Propane, an ideal model locomotive fuel

Propane gas is not manufactured, it is a fossil fuel separated from crude oil by a process called “cracking”. Discovered in 1857 by the French chemist Marcellin Berthelot, and again in 1910 when it was discovered by American chemist Walter Snelling as a component of the then gasoline. He had the good sense to patent it. Gasoline was at that time sold in gallon sized containers and was very volatile. Buyers complained that they would get a container and by the time they tried to use it about half of it would flash off into the atmosphere. The higher vapor pressure of the propane component would boil off and cause the gasoline to be agitated and vaporize too.

Propane and butane are very alike and can be used in the same burner systems except that propane has a much higher vapor pressure.

At 70 degrees fahrenheit propane’s vapor pressure is 110 psi, versus 35 psi for butane. This is why your BBQ tank is steel and your pocket lighter is made of plastic. Oddly butane has a slight edge in the amount of heat per volume. In the southern United States the propane you buy has more butane in it especially as a “summer” mix and if you get your motorhome tanks filled while on summer vacation in Texas you won't be able to get a flame in Minnesota at Christmas. Propane and butane are both heavier than air and so they will “pool” in containments like boats or closed bottom rail cars. This is compounded by the fact that compressed gasses leak unnoticed through very tiny openings. With pressures of 100# and above propane systems have to be durable. Pipes and hoses should be rated for pressure. Propane hose is rated for 300 psi and is physically durable.

For our use the propane pressure needs to be reduced. This is accomplished by mounting a regulator at the tank. I recommend barbecue regulators that are adjustable and also recommend a gauge in the line so you know what your pressure is. Barbecues usually run at about 3 pounds pressure and most of the locomotive burners I have seen operate at 5 to 10 pounds of pressure.

PROPANE TECHNICAL INFORMATION:

Propane Vaporization Chart, Properties and Combustion Data

VAPORIZATION RATE - 100 lb. Propane Cylinder (Approx)

Pounds of propane in cylinder	Maximum continuous draw in BTU/hr at various temperatures in degrees F.				
	0°	20°	40°	60°	70°
100	113,000	167,000	214,000	277,000	300,000
90	104,000	152,000	200,000	247,000	277,000
80	94,000	137,000	180,000	214,000	236,000
70	83,000	122,000	160,000	199,000	214,000
60	75,000	109,000	140,000	176,000	192,000
50	64,000	94,000	125,000	154,000	167,000
40	55,000	79,000	105,000	131,000	141,000
30	45,000	66,000	85,000	107,000	118,000
20	36,000	51,000	68,000	83,000	92,000
10	28,000	38,000	49,000	60,000	66,000

This chart shows the vaporization rate of containers in terms of the temperature of the liquid and the wet surface area of the container. When the temperature is lower or if the container has less liquid in it, the vaporization rate of the container is a lower value.

PROPANE DATA

Properties of Propane:	
Chemical Formula	C3H8
BTU per Gallon (Vaporized)	91,690
BTU per Pound	21,591
Weight per Liquid Gallon	4.23
Vaporization Temperature	–44°F
Specific Gravity - Vapor (Air=1)	1.53
Specific Gravity - Liquid (Water=1)	0.51
Vaporization Rate (Liquid to Vapor)	272:1
Combustion Data :	
Limits of Flammability, %of gas in air	2.3% to 9.5%
Air required to burn 1 Cu Ft Vapor	23.5 Cu Ft
Oxygen required to burn 1 Cu Ft Vapor	4.9 Cu Ft
Ignition Temperature	920-1029°F
Optimum Flame Temperature	3500°F
Vapor Pressure at 0°F	28 PSI
Vapor Pressure at 70° F	122 PSI
Vapor Pressure at 100° F	190 PSI

Propane Vapor Pressure Chart, PSI

	OUTSIDE TEMPERATURE, DEGREES FAHRENHEIT														
	–30°	–20°	–10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°
100% Propane	6.8	11.5	17.5	24.5	34	42	53	65	78	93	110	128	150	177	204
	VAPOR PRESSURE, PSI														

Some data showing the relative temperature pressure relationship and storage capacities.

A propane fire is basically just hot gas. Sure there is some radiant energy released but nothing like our traditional solid fuels. The biggest problems for the use of propane in model locomotives is poor burner design and a lack of understanding of just what is happening in the firebox. So many burners are mounted too high. The refitting of a gas burner to a coal burning locomotive is generally with the manifold mounted near the level of the original grate, with barber jets, this places the flames almost 2 inches higher than the grate. So much of the water legs are heated by conduction, not directly. Add to that the cold air flowing into the firebox is cooling the firebox wall. I suppose you could make a case for “it’s preheating the air” but warmer air is less dense. I read a study of model locomotives that claimed that 80% of the heat of a coal fire was transferred in the firebox. You can imagine that it’s going to be a lot more evenly distributed with a gas fire.

All of the “science” of smokebox drafting and petticoats is pretty useless for propane. The ideal drafting now is to eliminate the pulsations of the exhaust up the stack and create a low but constant draft. The draft should draw secondary air into the firebox and evacuate the burnt fuel into the smokebox at a rate that just matches the gas burning rate. That’s the ideal because with too little draft your fire becomes too rich and stinky as partially burnt gasses choke the fire. Too much draft and you're just wasting energy as the heat that is produced is very quickly evacuated to the smokebox and blown up the stack.

The secondary air is the air that is drawn into the burner area around the flames to provide an abundance of oxygen to further complete combustion. Air of course is a mixture of gasses and the one we need is oxygen which is typically 21% of the air. The other gasses are along for the ride and are a medium to carry the heat. So the super heated gasses want to dump that heat and at 1500 degrees or so, a 300 degree locomotive boiler looks really cool. The challenge is to get enough gas to transfer its heat to the boiler walls, without pulling in too much cooling gas.

Primary air is that air that is initially mixed with propane gas in the burner to allow the gas to burn well, combining the hydrocarbons with oxygen. It is a reaction that starts with the addition of a little energy (a spark) and then the reaction releases so much heat it is easily self-sustaining. The burners job is to mix those gasses in the right ratios to release the maximum amount of heat.

The volumes of propane to air are very different. Remember there is a lot of gas (78%) that is not part of the reaction that also needs to pass through the burner. Hence the great size difference between the gas orifice and the ports supplying the air.

Also just to complicate this already complex system, we mix pressurized propane with air at atmospheric pressure. A jet of propane shoots out of the orifice at high speed expanding as it goes and the slight vacuum created behind it, drags the air into the burner. Ideally there is enough, but not so much air that you diminish the slight vacuum pressure in the mixing area. Of course we desire a system that has a wide control area, and we control the output of the burner by turning up and down the gas flow. Let me point out that every valve is a pressure regulator, and as we close the control valve the gas pressure at the orifice (mixing jet) is lowered and the gas jet is not as energetic so the vacuum pressure drops and the amount of air dragged into the mix decreases. But it is not linear. The good news is that the system is fairly tolerant of these changes and our use is fairly constant. I mean you use about the same amount of heat constantly unless you are just not using any steam. If your burner was too big then you could find yourself using less heat and operating in an inefficient area where the gas mix will go rich from not inducing enough air.

It seems like an ideal system would be one that turns on the required number of burners as needed. I built a burner array like that but although the theory was good, burners that are just sitting in the firebox with no cooling gasses flowing through them melt. And in testing, throttling the gas supply worked as well as the staged burners.

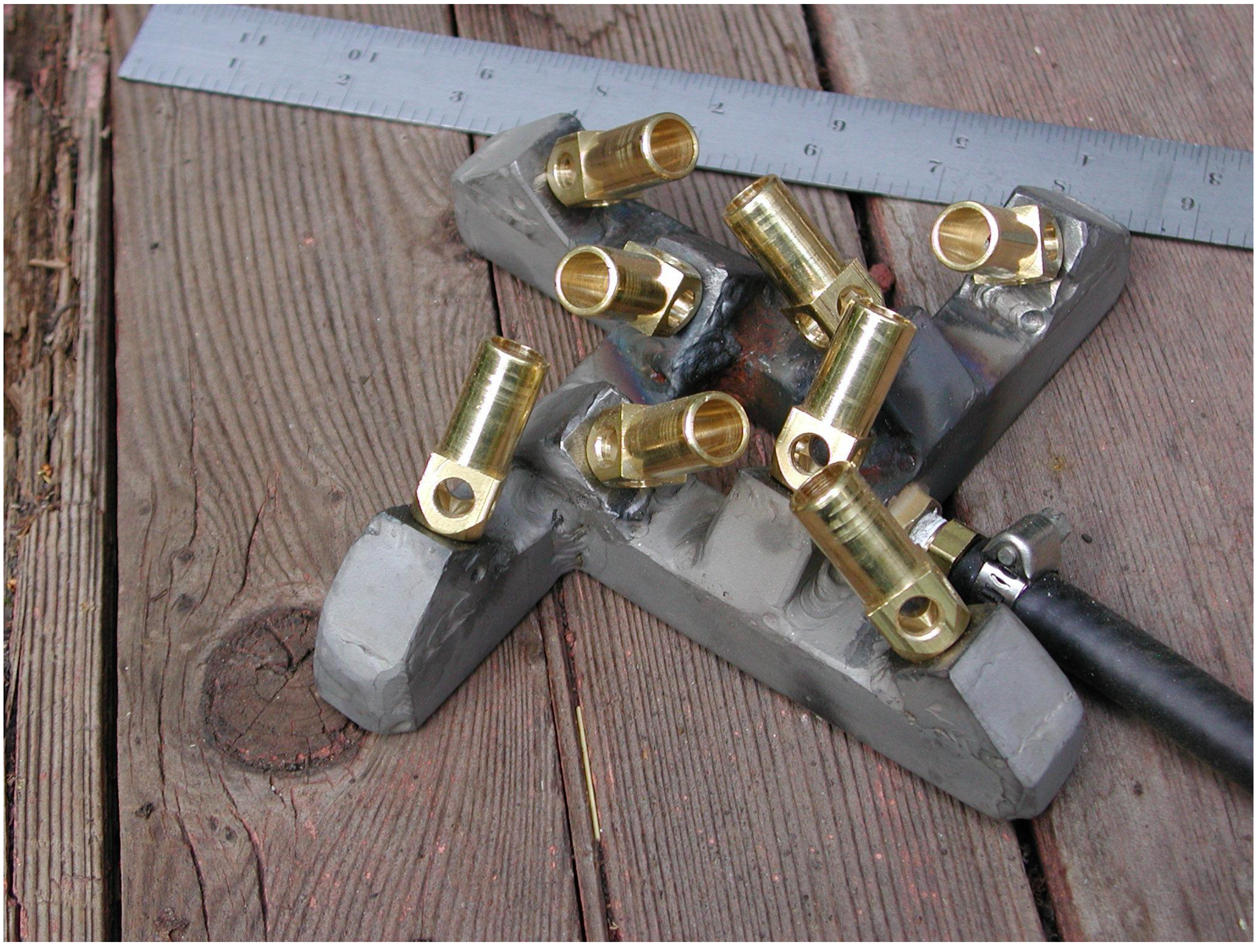
The Burners:

Live steamers basically use three types of burners. Barber jets, Impinged burners, and bar burners, and that seems to be in order of popularity. Barber jets are a family of individually mixing units with various sizes and top caps to spread the air/gas mixing different patterns. The most commonly used is the star pattern. By making a manifold with mounting holes, arrays of burners can be created very easily and with some care the results are very successful. The burners need to have enough room around them for the flame pattern to do its job of mixing in the secondary air. For narrow fireboxes a fan pattern can be a better choice with the fans spreading across the width more burners can be utilized.

I recently built a burner with a single row of 6 fan burners. Now it’s 5 burners because the air coming into the burner caused the furthest burner to starve and not mix gasses well. The burner assembly worked better with fewer burners operating at higher levels.

A group of barber jets, star and fan pattern. With a couple jet burners and a propane torch head as well.

Larger fire boxes can benefit from impinged burner design. An impinged burner utilizes pairs of burner jets that have no spreader caps. The air /fuel mix is a stream and the pair of burners are mounted to cause the gas streams to impinge each other at 90 degrees. In use a ball of flame is formed at the point the streams impinge and this ball of flame uses all the air it needs. This type of burner is very efficient and clean burning, it also seems to throttle well. A time when “crossing the streams” is a good thing. The mounting for the jets is more complicated but burner units made of cast iron are very available through the internet. The obvious issue is that this type of burner needs a bit more height in the firebox.



A home made 8 jet impinged burner with temporary gas connection for test.

I recently supplied a friend with a larger impinged burner for a gorgeous antique coal stove that heats his home and we ended up plugging 4 of the jets to lower the amount of heat. It was already using the smaller type of jet burner but this fine tuning made it just what he needed.

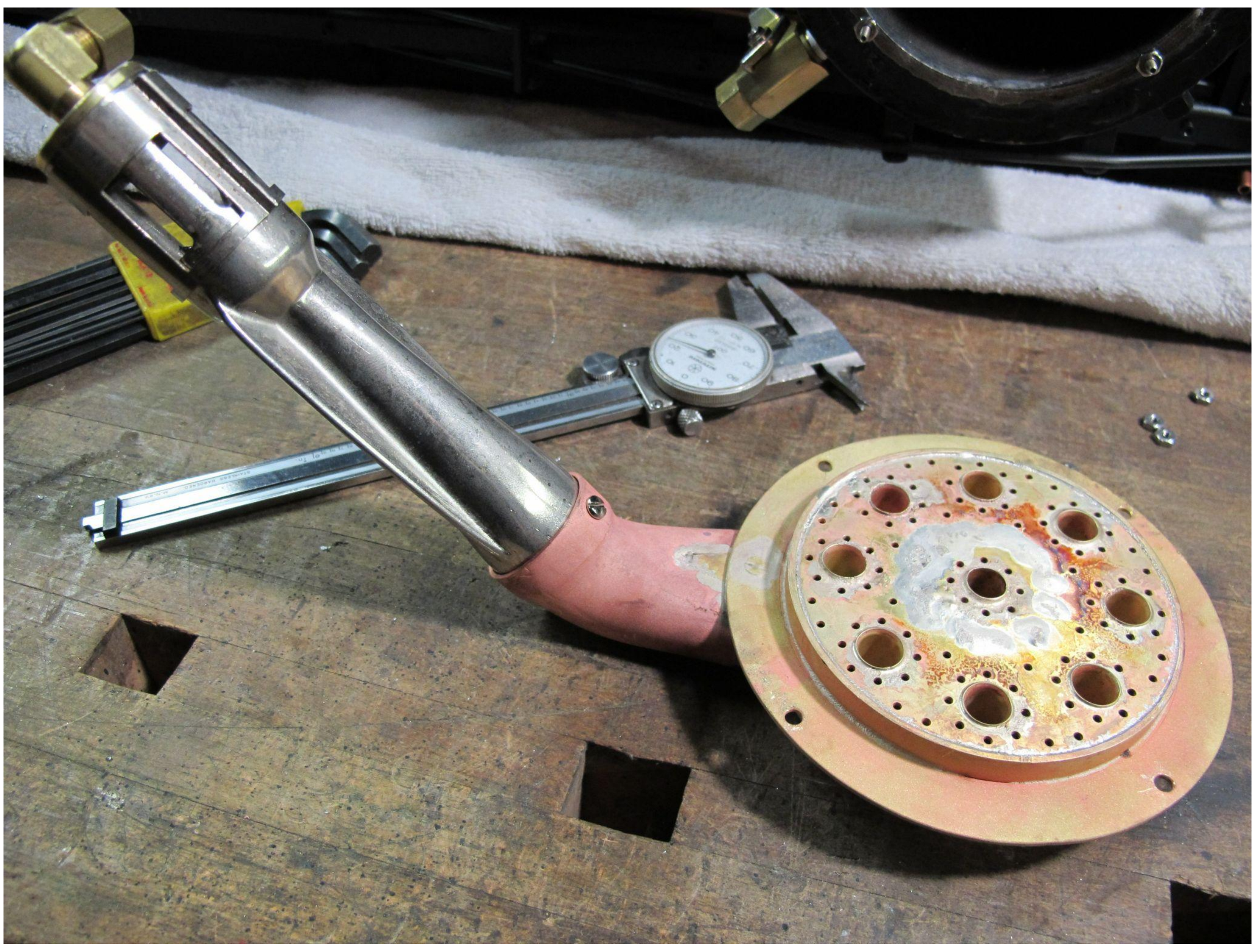
Not quite, full burner.

Bar burners are often seen in stove ovens and barbeques. The style is a piece of tubing with many narrow slits cut into the top surface or rows of perforations. In its simplest form the gas / fuel mix is accomplished at one end with a jet of gas firing through a simple venturi to drag the air in and mix with the gas. This mixture then flows through the slots of perforations. The gas pressure in the tube is very low but the flames cannot propagate through the little holes.

A really extravagant and a simple bar burner. A 10 jet impinged burner with extra, smaller jets that create less heat. Also a ceramic burner tile and mixing venturis both home made and salvaged.

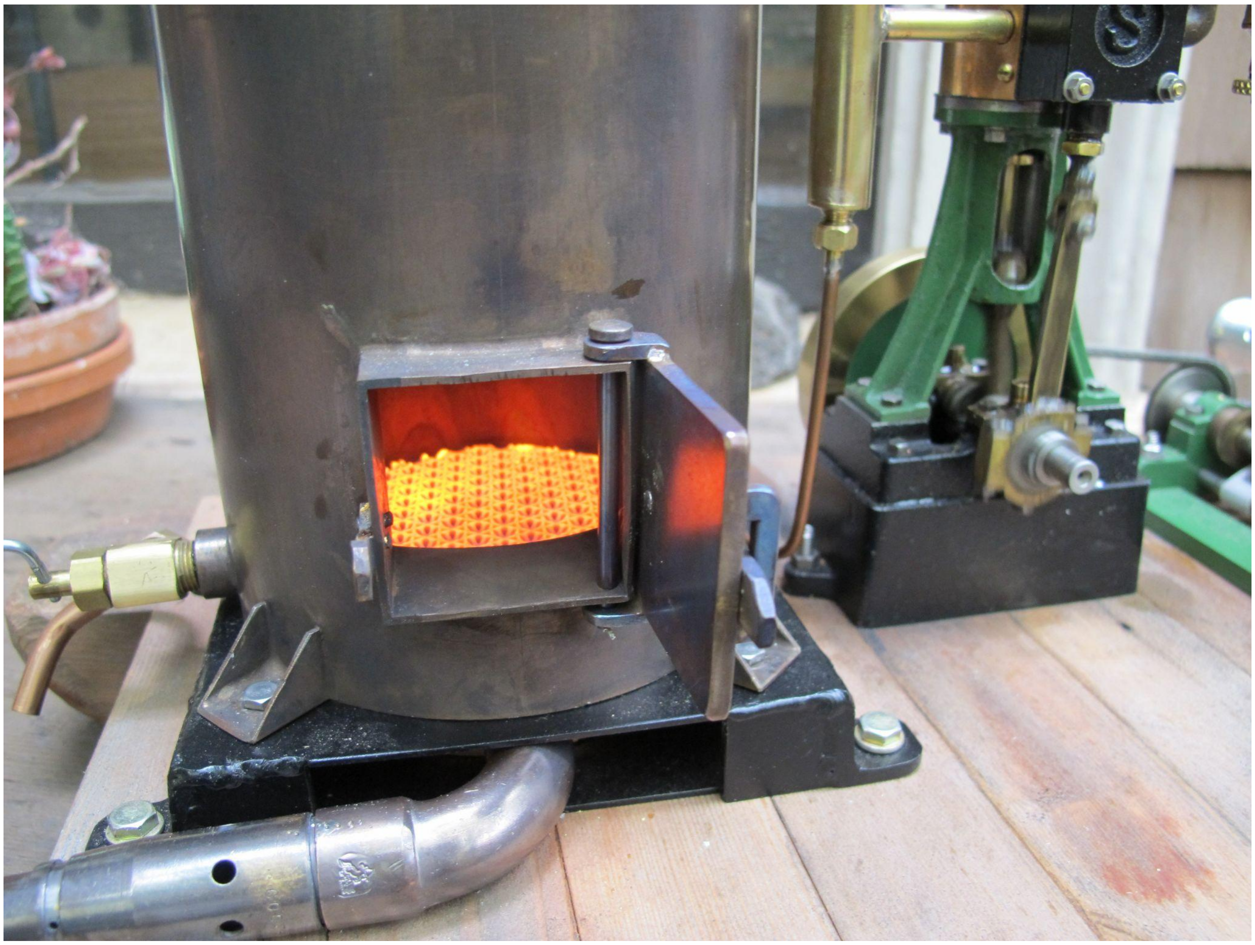
Another burner I need to mention is one of my own devising. It was inspired by the need to have a good burner in the very shallow space under a tee boilered shay. Specifically a model of the MichCal #2. Based on the Bill Harris design there is very little space under the boiler. To mount Barber jets in the firebox would place the burners very high and the air inlets to the

burners would be in the area of the fire. Harris used a modified version of the Shattoc pot burner for liquid fuel vaporization.
I built a burner plenum by making a box with circular arrays of burner holes, each around a center tube that passed down through the plenum to bring a source of secondary air into the circles of flames. The plenum is then fed by a venturi gas mixing system similar to the bar burner. Essentially I just changed the format of the bar burner to fit the space. It works quite well and gets the flames right to the bottom of the firebox. It can be built as a replacement for the ashpan structure. Beyond the Shay I have equipped a “Speedy” (British design) with it, a vertical boiler unit, and another locomotive with a small firebox. All exhibited excellent results. When driven very hard the individual flames on the gas holes cease and the area becomes a mass of burning gas.



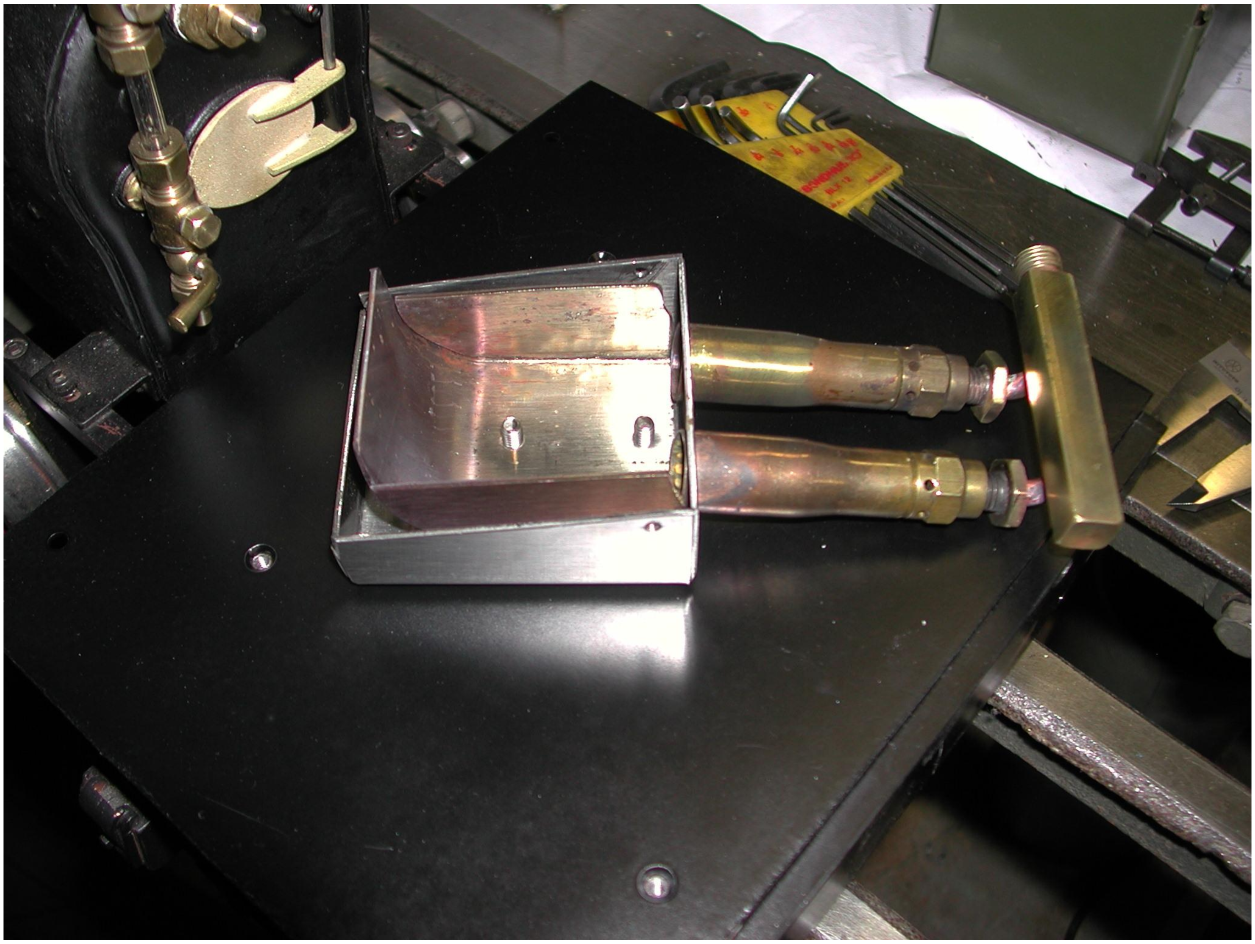
This burner was later replaced with one that was even thinner. The tube to the left is a venturi mixing the gas and air.

There are other types of propane gas burners, radiant types, ceramic and stainless, and jet burners, but they have not proven to be successful in our general size category. Ceramics are often used in G scale sizes and would be a possibility for 2” or 3.5” gauge locomotives.



Here’s a ceramic burner in a 4” diameter vertical boiler using a propane torch burner as a mixing system.

Jets burners are fine but noisy. I over burnered a Falk 1 locomotive with 4 jets.



Here is a two jet burner for a Tich firebox. It is made with repurposed propane torch burners.

Installation:

The parameters of burner installation are driven by many factors. First off we need to remember that everything will get hot. Sounds simple but it is often overlooked and I have seen rubber hose connected to a fitting on the burner pipe. And a length of copper line does not isolate the heat much so be sure your controlling valve is up to the requirements. Another often forgotten item is the need to remove the burner for boiler inspection, so the burner assembly should be removable with a couple of screws or pins. That and an easy gas line connection will reward your forethought over and over. The burner needs good access to the air so if anything, open screening is about all you can put across the bottom. I have seen even 50% screens being too restricting and the burner running rich.

The sort of burner you use is affected by physical requirements. As always the best approach is to see if there is a similar locomotive that is running successfully and evaluate how that would fit to your application. Here is where you have the opportunity to improve on what has been done.
Lets also address safety. The output of burnt gas is carbon dioxide (CO_2) and carbon monoxide (CO) for the most part so only test and operate in a well ventilated area. Also stay aware of the fact that it's an ignition source so be care with volatiles.

Making burners:
Yes if you're handy in the shop and willing to take on a repetitive task, burners can be successfully built. And they can be modified as well. There are designs for barber jets available and they have been around so long that there are no patent restrictions. I have built all sorts of burners but lately so many are available that time is better spent on other areas, as long as these burners suit your needs.
Here is an article written by GGLS member Dave August on his very successful method of making barber jets (aka: Marty burners) note the 6 burners for his LE American
https://www.discoverlivesteam.com/magazineold/186/index.htm

And I have to show this, Ken Brunskill was dissatisfied with the Marty burners he made and so he devised another top cap. I've named it the "Brunsen Burner" and it works really well. It took a lot of experimentation but it gives a really good flame pattern.

I suppose the overall point of this article, beyond information, is that more is not always more and care in design and experimentation should be embraced. This coupled with educated operation will give you the reliable and easy steaming you desire.

So why did I say that Propane is an ideal model locomotive fuel?
Simply, you can turn it off with the twist of a knob. Heat with an off switch.

For further reading

https://solarflo.com/products/
This is probably the largest supplier of engineered burners. If you want to buy 500 barber jets or heat full size railroad cars they are the people to talk to.