# PGI Discussion: Types of Ethanol Stoves

**Introduction – Why use ethanol?**

Ethanol has not been popularized as a cooking fuel except in niche applications where heavy cooking is generally not required. This is because (1) the developed world has had access to electricity for cooking for 70 years, and (2) because natural gas, propane, and town gas have been widely available in Europe and on the American continent.[1] This is also because an adequately high performing stove (easy to use, safe, reliable, an burns with adequate power) that burns ethanol has never been made widely available. Historically, alcohol has been used solely for camping stoves and for warming food. Since alcohol stoves have not been built to produce a lot of power, ethanol has not taken its place among the modern cooking fuels—kerosene, butane, propane, LPG, natural gas, and electricity. As a result, the benefits of ethanol as a cooking fuel have been under appreciated.

Some of the benefits of ethanol as a cooking fuel are as follows:

- ✓ Ethanol is a biofuel, and thus can be made by fermenting plant biomass. Some of these plants are very efficient photosynthesizers, such as the C4 plants, and thus make great energy sources.
- ✓ Ethanol is a liquid, so it can be stored and handled with a fuel infrastructure essentially identical to that of kerosene. When kerosene replaced whale oil it was appreciated (like whale oil) for the fact that it could be more easily transported and used than solid fuels. During the transition between whale oil and kerosene, ethanol mixed with turpentine (made from pine trees) was used for lamp oil.
- ✓ As a biofuel, ethanol is part of a $CO_2$ lifecycle process (e.g. its combustion releases $CO_2$ that was fixed through photosynthesis). Cleanly combusted, ethanol is $CO_2$-neutral. Certain plants return and store carbon in the soil, and if these plants are used for ethanol production ethanol fuel is $CO_2$-negative.
- ✓ Fermentation and the distillation of ethanol are highly scalable, meaning they can be carried out on large or small scales.
- ✓ Fermentation and distillation are well understood- they have been carried out for thousands of years. The production of ethanol by this means continues to advance technologically, becoming increasingly efficient.

[1] Most households in rural America transitioned from cooking with wood and coal directly to cooking with electricity by the mid 20th century, while city dwellers transitioned from wood and coal to gaseous fuels, fuel oil, kerosene or electricity. Where town gas, a low-energy gas, was introduced, this was eventually replaced by natural gas.

- ✓ Ethanol is much less toxic than any other liquid fuel (OSHA PEL 8H TWA 1,000 ppm compared to 100 ppm for kerosene).
- ✓ As a distilled fuel, ethanol is almost completely free of contaminants.
- ✓ Azeotrope ethanol (~95%) burns well.
- ✓ Ethanol is water-soluble; an ethanol fire is extinguishable by water.
- ✓ Ethanol biodegrades rapidly in the environment.
- ✓ Ethanol produces almost no soot or black carbon during combustion.
- ✓ The properties that characterize ethanol as a fuel (lower and upper flammability limits, flash point, auto ignition temperature, vapor pressure, boiling point, vapor density relative to air, etc.) can all be managed for safe and efficient storage, handling, combustion, and use in small appliances. While care is required, the properties of ethanol present no drawbacks, and in fact offer distinct advantages when compared to other fuels.
- ✓ When combusted efficiently, ethanol burns with a flame temperature similar to propane.
- ✓ Ethanol mixes with methanol, the other simple alcohol, in any proportion. Methanol, with more oxygen, promotes more complete combustion of ethanol, especially if it contains higher alcohols.

**Types of Ethanol/Alcohol Stoves**

1. Pressure Alcohol Stoves

Examples: Primus Alcohol Stove, NARI Stove, Bonfire Stove (New Delhi), etc.

Pressure alcohol stoves store alcohol as a liquid in a fuel tank under pressure. The tank is pressurized by means of a hand pump. The liquid is pushed through a tube to a nozzle and sprayed into the burner. When the burner is hot, the tiny droplets of liquid ethanol vaporize at the burner surfaces and feed a flame supported by the burner. The burner is designed to promote air mixing and to produce a flame of a particular size and shape.

The pressure stoves require frequent pumping to maintain pressure in the tank, while only a few psi are required to promote good fuel supply and atomization at the burner. The fuel tanks of these stoves tend to leak because alcohol dehydrates the gasket material around the pump shaft connected to the tank. This promotes the failure of the gasket. Alcohol, with its low molecular attraction, is able to penetrate through even the smallest opening because its molecule is tiny and does not stick to other molecules, instead moving through capillary action. As a result, gasketed seams need to be repaired regularly to prevent leaking.

The NARI stove is a pressure stove that uses low-grade ethanol.

2. Non-pressure Stoves

Examples: Cooksafe Stove, Chinabest Alcohol Stove, Millennium Gelfuel Stove, Sterno and fondue stoves, Proimpex and ISPM stoves (Madagascar).

Non-pressure stoves hold alcohol in an open container, where it is burned immediately above its surface. The alcohol is either liquid or may be gelled with a hydrocolloid. If liquid, the alcohol may be contained in a porous or fibrous medium that wicks the ethanol to its surface through direct contact with a reservoir of ethanol below. Stoves are being developed with a remote reservoir where fuel is fed by gravity through a small tube to the burner. Care must be taken not to flood the burner and spill ethanol. If the burner is fitted with a porous medium it will prevent a flame within the structure (given that there is less oxygen content), but will still allow a flame over its surface.

Where fuel is gravity fed, the fuel flow must match the fuel consumption of the burner to prevent overflow.

Variant: Gelled and Solid Fuel Stoves

Ethanol can be gelled and also can be formed into waxy blocks. The gel is burned from a can, as in a chafing dish stove. The waxy blocks can be burned like any solid fuel (like in the Churrasco restaurants of Brazil- where they are often placed on a bed of charcoal to add heat and flame). Solid blocks of ethanol burn very cleanly and can be used in open-air restaurants because they do not produce smoke or dangerous emissions.

The most common non-pressure stoves are gel fuel stoves, fondue and chafing dish stoves, and Sterno™ stoves. These may not achieve optimal combustion of the alcohol due to poor fuel-to-air mixing. A consequent problem is that they do not burn as hot as stoves that achieve good air mixing. There are several reasons why gel fuel stoves do not burn at peak temperature. First, often combustion in these stoves is incomplete, evidenced by the higher than expected production of carbon monoxide (the simple alcohols are normally low CO-producing fuels because they contain little carbon). Second, fuel may contain less energy because water is usually added for better gelling of the ethanol (Most gel fuels contain 20% water). If the ethanol burns with a lazy, rolling flame, this indicates that the flame is not hot enough and likely does not have enough air mixing.

3. Self-pressurizing Stoves

Examples: Lili Stove, Britelyt Stove, SuperBlu Stove (Bluwave Ltd.), Trangia Stove, “Pepsi Can” stove, etc.

This stove converts alcohol from a liquid to a gas in a restricted space and uses the consequent pressure to force it out of a series of small openings, nozzle, burner element, or mantle into a flame. The Primus stove uses this principle too, but also relies on pressure in the fuel tank.

Camping stoves like the Swedish Trangia, "Pepsi Can," stove are examples of stoves that contain liquid alcohol in the same cavity where the fuel is vaporized and pressurized. The vaporized fuel is then forced out through openings where it burns. These stoves are small, with compact burners and limited fuel reservoirs, usually burning for 15 to 30 minutes. The fuel reservoir is close to the flame and essentially is contained within the burner. Their small size generally makes them safe to use. It is uncertain whether they could be sized larger and redesigned to overcome their operational limitations to become a suitable stove for family cooking, or if this would cause prohibitive safety hazards. Overall, these stoves suffer from safety and consumer "usability" issues- hazards of explosion, inability to adjust flame, inability to turn on and off, small size, shortness of cooking time, as well as other issues.

The Britelyt stove combines features of the pressurized and self-pressurizing stoves to create a variant that requires only light pumping; generating most of its operational pressure, around one or two psi, from boiling the ethanol in a heat loop in the fuel feed tube before it reaches the burner. This is adapted from the Britelyt lantern, which uses a mantle (the mantle, super-heated by the burning alcohol, produces a bright light). The stove's burner structure acts as a diffuser to promote mixing with air.

Like the Primus stove, this stove has to be primed (preheated) to be lit.

The Britelyt stove derived from the kerosene mantle lantern developed by the German Petromax Company in the early 20$^{th}$ century. This Petromax design was adapted to use alcohol in 2002 as part of the research conducted by Project Gaia.

The advantage of this variant on pressurized stoves is that it takes full advantage of the volatility of ethanol in transport from the tank to the burner. Since ethanol burns as a gas, vaporizing it before it makes contact with the burner increases performance. This stove overcomes the usability limitations of the self-pressurizing camping stoves described above.

4. Evaporative Stoves

Example: CLEANCOOK Stove

The CLEANCOOK stove represents a fourth category of alcohol stove. It has a unique fuel storage and delivery system that allows the ethanol to be delivered to the stove burner as a gas through evaporation. The CLEANCOOK stove may be the only example of this type of stove. The CLEANCOOK stove was developed in 1978 by Bengt Ebbeson of the ORIGO Company of Halmstad, Sweden, and represents a breakthrough technology for burning alcohol in a stove.

Liquid ethanol is poured into a fuel canister through an opening in its top. The canister must be taken out of the stove to be filled. The opening in the canister is wide (8 cm diameter) relative to the volume of the canister (1.2 liters). The fuel is then is adsorbed onto the surface of a densely packed refractory ceramic fiber contained inside the canister. The liquid alcohol moves by capillary action from all parts of the canister to the evaporative surface at the top. The canister opening is sized to fit under the combustion chimney in the stove body so that ethanol from the fuel canister will evaporate directly into the chimney.

Air is let into the chimney from side vents. Ethanol and air vapor form a combustible mix in the chimney. To light the stove, a flame is introduced at the top of the chimney. It ignites the vapor, which combusts in the chimney above the surface of the fuel canister. As the chimney heats, a self-pressurizing effect is achieved, as the rate of alcohol evaporation from the fuel canister increases. Since the stove combustion chimney heats quickly, this peak flow is achieved in only a few seconds. Increased convection pulls more air in through the side vents. A flame spreader at the top of the chimney acts as a diffuser and promotes fuel-air mixing at the top of the flame.

The size of the flame (the rate of fuel flow) into the combustion chimney is controlled by a regulator that slides across the mouth of the canister, adjusting the size of the evaporative surface of the canister mouth. As the evaporative surface is reduced less ethanol is evaporated into the combustion chimney. When the regulator is slid across the entire surface, the ethanol vapor is shut off and the flame is extinguished.

This stove was designed with the properties of ethanol in mind to exploit its advantages as a fuel. The volatility of ethanol is used as the way to deliver fuel to the burner. The low surface tension of ethanol is exploited to promote safe storage on the extensive surface area of the ceramic fiber densely packed in the fuel canister. When charged into the canister, the liquid ethanol will not drip or leak out unless the capacity of the surface area of the fiber in the canister has been exceeded. The operator can easily determine this when he or she sees ethanol pooling in a depression inside the canister mouth. Capillary action in ethanol is used to direct fuel through the fiber to the canister mouth. Ethanol has a high latent heat of evaporation, meaning the when the ethanol evaporates from the canister the liquid ethanol in the canister cools as the heat is released in the evaporated vapor.

The lower and upper flammability limits of alcohol have been considered in designing the fuel canister and the combustion chimney. The alcohol vapor lacks enough oxygen to burn in the fuel canister but reaches an ideal mix with air for combustion in the chimney.

The careful design of the stove in accordance to the fuel properties assures that cooking can be done safely, conveniently, and efficiently- outdoing other alcohol stoves. The CLEANCOOK stove is fueled with liquid ethanol, stores it as if a solid, and burns it as a gas.