the outer drum for easy maintenance and for making modifications.

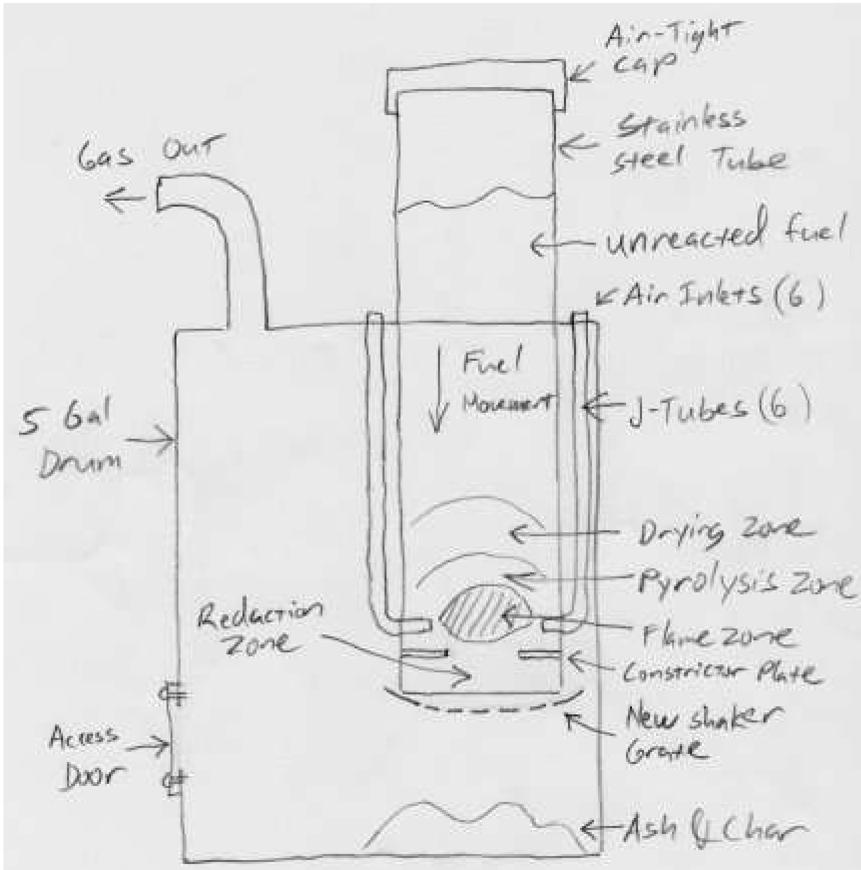
In operation, air enters the reactor through the j-tubes and is pre-heated as it moves downward. Combustion of the biomass occurs in the flame zone between the j-tubes.

Radiant heat from the combustion drives pyrolysis reactions in the pyrolysis zone. Lower-grade heat further up dries the fuel in the drying zone. A constriction just below the flame zone forces gases produced in the pyrolysis zone to pass through, or at least very near the flame zone to exit the reactor. This helps thermally crack the tars.

Hot charcoal exiting the flame zone moves down into the reduction zone between the constriction and the shaker grate. Combustion gases leaving the flame zone get reduced in the hot charcoal. Shaking the grate periodically allows ash and spent char to sift through the holes in the grate, and drop off the edges of the grate. This allows fresh fuel to move downward through all the zones.

Originally I used a motorized blower attached to the gas outlet pipe to pull air through the gasifier. Later I built a manifold connecting the tops of all the j-tubes and used compressed air to run the gasifier. Ideally the gasifier would be driven by the manifold vacuum from an engine it is supplying fuel gas to.

More on all this later. Go to the next step to start building the gasifier.



Step 3: The Structure of the Gasifier

I tried to use inexpensive and easy to find parts to build the gasifier. At the beginning of this project I did not have regular access to a welder, so I tried to minimize the amount welding necessary. It should be fairly easy for any well-equipped, backyard tinkerer to build a gasifier like this.

1st Photo:

The basic structure of the gasifier is built around a 5 gallon steel drum, and a stainless steel tube 4 1/4 inches in inside diameter, and 14 inches long. These dimensions are not really critical. The tube could be a little longer or shorter, and a little wider or narrower in diameter. I got the drum at work. We use a variety of chemicals that come in small metal drums like these, and we always have a lot of empties around. The stainless steel tube came from a scrap yard. It was a little pricey. I have since discovered that many fire extinguishers have stainless steel bodies that are about the right size for use in a gasifier. Old fire extinguishers are easy to find and cheap.

The purpose of the drum is to be the main body of the gasifier unit. It contains everything and collects all the gas, ash and char the unit will produce. The smaller of the two bungs on the drum will be the gas outlet. The stainless steel tube serves several purposes. The bottom of the tube will be the reactor where the gasification takes place. The remainder of the tube is a hopper for holding un-reacted fuel. The tube will be subjected to very high temperatures and corrosive gasses. Stainless steel is the obvious choice here.

2nd Photo:

I started by cutting a large hole in the top of the drum so the stainless steel reaction tube can be inserted. The hole was made very oversized so that the entire core of the gasifier will be easily removable. The hole is offset to the side of the drum opposite the small bung. The large bung was sacrificed, since I wasn't planning on using it.

3rd Photo:

Next I cut a flange from a piece of 1/8 in steel for mounting the reaction tube into the drum. The flange is large enough to completely cover the large opening in the top of the drum. The hole in the flange is just the right size for the reaction tube to slip snugly through.

4th Photo:

I installed clip nuts on the corners of the hole in the top of the drum, and drilled mating holes in the above flange. This would allow me to bolt the flange down to the top of the drum. My idea here was to make the core of the gasifier easily removable for service and modification.

5th Photo:

Here is the access door in the side of the drum. I cut a rectangular hole in the side of the drum just big enough for me to get my hands inside to clean out the ash and char. then I cut a larger rectangular piece that would overlap the opening on all sides out of another drum to serve as the door. The door is held in place with six more clip nuts and bolts and sealed with lots of high-temp silicone gasket material.

Step 4: Mounting the Reaction Tube

1st Photo:

I made some angle brackets out of aluminum and used them to bolt the reaction tube to the flange. I left 6 1/2 inches of the reaction tube sticking up above the flange.

The rest protrudes down into the drum. At this point in the project I did not yet have access to a welder. Even if I had one, I'm not sure I could have welded the mild steel flange to the stainless steel reaction tube anyway. Here the unit is being test fit on top of the drum. The holes in the ends of the angle brackets align over the clip nuts in the top of the drum.

2nd Photo:

This is my new best friend. I went through several tubes of this high temperature silicone gasket material. I used it to seal every crack, crevasse, joint, seam and bolt hole in the gasifier. It works great.

3rd Photo:

Here I have used the gasket material to seal the gap between the flange and the reaction tube. I put a bead of the silicone around both the top and underside of the gap.

4th Photo:

Here I am doing another test fit to make sure all the bolt holes line up with the clip nuts in the top of the drum. When mounted for real, a bead of the high-temp silicone gasket material between the drum and flange will seal it air-tight. I have also installed a ball valve on the small bung. The valve ensures that I can completely seal off the gasifier when it is shut down.

5th Photo:

The top of the reaction tube needs to be capped with an air-tight cap during gasifier operation. This is a rubber cap for PVC pipe I found at a hardware store. It is actually meant for a slightly smaller OD pipe than the reaction tube. So it is a really tight fit, even without using the clamp that was included with the cap. The cap can be easily removed for loading fuel.

Step 5: Installing the J-Tubes

The design of the gasifier evolved over time. The j-tubes were not part of the original design, and were added later when it was discovered they were needed for the gasifier to work better. So that is why the gasifier looks well cooked and encrusted with lots of red silicone in these photos.

1st Photo:

Here I have installed the six j-tubes. They are made of 3/8 inch copper tubing. They are called j-tubes because they are shaped like the letter J. I used a large hose clamp cinched down tight to hold the tubes in place. The opening in the top of the drum needed to have a few notches cut in it to accommodate a couple of the j-tubes that stuck out too far.

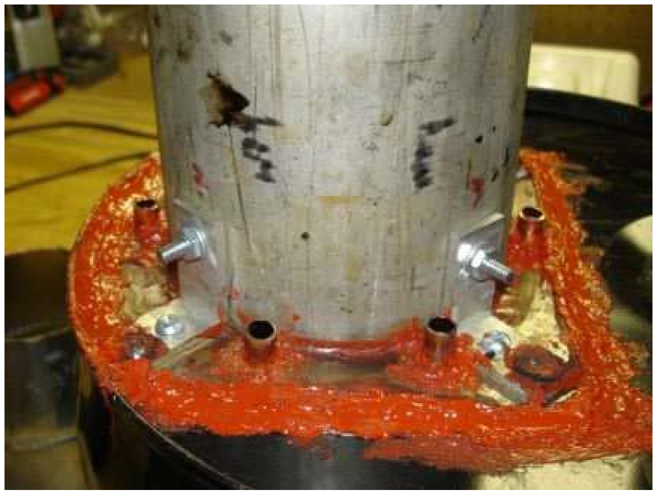
This photo also shows the chains that suspend the shaker grate. More on that later.

2nd Photo:

Here is a look up the bottom of the reaction tube at the business ends of the j-tubes. Copper is probably not the ideal material to use to make them, since at least in theory, the temperature at the point the air is injected could be high enough to melt them. So far my gasifier doesn't seem to get anywhere near that hot, and the copper is holding up well. However, in my next gasifier, I will probably make at least the tips of the air inlets out of steel. Copper is just so much easier to bend and work with compared to steel tubing.

3rd Photo:

Here is a photo of the top of the partially assembled gasifier showing the tops of the j-tubes poking out of a sea of red silicone gasket material. It's a little messy, but to me it was a thing of beauty. If you are following in my footsteps and trying to build your own gasifier based on my design, I recommend you extend the j-tubes at least a couple of inches above the flange. This is a change that will make your life easier in later steps when it is time to make a manifold to connect the tops of all the j-tubes together. I did it the hard way, but you don't have to.



Step 6: The Restrictor Plate

We aren't talking NASCAR racing here. This is a different kind of restrictor plate. The gasifier has a restriction just above the bottom of the reaction tube, immediately below the j-tubes. The purpose is to force all the gases exiting the gasifier to pass through he hottest part of the reaction zone. This will cause tars to be cracked by the heat. My first restrictor plate was too big. I made it smaller after doing some testing.

1st Photo:

Here is a view of the original constrictor plate I made. By this point in the project I had my own welder (Yahoo!) and was getting somewhat proficient at using it. To make the plate I cut a circle out of 1/8 inch sheet steel that would fit in the bottom of the reaction tube. Then I cut a 2 1/2 inch diameter hole in the center of the circle. To mount the constrictor in the reaction tube, I welded three 1/4-20 nuts to the plate, and drilled passage holes in the reaction tube for three 1/4-20 bolts.

2nd Photo:

Here is a view of the constrictor plate installed in the bottom of the reaction tube. Building it this way made it easily removable. I had a feeling I might need to modify it.

Turns out I was right.

3rd Photo:

After some testing I reduced the size of the constrictor plate. Now the opening is only 1 1/2 inch in diameter. The theory here is that by making the restriction smaller, the tar has to pass through the hottest part of the reaction zone and gets cracked. My original larger opening was allowing tar to sneak out without passing through the hottest zone just below the j-tubes.

Step 7: The Shaker Grate

The shaker grate hangs about 1/2 inch under the bottom of the reaction tube. It prevents material from just falling out of the bottom of the tube. It also holds hot char exiting the bottom of the reaction tube. Gases exiting the bottom of the reaction tube have to pass through this layer of hot charcoal and get reduced. Shaking the grate periodically allows fine char and ash to sift out through the holes in the grate. Since the grate is hung about 1/2 inch below the bottom edge of the reaction tube, larger pieces of char can also exit off the sides of the grate. By the time char makes it to the edge of the grate it is too cool to further reduce the gases, so it can be ejected by shaking to make room for fresh, hot char.

1st Photo:

Note that the core assembly is upside-down in this photo. Here I have installed the shaker grate. I made it by cutting the bottom out of a stainless steel colander I bought cheap at a yard sale. The colander already had a lot of holes in it, but I drilled quite a few more in it as well. If I had it to do over again, I'd make even more and bigger holes. The holes should be just small enough that the fuel pieces can't fall through until they have been well cooked and reduced in size. The grate is suspended under the bottom of the reaction tube by four chains. This allows the grate to move with respect to the reaction tube so I can shake it from time to time to promote flow through the system.

2nd Photo:

This photo shows how the other ends of the chains are attached to the bolts on the bottom of the flange. I used ring terminals crimped onto the ends of the chains. When the core assembly is inverted and inserted into the drum, the shaker grate will hang from the chains below the reaction tube.

3rd Photo:

Here is a look down the reaction tube from the top. Past the ends of the j-tubes and the constrictor plate is the shaker grate at the bottom.

4th Photo:

I attached a length of stainless steel wire to one of the chains of the grate and ran it outside the drum through a tiny pinhole drilled in the side of the drum just above the access door. The hole is so tiny that not much gas escapes the drum. Tugging on the wire makes the grate shake and twist. It is not an ideal system, but it seems to work.

5th Photo:

I put a ring on the outside end of the wire to make it easier to grip so I can easily tug on it to shake the grate. I normally shake the grate every few minutes during operation.

Step 8: Making the Air Manifold

Drawing:

Here is another drawing showing the gasifier in its final (so far) form. If I had been thinking in the beginning, I would have made the tops of the j-tubes stick up enough so that they could all be connected together with standard copper pipe fittings to make a manifold. Unfortunately, I wasn't thinking that day. So later, when I came to the realization that I needed to connect all the j-tube inlets together, I had to come up with another idea. Those of you trying to build your own gasifier should just extend the jtubes a little and plumb them together. Don't do it the way I did unless you are a glutton for punishment. My improvised manifold is always springing leaks, and tends to break loose when I remove the core assembly from the drum.

Ignore the part of the drawing that says "extended reduction zone" since that is an experiment I tried that didn't really produce any benefits.

1st Photo:

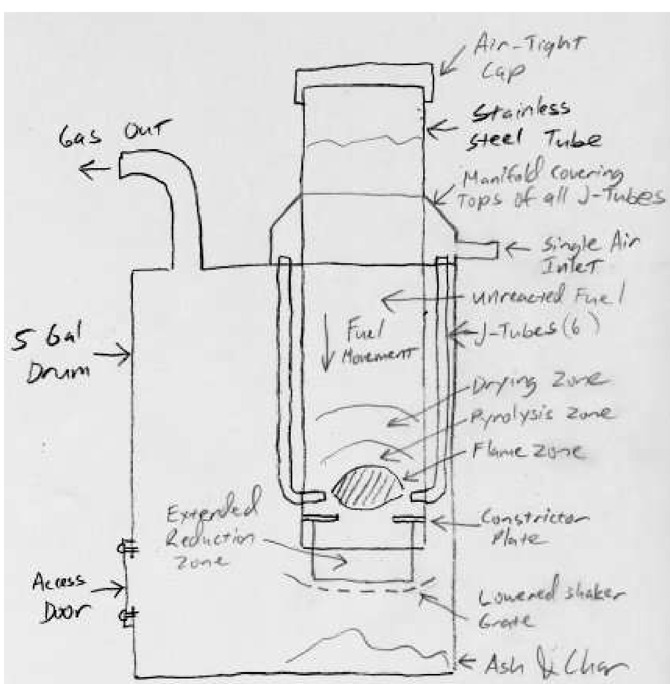
Here is the manifold I made to cover the inlets of all six j-tubes. It was cut from a 6 in to 4 in steel AC duct reduction fitting. It slips down over the reaction tube and gets siliconed to the top of the flange. A single air inlet fitting will be installed on the side of the manifold.

2nd Photo:

Here is the new single air inlet on the side of the manifold. I used a Tee fitting. One leg of the Tee goes into the manifold. One leg has a hose fitting installed that I can use to inject compressed air. The third leg of the tee is plugged for now. My idea here was that I could start the gasifier on compressed air, then once it was running, I could unscrew the plug, and let engine vacuum pull air through the gasifier (from whatever engine the gasifier eventually gets connected to).

3rd Photo:

Here is the manifold in place on the gasifier. Everything is all buttoned up and sealed with yet more great gobs of red silicone gasket material.



Step 9: The Fuel

I failed to do a lot of basic research about gasification before just diving in and trying to build a gasifier. So I wound up repeating a lot of the same mistakes other people made before me. So this gasifier went through many versions, re-designs and re-builds before getting to this state.

One early mistake I made was poor initial choice of fuel. It turns out gasifiers are finicky about what you feed them. They like fuels that are uniform in both particle size, shape and composition. Non-uniform fuels produce lots of gunky tars. My first choice of fuel was about as bad as it gets. I tried to run the first version of the gasifier on wood mulch.

1st Photo:

My dream fuel for the gasifier in the early days was free wood chips and mulch available from lots of places nearby. I know of at least three places I pass on a regular basis that have signs offering free wood chip mulch to anyone who would come and haul it away. There are probably dozens of other sources I could find with a little research. So I got myself a bag of wood chip mulch. The chips were very wet. So here I am drying them with a fan. After 2 weeks under the fan, they were bone dry and ready to burn in the gasifier. I realized that if this worked, I'd have to find a less energy intensive way of drying the wood chips in the future. But it didn't work. The gasifier didn't really work at all on wood chips. The non-uniform size and shape of the chips, combined with their mystery composition led to terrible problems. The chips didn't feed right, didn't burn right, didn't pyrolize right, and often wouldn't even burn at all. When the gasifier was running on these chips I got far more tar than gas out if it. Out of frustration I hit the books to try and figure out what the problem was. That's when I learned about gasifier fuel needing to be uniform to work well. So I started groping around for a better fuel option.

2nd Photo:

I thought wood pellets would be a good fuel. So I settled on hay pellets. I could get them from feed stores. They are more expensive than I would have liked, but they didn't break the bank for testing purposes. with their uniform shape, size and composition, they seemed like a reasonable substitute for wood pellets. The gasifier worked much better on hay pellets. There was more gas and less tar. The pellets fed nicely through the reaction tube and exited as little beads of char. I could start seeing the potential of this machine.

3rd Photo:

I finally found some wood pellets. On one of my trips to my Arizona property, I bought back two 40 pound bags of wood pellets. They were dirt cheap too. Less than $6

Step 10: Getting Air Through the Gasifier

Air must flow through the gasifier for it to operate properly. In normal operation, the manifold vacuum of whatever engine the gasifier is connected to will pull air through the gasifier and keep the reaction going. When first starting up a cold gasifier, or testing a unit not attached to an engine, there must be another method of forcing air through the gasifier.

1st Photo:

Most gasifier projects I have seen use a blower to pull air through the unit. It is usually used to start the gasifier, then once running, the vacuum from the intake of the engine the gasifier is meant to power keeps the gas flowing. I initially chose this method too. This blower is a little under powered. However, it was the only all metal blower I could find at the time. Most blowers these days are full of plastic parts. The plastic would melt at the temperatures the gasifier operates at. So I made do with my undersized blower. I actually had some success with it.

2nd Photo:

This photo shows the jet of gas coming out of the blower ignited and burning nicely. The blower worked, but it was very undersized. the gasifier wasn't heating up to optimum running temperature because it was starved for oxygen. To get good performance out of the gasifier I knew I was going to have to increase the air flow. I looked into buying a larger blower, but powerful all-metal models were rare and very expensive.

3rd Photo:

Then I had a brainstorm. I have an endless supply of compressed air in my workshop. So why not blow compressed air through the gasifier, rather than using a blower to pull it through? So I scrounged up a pressure regulator, a valve and some hose and hooked it all up. This is the idea that forced building the manifold to connect the inlets of all the j-tubes together several steps back.

4th Photo:

This photo shows the air hose from the regulator attached to the air inlet of the gasifier. I am using a piece cut from a silicone cooking sheet as a heat shield to protect the hose from melting where it touches the hot drum.

The compressed air really worked great. The gasifier starts up almost instantly, and gets much hotter than before. The quality of the gas has greatly improved.

Step 11: The Flare Stack

Eventually I had the gasifier working well. It was making lots of gas and hardly any tar. Everything was working great. The gasifier was producing a huge volume of gas.

The problem is that this gas is flammable and toxic. I needed to burn or flare off the gas to keep it from being an explosion or health hazard. Just lighting the jet of gas coming out of the outlet pipe of the gasifier didn't really work very well because the wind would quickly blow out the flame. I decided I needed a better way of flaring off the gas. So I bodged together a quick and dirty gas burner.

1st Photo:

After some experimenting, I determined that the gas needed to be mixed with the air to properly burn, and a flame holder was needed to prevent the wind from blowing out the flame. My flare stack is made from an old tin can and a stainless steel vegetable steamer. I just drilled a bunch of holes in the bottom of an 18 ounce steel can, and bolted it on top of the gas outlet pipe. I then put an old stainless steel vegetable steamer over the open top of the can. It works great as a burner. The flame doesn't blow out even in very strong wind gusts. I increased the stack height to prevent the heat from the burner from cooking the rubber and silicone parts on top of the gasifier.

2nd Photo:

Here you can see the bottom of the burner. It is just an old 18 ounce bean can with lots of air holes punched in the bottom. It sits on top of the outlet pipe of the gasifier and the gas enters through a large hole in the center of the can bottom. The top of the can is open. The gas and air mix inside the can.

3rd Photo:

This photo shows the stainless steel vegetable steamer sitting upside-down on top of the can. There are three screws that go into the can. The steamer is wired to these screws with stainless steel wire to keep it in place. This setup works great as a gas burner. It didn't cost anything and took almost no time to build. The burner holds the flame even in very strong winds.

Step 12: Starting the Gasifier

My method of starting up the gasifier takes a few minutes, but it starts producing relatively clean gas quickly.

1st Photo:

I begin with hardwood lump charcoal. This sort of charcoal starts easily and burns very hot. Briquettes might work, but I haven't tried them. They would need to be broken up into small pieces. The lump charcoal is soft and breaks up easily.

2nd Photo:

I break the charcoal up into small bits. Here the bits have been placed in a stainless steel vegetable steamer and I am using a propane torch to start the charcoal burning.

The small bits of charcoal rapidly catch and quickly heat up. Once the charcoal is good and hot, I dump enough down the reaction tube to fill it from the shaker grate up to the j-tubes.

3rd Photo:

Then I fill the reaction tube up the rest of the way with wood pellets and put the cap on the end of the tube. The bed of hot charcoal in the bottom of the reaction tube really jump starts the gasification process.

At this point I can open the valves and start the air flow. Within a couple of minutes the gas coming out the flare stack will support combustion.