

Kermit was a Pessimist: But... we CAN have Greener Kilns

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For ceramicists, going greener will have much in common with greening activities in other areas of life. If you own the property or have a sympathetic landlord, insulate and seal the building and install solar panels. Paint the building (including the roof) a light colour. In hot sunny areas plant shade trees or add verandas or other external shading. In cold areas construct (or plant) wind breaks on the windward side. Install or upgrade energy efficient lighting and heating and cooling systems. Buy your electricity from a "green" supplier if available. Walk, bicycle or use public transport where possible. Don't take too many round the world air trips, the greenhouse gas emissions of one such trip equates to somewhere between 4 and 10 years of car driving. None of this is ceramics specific, just good responsible green behaviour.

But what can we do as ceramicists (as well as other 3D craftspeople and sculptors) to reduce our energy consumption? Often, we have to move a lot of heavy stuff around. Unless we are lucky enough to live in an area that is well serviced by delivery people and couriers, it's difficult to get by without a vehicle. Even if we outsourced our collections and deliveries via couriers, I wonder how much greenhouse emission would actually be saved? If we need a vehicle, we should aim to drive an energy efficient one. Increasingly, electric vehicles will become practical, affordable and rechargeable via solar panels.

One area where we can make a big difference is improving the construction and performance of our kilns.

Kiln Construction

Those of us who buy kilns are largely at the mercy of the kiln manufacturers. We can, however, apply some market pressure. When purchasing a new kiln, actively seek out energy efficient kilns. Ask the manufacturer or salesperson what the thermal performance of their kilns are. Make sure that they know that energy efficiency is an important consideration in your purchase decision. A small amount of extra insulation can make a huge difference to energy usage (and costs) over the life of the kiln.

Those of us who build our own kilns have more agency here. Insulate, insulate, insulate. Use insulating bricks and fibre appropriate to their position in the kiln. Where dense refractories are needed (and they are in some cases) use good back-up insulation. Keep in mind the idea of "thermal mass" - the mass (weight) of the kiln x temperature change during the firing x ceramic/brick specific heat. For ceramic materials the specific heat is about 0.9 Kilojoule per kilogram x °C (kJ/kg°C) or 0.22 Btu per pound mass x °F (Btu/lb_m°F). A dense refractory brick has a mass of about 4 kg or 8.8 lb; heating it to cone 10 will require about 4.5 MJ or about 4300 Btu. An entire kilogram or half a US gallon of liquid propane (or 3 kg, 6.6 lb of dry wood) needs to be burnt to raise just 11 dense bricks to cone 10.

Worse, this calculation assumes perfect combustion and perfect heat transfer. Perfect combustion never happens as we spend most of the firing deliberately making the combustion imperfect, by adding too much air, (oxidation), or too much fuel (reduction). In

addition, much of the heat produced by this imperfect combustion is transferred not into the bricks or ceramic items but up the chimney.

So, what's a keen wood firer to do? Traditionally, dense fire bricks have been favoured being necessary to achieve those "wood fired" effects that are so sought after. I have some skin in this particular game. I'm about to begin building a two-chamber wood fired kiln. And yes, the first chamber, throat arches etc. will be lined with dense fire brick. Perhaps we need to develop other ways of firing in low thermal mass kilns, for example, a long soak a cone or two below finishing temperature.

Kiln Firing

Energy use in electric kilns will mostly be determined by how well the kiln was manufactured, but we can do a few things to minimise consumption, for example closing the bung holes as early as possible during a bisque firing. This depends on the particular clay body, somewhere between 700-900°C, after dehydroxylation, aka ceramic decomposition, has taken place. Other actions would be taking care not to overfire and buying green electricity if available and affordable.

Most commercially built electric kilns use significant power, so batteries charged by solar panels for medium and large kilns do not seem to be a viable option for the foreseeable future. As an example, our electric kiln is rated at 13.3 kW, and requires almost the entire storage capacity of a current model battery (e.g., a Tesla Powerwall 2) to run for an hour at full power. However, most batteries can only be discharged at a rate that is a fraction of their total capacity. For the Tesla PW2 example, its maximum continuous discharge rate is 5 kW, so we would need a bank of three of these batteries to run our kiln at full power (for about 2.5 hours). In all, we would probably require about 10 batteries for regular production firings. If you include installation costs (and not including a large array of solar panels) and added heavy duty circuitry, each battery will cost at least \$8,000 US...that \$80k could be more productively spent elsewhere. An electric car or pickup maybe?

Having written the above paragraph, I realised that Steve Harrison (who taught me kiln design in the early 1980s) had proved me wrong, at least for a small kiln fired on a sunny day. Steve, besides being a teacher, was until his recent retirement Australia's best known kiln builder (Hot & Sticky Kilns). For his own use he built a small electric kiln that ran on the output of his 6 kW of solar panels, boosted by a single Tesla PW2 battery, and two small pilot sized propane burners, which he uses only for reduction. The kiln's energy use peaks at about 10.5 kW. He is able to achieve stoneware temperatures in 5 – 6 hours, by starting the firing at 9 or 10 am, so that the increasing need for power as the firing progresses is partially matched by the ascending sun, the battery providing top up power, with some occasional input from the grid. It's not a large kiln, but it may be large enough for some potters. The kiln may be seen on Steve and Janine's website and blog:

<https://tonightmyfingerssmellofgarlic.com/sustainability/>

The article is titled "Sunshine Came Softly Through My Spy Hole Today" and is the text of a talk he gave at the Ceramics Triennial Conference in Hobart, Tasmania. It's Steve and Janine's personal kiln but seeing the photographs of it may give ideas to those with a high enough level of technical skill.

Fuel burning kilns probably give us more scope to reduce our emissions from their current level. I'm not suggesting a change from electric to fuel burning kilns, rather, if you already

use or intend to use a fuel burning kiln, there may be room for a considerable reduction in greenhouse gas production (along with savings in fuel costs) by fine tuning your firing (both fuel and damper control), without sacrificing glaze or surface quality.

In the early 1990s the art school where I taught was amalgamated with (i.e., swallowed by) a major university. One of the few benefits was easy access to a small research grant, which I used to purchase an automotive exhaust gas analyser. At the time these analysers were quite expensive, well beyond the reach of most ceramics practitioners. I adapted the analyser so we could use it for extended periods in situations much hotter than vehicle exhausts and started poking it into the college's collection of gas fired kilns. The analyser allowed us to measure carbon monoxide (CO), carbon dioxide (CO₂) and oxygen (O₂) levels in real time.

First, some theoretical background. Air at sea level is nominally made up of about 21% oxygen, 78% nitrogen, variable water vapour (the relative humidity) and very small amounts of other gases, carbon dioxide being the largest of these, at slightly over 0.04%. Our gas analyser would read something like CO = 0, CO₂ = 0, O₂ = 21. Most fuels (e.g., wood, propane, butane, waste oil, natural gas) contain carbon plus some hydrogen, so complete combustion at atmospheric pressure would result in no remaining oxygen, essentially all the nitrogen, more water vapour (from the fuel's hydrogen content) and about 14% carbon dioxide. Our gas analyser should now read CO = 0, CO₂ = 14, O₂ = 0. For fuels with a higher hydrogen content like natural gas (CH₄) the maximum CO₂ reading will be a bit lower than 14%.

If these idealised readings came from a kiln, it would be in neutral combustion. If we wanted to change to oxidation, for example by opening the damper slightly, allowing a few percent of extra air (say 10%) into the kiln, we may get a reading like CO = 0, CO₂ = 12, O₂ = 2. Putting the kiln into reduction by increasing fuel or closing the damper would use up all the oxygen and produce carbon monoxide, our main reducing agent. How much CO we need depends on the particular kiln and the type of glaze, but 2% CO is a good place to start. Our analyser might now read CO = 2, CO₂ = 12, O₂ = 0.

Note that the CO₂ reading is at its highest when we have neutral combustion, and that CO₂ levels drop when we move into either oxidation or reduction.

It is important to remember that any departure from neutral (i.e., complete or perfect) combustion will produce less heat, so to get those cones to bend, we will use more fuel, pay more and produce more greenhouse gases. If we over oxidise, we expend considerable energy warming up a whole lot of nitrogen (it's nearly 80% of the air) and then pushing it up the chimney. All that excess air is diluting our heating efforts. On the other hand, if we over reduce, we waste a lot of fuel and produce more (poisonous) carbon monoxide than we need to strip the oxygen from the iron or copper or other components in the glaze or body.

Carbon combustion is a two-stage process. In the first stage one atom of carbon joins with one atom of oxygen producing one molecule of carbon monoxide (CO), releasing some heat. In the second stage, one molecule of CO joins with a second atom of oxygen to form carbon dioxide (CO₂) and a lot more heat. It's this second stage of combustion that really drives the heating in our kiln. The more we reduce, the more we inhibit this second stage of combustion so the more we slow the rate of temperature rise in our kiln, or in extremis, we send it backwards.

The aim should be to have just enough excess oxygen or carbon monoxide to make your particular ceramic processes work, and no more. As may have been guessed from the preceding few paragraphs, when I started poking the gas analyser probe into the kilns during firing, we found both oxidation and reduction in excess. We were able to tune the kilns for particular types of firing. So, use this gas pressure and this damper opening until this temperature is reached, then a new gas pressure and damper position and so on until firing is complete. This kiln tuning enabled us to produce standardised, repeatable, predictable firings.

An extra finding from our probe studies was that it was better not to fiddle with the primary air control on the gas burners. We found it was best to open the primary air on the burner until it started to roar, and then close it until the burner roar just stopped. It was counterproductive to have a flame like a wafting yellow wand, or a raging blue cone lifting off the burner tip. Kiln control became much simpler (and more efficient and less wasteful). The gas pressure controls the amount of fuel entering the kiln and the damper controls the (secondary) air entering around the burner. Keep it simple: two adjustables only. Often, we found that adjustments made by students (and in some cases staff) were having opposing effects in the kiln. Not useful.

Vehicle exhaust gas analysers are now much cheaper (about a quarter of the price of 30 years ago) and are well within the range of a ceramicist or a ceramics group. For use in a kiln, some adaption to the sample probe is necessary to cool the gases, remove the condensate (of which there's a surprising amount) and filter out the smoke and soot, otherwise damage to your expensive investment will occur. In the long term the added control and precision an analyser brings to the firing process will pay for itself in fuel savings and stress relief by making your firings much more repeatable.

One of the least spectacular but important contributions we can make to greener ceramics is good firing practice. Invest in a quality digital pyrometer (type R if you can afford it), keep a kiln log, record your data (temperature, analyser readings, gas pressure, stoking rate, damper position), and graph the progress of your firing on a chart (temperature v. time). If you have regular firings to a specific cone, draw the desired temperature-time curve on the chart, and attempt to follow it each time you fire.

If you're a wood firer, what to burn? This gets a bit tricky, 'cos wood ain't wood. All trees are different but tend to fall into two broad classes: those with high levels of calcium and magnesium oxides in their ash, and those with high silica content ashes. Even within the same species of tree and within the tree itself there is variation, e.g., heart wood (less ash) versus twigs and small branches (more ash). Perhaps we can borrow the French winemakers' concept of "*terroir*", which is the complete natural environment in which a particular type of tree grows including the soil, the underlying rock type, the topography and the climate. All these factors influence the composition of the ash released when the wood burns, and by extension, the surface qualities of the fired ceramics. In some cases, we may need to find a balance between the aesthetic qualities of the work and our desire to be green. If possible, use waste wood, off-cuts from sawmills or wood shops (don't use chemically treated or preserved wood!). Link up with the local arborists or try to use weed species. If you've got space, plant some trees.

Remember, smoke does not equal reduction. What it does equate to is wasted fuel, which is not very green. To achieve reduction, we need to produce a small amount (a few percent) of (invisible!) carbon monoxide. To reduce in a wood fired kiln without producing masses of smoke requires attention and control. Some fire boxes, such as the Sèvres design first described by Emile Bourry (and further developed by Michael Cardew, Ivan McMeekin and Steve Harrison), make that control easier than others.

Kermit's pessimism notwithstanding, there ARE some easy things we can do to make ourselves and our ceramics greener.

Further Reading

I have three suggestions here. The first is Fred Olsen's "The Kiln Book". First published 40 years ago, it contains a wealth of technical information and background about different types of kiln and kiln construction. 2011 is the most recent edition, it's readily available from that well-known online bookseller.

For anyone interested in wood firing, Steve Harrison's "Laid Back Wood Firing" is essentially indispensable. First published 44 years ago and now in its 7th edition, it contains numerous plans, ideas and methods of designing and firing kilns with a Bourry firebox. It's self-published, so get it directly from Steve at: hotnsticky@ozemail.com.au

Steve Harrison and Janine King's website <https://tonightmyfingerssmellofgarlic.com> is a cornucopia of green ideas and philosophical speculation mostly about "pottery making, wood firing, art, travel, gardening and the cooking of what we grow in our garden", including lots of good stuff about energy efficient kilns. Steve and Janine's pottery and kiln factory were burnt out in the catastrophic fires that tore down the east coast of Australia in late 2019. Steve only survived by crawling into a small shelter (the size of a coffin!) hastily made from ceramic fibre blanket as his pottery burnt down and the inferno raged over him. His gut-wrenching description (with photographs) is in the December 2019 and January 2020 archive of his blog.

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Dr Richard Tarrant studied ceramics at Kempsey College and at the National Art School in Sydney Australia. On graduation, he studied sculpture at Sydney College of the Arts. He then managed an artist's organisation for a year before returning to SCA to undertake postgraduate work in ceramics. For several years he taught clay, glaze and kiln technology at art colleges in the Sydney region before entering the MSc and then PhD programs in the School of Physics at the University of Sydney, where he worked on plasma deposition and the surface modification of materials. After a period of postdoctoral research, he was appointed director of the first-year Physics lab at the University of Sydney. Richard has given presentations and sat on panels at several Australian National Ceramics Conferences, published in International Ceramics Monographs, Ceramics Technical and Pottery in Australia/Journal of Australian Ceramics and written catalogue essays for exhibitions by Gudrun Klix and Sandra Taylor.

With his wife and partner (American-Australian ceramic artist Gudrun Klix), he has recently moved to the north coast of the state of New South Wales where the renovation of two old rural buildings (using a lot of recycled materials!) into ceramics studios and a large kiln shed is nearing completion.