

# The “Jolly Roger Ovens” family of Biochar-making devices

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## Introduction

There are many designs for devices that pyrolyze biomass and leave a carbonized solid behind – the char - usually called either charcoal or biochar. When labeled “charcoal”, one is likely intending to use the char for cooking. When called “biochar”, one is implying that the ultimate use of the char will be as a soil amendment.

We are of the school that better biochars are made at significantly higher temperatures than most cooking charcoals because, as reported in the biochar literature, these higher temperature chars will exhibit higher adsorption capacity. As such, the devices intended to convert biomass into biochar have to be able to reach higher temperatures than their charcoal-making relatives. This involves both the design and operation of the devices. The intent of this discussion is to share some details involved in making and operating a family of devices we are calling “Jolly Roger Ovens” or J-ROs for short (pronounced “Jay-Rose”).

Without belaboring the origin of the concept and name, we would like to acknowledge the contributions of many biochar enthusiasts. They know who they are and they are appreciated. The Jolly Roger Oven approach to making biochar is an open architecture and all are invited to contribute to the common knowledge. Please don't take things away and claim them as your own. Even then, if you do, as pirates, we will just steal your ideas and use them as we see fit – such is the way of carbon pirates.

“Carbon pirates bury black gold...so future generations will be richer.” - John Rogers.

A companion video is available at: <http://www.youtube.com/watch?v=Kg95KYrH8PI> or by searching the keywords "Jolly Roger Ovens Biochar".

## Biomass considerations, utilizing Wood Gas and Draft control in J-ROs

The basic concept of Jolly Roger Ovens starts with a scaled up version of the TLUD micro-gasifier. TLUD technology is popular in improved cookstove designs, where the biomass is gasified to char and the wood gas is burned to provide a clean source of heat for cooking (see <http://www.gtz.de/de/dokumente/giz2011-en-micro-gasification.pdf>). As in the case of TLUD cookstoves, it is possible to produce biochar by stopping the burning process when the descending pyrolysis zone reaches the bottom of the column of fuel, having been initially lit at the top.

One of the features of TLUDs is a relatively uniform heat output for the bulk of the time the descending pyrolysis zone is converting biomass to char and generating wood gas. Whereas in the past, this uniform source of heat has been used for cooking food, in J-ROs this heat can be used to “cook” a retort. Just as an oven bakes dough into bread, a Jolly Roger Oven can bake biomass into biochar. Thus, in one variation of the J-RO, we mount a retort oven over a TLUD

heater. The label of “Oven” implies a larger device than a cook stove, but well short of the potentially massive industrial versions of kilns and retorts. To date our largest combination has been a 30-gallon retort over 55-gallon TLUD.

When operated in this “retort over a TLUD” mode, the J-ROs simultaneously create two biochars, a retort biochar and a TLUD biochar. An added versatility of the J-RO lies in the fact that TLUDs and retorts generally consume biomasses with different qualities. TLUDs require small pieces that are randomly packed into a column of fuel, whereas retorts generally perform better with larger and/or longer stalks and limbs, more loosely packed, as shown in Figure 1.

Larger retorts depend on internal convection currents to distribute the heat within the retort chamber. This is why retorts do not function well when packed with wood chips, in that there is too little internal circulation to move gases and heat. As such, many fuels that do not work well in retorts may be good candidate fuels for TLUDs, such as shown in Figure 2, and visa versa. As an added feature, on a dry biomass basis, the yield of retort biochar is generally about twice the yield of TLUD biochar (discounting the additional fuel to heat the retort). With a little planning of what biomass goes where, the J-RO has the potential to process many combinations of biomass and produce a wide variety of biochars.



**Figure 1** Various retort chars



**Figure 2 TLUD char (from shredded pallet wood)**

In addition to fuel shape, the TLUD and the retort have different tolerances for residual moisture in the biomass. In theory, a retort can tolerate any incoming biomass moisture, since one just keeps supplying heat until the moisture boils off, then the biomass carbonizes. And indeed, in the J-ROs, there is some flexibility as to biomass inputs and moisture levels in the retort. The major restriction, as mentioned above, is that the biomass cannot pack too tightly and prevent the circulation of gases – both hot vapors to reach the cold biomass and pathways for steam and volatiles to exit the retort. Another consideration is to match the retort process time to the TLUD run time or plan on multiple TLUD runs to fully char the biomass in the retort. This involves the size, shape, density and moisture level of the biomass pieces in the retort as well as the characteristics of the TLUD.

Until the retort begins producing wood gas, the retort is heated by the combustion of the wood gases exiting the top of the TLUD. During this time, there is a need to match the heat generation of the TLUD to the heat consumption of the retort and the draft characteristics of the entire J-RO. Ideally, one wants the TLUD flames to cover the bottom and extend up the sides of the retort. The best way to manage the TLUD flame characteristics is by providing additional air, both primary and secondary with small fans or blowers.

Once one makes the leap to forced draft TLUDs, new opportunities of control and performance become available – the best of which is that the fuel does not have to be as dry. Having said that, drier fuel is always better, since it is always advantageous to minimize the energy required to evaporate water. Still, with a little help from a fan or blower, any reasonably dry biomass (in small, randomly packed pieces) can be used in the J-RO TLUD.

There is a price to be paid though, and that is the char yield. TLUDs run on bone dry fuel can yield (by weight) up to 20% biochar. The same TLUD using the same fuel, but with 10% moisture, might get 15% biochar yield – since some of the char is oxidized boiling off the water present. At 20% moisture, the yield falls to around 10%, with more char being consumed to evaporate more water. At some point, there is negligible surviving char, but the forced draft TLUD has managed to use a relatively wet biomass as a fuel. With increasing moisture levels,



there is an increasing requirement for Forced Air – to burn the char necessary to evaporate the additional moisture. In TLUDs, as in life, there is no free lunch.

### **“Bigger and Better” components utilized in the J-RO**

The intrinsic design quality and economy of mass produced steel drums and pails greatly simplifies creating J-ROs. Since we want some mechanical integrity built into the starting components, we take care to select sound vessels and other components – don’t fool yourself that a disposable grease drum from the local mechanic, which has the wall stiffness of a beer can, is going to survive the temperatures necessary to make quality biochar. Additionally, we do not recommend hand fabricating equivalent size containers. The most dangerous situation for a J-RO would be a structural failure, such as a wall buckling, during a burn. Don’t worry about any paint – it will burn off, but do worry if the drum or pail is excessively rusted or weakened in any area.



**Figure 3 The “30 over 55 J-RO”**

A representative “30 over 55” J-RO is shown in Figure 3.

This J-RO has a 55-gallon TLUD heating a 30-gallon retort, with a 55-gallon heat shield and 12” dia x 42” tall stack on top. The 55-gallon TLUD has supplemental primary air being supplied to the concrete block base, in addition to secondary air being blown into the center of the bottom of the 30-gallon retort. There is an angle iron drum rack that centers and stabilizes both the 30-gallon drum and the upper 55-gallon drum.

In the photo, the “30 over 55 J-RO” is operating, as evidenced by the bright yellow flames visible between the two 55-gallon drums. As can be seen in the photo, there is little or no smoke coming out the top chimney of the J-RO. Brief intervals of smoke, especially when the TLUD is initially lit, are common but short-lived when operating J-ROs. Smoke is an indication of too little combustion air and the forced air should be increased, if possible.

Now let's focus on the specifics of individual J-RO pieces – the modifications of the drums, the construction of the supports that stabilize the retort drum stacked on top of the TLUD drum and the small fans and blowers that make the clean operation of the J-ROs possible.



**Figure 4 Modified Drums and support racks for the J-RO**

Figure 4 shows three details: the modification of the bottom of a retort drum, the rack to stabilize the drums and a stack inserted in the lid of a drum (note: the drum on the right is an open head 55-gallon drum, with the lid sitting without the attachment band on the open top of the drum).

The left drum is a 30-gallon open head drum standing with the opening down, so the slits have been made in the bottom of the drum. The slits, as shown, are evenly spaced and in a random pattern – and there are not too many. The idea is to provide a uniform set of slits for the gases to pass without overly weakening the drum bottom. The slits also provide room for the metal in the drum bottom to expand when heated. This expansion results in the slits getting wider due to misalignment of the two sides after the drum is heated a few times. This widening of the slits is normal and perfectly acceptable for the operation of the J-RO.

The slits are made with either an angle grinder or a circular saw, using a metal-cutting blade. The slits can also be made with a cold chisel, but it is much more work and generally weakens the drum bottom due to the tearing of the metal, as opposed to removing the metal in the slit with a



metal-cutting blade. Alternatively you can drill holes, but this can turn into a lot of work to provide the same effect as a uniform pattern of slits.

For a retort, the slits can be made in either the top or the bottom of an open headed drum if the lid still fits tightly after any gasket material, which would just burn up on the first firing, is removed. With the slits in the lid of the drum, the retort is filled, banded and then inverted when it is put on top of the TLUD. Any gases that leak at the rim simply join with the gases coming out the slits. Alternatively if the lid and rim seal well after the gasket is removed, the bottom may be slit and you won't have to invert the retort drum. If the banded lid seems loose after the gasket is removed, then we recommend that the slits be made in the lid. Either way the retort gases should come out at the bottom where they can meet the flame of the TLUD.

The supporting rack is made of steel angle iron. Figure 4 shows a rack made of "slotted angle", which is available at hardware stores or from McMaster-Carr via mail order ([www.mcmaster.com](http://www.mcmaster.com) part number [8968K26](#)). One six-foot section, cut into 2 x 21" and 2 x 15" pieces will bolt together as shown. Over time the supporting rack may distort, but does not get hot enough to fail during burns. Old bed rails are one salvage alternative if you can find them. Don't use aluminum - it will melt.

The chimney of the J-RO may be made from either black or galvanized stovepipe, also available at hardware stores and from McMaster-Carr. Use a minimum 26 gauge. Don't use the thinnest intended for forced air distribution system in homes - it will not survive the repeated heating and cooling. The chimney can be attached to the drum lid by tracing the chimney outline and cutting the hole with either an angle grinder, saber saw or tin snips. The bottom of the chimney is then cut into an even number of tabs and the tabs alternated above and below the lid, as shown. The minimum recommended chimney is 2 feet tall and 8 inches in diameter. Larger diameter and taller stacks increase draft, improving turbulence of the secondary combustion occurring around the retort. After a few runs and given a consistent feedstock, one can generally arrive at a configuration and recipe for a smoke-free burn and desired biochar qualities.

### **Fabricating small fans and blowers for J-ROs**

The small fans and blowers that assist effective J-RO operations are readily available and easily modified. They are typically used in computers, projectors and many other electronic devices and inexpensively available as salvage on ebay or new at vendors like Best Buy, Radio Shack and Staples

The simplest devices are shown in Figure 5. The small blower at the top-left is powered by wiring a small transformer that supplies 9 volts DC. Such transformers are provided with consumer electronics, such as wireless telephones and cell phones and just about every home in America has a collection of such discards. The lower-right fan is from a PC power supply and wired to a 9-volt battery plug. This allows the fan to run off a standard 9-volt battery, but such a small battery will not last too many batches. For sites remote from grid power, a 12V car, motorcycle or computer UPS battery is a good power source for fans or blowers. Blower speed, and resulting airflow, can be controlled with an adjustable damper or a low cost PWM (pulse width modulation) motor speed controller. The battery can be recharged by hauling back to a

grid powered charger, by putting it back in the vehicle or onsite with a solar electric charging system. Alternately, the fan can be run off any small transformer that supplies either 9 or 12 volts. Low or no cost options are abundant. Just ensure that the transformer is putting out adequate DC current of the appropriate voltage and pay attention to polarity – DC fans only run in one direction. If they fail to turn, it may be that the polarity is reversed.

A few observations about the examples in Figure 5: The computer fan is used and dirty with accumulated dust – that doesn't matter. Alternately, new ones can be bought at any place computers are sold – they are known as 80 mm case fans, or they can be removed from any dead computer power supply. In addition, the corners of the fan facing the label have been cut off – to improve the match with the can. The amount of “boost” can be controlled by either adjusting the supply voltage or by restricting the air inlet of the fan. An example of restricting the air inlet can be seen in the bottom right of Figure 5 where a can lid is being used as an adjustable damper.



**Figure 5 Typical small fan and blower, adapted for the J-RO**

The fan is mounted in one end of a typical medium size can, as shown in Figure 5 on the right. In this case, a small coffee can was used and the fan mounted into the end with the lip at the top. The bottom of the can is removed with a can opener. The fan is attached to the can with electrical

tape to seal the gaps at the sides of the fan and hold the fan to the can – a little tape is all that is needed.

The blower is mounted in the top of a typical medium size can, in this case a 28-ounce tomato sauce can. A square opening is made in the end of the can to match the blower outlet, and then aluminum tape holds it all together. Both the tomato sauce can and the small coffee can are just under 4” in diameter and fit snugly in a 46 ounce juice can, just over 4” in diameter, with both ends cut out. In this way, the fans and blowers can be adapted to 4” galvanized steel duct that extends into the primary and secondary air supplies for the J-RO.

### **Assembling, Loading, Lighting, Burning and Extinguishing J-ROs**

Jolly Roger Ovens are an open architecture approach to biochar production and individuals are encouraged to experiment with what they have available. As such, this section is intended to provide guidance, but stops short of prescriptive instructions providing every detail. Each J-RO operator needs to take ownership of what he or she is building and how it is operated. If you don't understand what is involved, please seek assistance from someone with appropriate skills. A little “common sense” can go a long way to avoiding foolish mistakes – which is why this section will focus on “foolish mistakes worth avoiding”.

Since J-ROs tend to be large devices, make sure you have enough space for adequate clearances and provide a solid, level foundation to support the drum(s). Some kind of masonry or brick foundation works well but just a shallow pit in dry solid ground is also adequate, but watch out that the water used to extinguish the hot char at the end doesn't undermine the base.

We typically use 4” galvanized or black stovepipe to connect the fans or blowers to our J-ROs. For the primary air, the duct is incorporated into the base for the TLUD as seen in Figure 3. We have been injecting secondary air between the TLUD and the Retort by crushing one end of the 4” duct into a “duckbill” and inserting it in the gap between the drums – the fan end simply resting on some improvised support. The most important feature is to be able to have the fans or blowers located a few feet from the drums to avoid the excess heat near the J-RO. Once the J-RO is under way, you may find forcing primary and/or secondary air unnecessary. Some fuels will operate in the TLUD without any additional draft from primary forced air, with drier and coarser fuels being the best candidates. Our experience has been that controlling the primary draft is most important and allows a wider range of fuels, including higher moisture levels.

If you stack drums, make sure they are centered and stable. Cold stack everything and shim it plumb (with short pieces of steel angle iron or equal) and make sure it does not rock. Once the assembly is tested to be stable, unstack it and add the starting material to top light the TLUD. Once the J-RO is lit “there's no stopping it short of a fire hose”. The only controls are adjustments of the air supplies, both primary and secondary, to achieve clean combustion. The primary air supply is generally adjusted to provide a strong heating source to get the retort going – once the retort kicks in, the TLUD draft can be slowed down to where it is just adequate to deal with the TLUDs own moisture load.

Lighting the large TLUD that is the core of the J-RO takes a bit of technique. The key is to get the entire top layer of the TLUD ignited at once. One safe and foolproof method coats a small



portion (perhaps half a gallon) of the TLUD fuel with biodiesel (or diesel or kerosene – but NOT gasoline) in a separate container. Just before the J-RO is to be run, a small amount of 91% isopropyl or methanol dry gas is added to coat the surface of the biodiesel-soaked TLUD fuel. This thin layer of TLUD fuel plus accelerants is then spread on the top of the remaining fuel in the TLUD. The rest of the J-RO is then assembled and shimmed so it is stable. Then the top of the TLUD can be lit with a match and a piece of newspaper (or a propane torch). The alcohol lights easily, yet burns with a slow flame that ignites the biodiesel, which ignites the top layer or the TLUD. The least amount of biodiesel and alcohol that will get the job done is best – they just serve to light the top layer of biomass and don't represent significant thermal energy for a device as large as the J-RO.

Once the J-RO TLUD is lit, the burn cycle is pretty much a matter of adjusting airflows for the best heat transfer from the secondary combustion of the TLUD to the Retort and the cleanest emissions out the stack on the top. There is usually a little smoke to lead off, especially if one has used a bit too much accelerant, but once the TLUD gets going and the drums heat up, these devices can run essentially smoke-free. Once the Retort gets hot, it will start generating volatiles, which will be burnt along with the secondary combustion of the TLUD. Depending on the properties of the Retort biomass, things can really get roaring, both figuratively and literally. Since Retorts generate heat that additionally heat themselves, they ramp up to peak gas production, then eventually run out of volatiles, calm down and stop all by themselves. It shouldn't take too much practice to learn to recognize when the Retort takes off – and when it has landed. It all comes down to a “little trial and error” to dial in each J-RO.

At the end of the burn, which is generally when the TLUD ends, we have been flooding the TLUD drum with water to quench the residual char glowing in the bottom of the TLUD. With such large TLUDs, it is not advisable to attempt to quench the residual char in the TLUD by stopping the air supply, because that would require disassembly of the hot stack of drums. The preferred approach is to flood the lower TLUD, then let the entire stack cool – the retort will stop by itself. Alternately, the TLUD and upper outer drums can be sprayed with water to cool the surfaces, and then disassembled (while wearing gloves – cooled surfaces can reheat quite rapidly). Please keep in mind that the Jolly Roger Ovens are relatively large devices – and deserve care when handling drums that can be both heavy and hot.

Once everything has cooled, it is time to harvest the biochar. Make sure the biochar is fully extinguished – it is not uncommon for warm TLUDs or retorts to hide hot char deep inside. If the hot char is left unattended, it will keep smoldering until all the biochar is turned to ash. Worse yet, it can reignite and start an unintended fire. Once the biochar is cold and stable, whether it is wet or not, it needs to be conditioned and charged before being added to the soil. Our preferred approach is to compost the fresh biochar with standard incoming compost ingredients. By the time the biomass is fully composted, the biochar is conditioned and charged and ready for addition to the soil as a plant's best friend. We are planning another paper and some videos addressing the conditioning and use aspects of biochar in 2012. If you can, do watch the companion video to this paper, available at <http://www.youtube.com/watch?v=Kg95KYrH8PI> or by searching the keywords "Jolly Roger Oven Biochar".