Low-cost, Low-emission Charcoal Kiln Design Elements, Version1.
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Much of this text comes from discussion with many colleagues, who in turn stand on the shoulders of the past giants, who are their teachers.

A useful URL:
http://www.fpl.fs.fed.us/documnts/fplr/fplr2213.pdf

For now I want to talk about basic Design Brief Essentials, then design particulars.
The design essentials identified so far :

1. **Good conversion quality of feedstock to char.**

Requires:- 500C core temp of char vessel (need: probe), therefore ~800C outer firebox temperature, and enough thermal momentum to hold the firebox temps for an hour (soak); therefore efficient insulation R values, and thermal mass, so: firebricks and cladding/mudding are favoured. Additional small bourry box for soak may be necessary.

2. **Clean burning in terms of GHG and visual and environmental pollution.**

A suburbia essential. In the first 10 -15 minutes there is a tricky juggle of airflow, start-up fire fuel mass and dryness. This is the nutshell of the task. Big airflows imply a good height of sealed chimney/stack/flue or fan forced air. The idea of a small "jockey" firebox, like the bourry box, at the flue end of the kiln, may be the best for consuming any smoke from the startup of the main firebox, and any unburned post-pyrolysing gases. This would be done by including the unburned gases in the air feed to this start-up fire, for ~15 minutes. Cladding and ducting this hot envelope of air and smoke on start-up to the air inlet venturi will help emissions. A cyclone added to the flue outlet will remove particulates.
Hot operation should be clean and easy to adjust air/fuel ratios, once draught and pyrolysis begin.

3. **Efficiency in terms of utilization of waste heat.**

At operating temperatures the kiln will provide excess heat. Attached to the cyclone and flue could be heat exchange coils in 3/4" copper, or water-jackets in stainless steel. At the low-tech end, just any metal tank, an old copper, 44's, gas bottles. Waste heat can be well used for drying feed-stock, after attending to fire risks.

4. **Low tech, low cost, replicable design.**

Not much choice on a burnt shoestring budget, other than choosing materials and processes that can be found in other countries, e.g. discarded oil drums, sheet metal from car bodies. Bricks could be purpose made for the kiln, and I see many reasons why unfired, high grog bricks included in the hottest part of the firing might be a whole new aspect of "breeder reactor kilns" that replicate themselves over 1/2 their lifetime...> exponential growth?

5. **Quality of char**

Char quality here will be a function of feedstock quality and moisture content, given that we can accurately control temperatures and emissions. Here is where Lukas Van Swieten's Pyrograms will help us fine-tune, look for crystobalite, and assess metal contents. So long as we can maintain the ideal conditions, and don't use CCA, wood painted white before 1975, and wood growing in cyanide gold mining holding pond runoff... we're set. Therefore, I see tip waste wood being a big problem. So many unknowns, and many people paint CCA to stop contamination.

6. Ease of operation - loading and unloading.

Here the decisions will have to be made on side or top loading, and stoking bays and handling areas. I have written before about the need for dedicated charcoal sheds and drying/storing areas for fuel, especially in Northern NSW. My first take is a larger-than-first-thought shed, with dirt floor, and a "Ken Kern" ferrocement kiln floor in fibrecrete, with integral piers into the subsoil, perhaps a major footing in bottle and rock rubble at the stress points for door pillars, jambs or chimney stacks. Waterproofing is an issue, as wet bricks make hopeless kilns, so the minimum is: membrane below and good roof above. Stoking bays and handling areas could be "grown" using "breeder bricks"

7. Safety, including bushfire.

Here the one that worries me is CO, as it is odourless, so a work area CO level + alarm system is a first priority, and a side-less shed with a good slope on the roof will help with this. High pressure water is a given; so important. A tank and standby gene if not available, especially out west. The usual fire gear and first aid, including aloe vera plants growing next to the rain tank, would be well used I reckon. All hot handling with leather aprons and gloves, and boots for fire-walking... (or bare feet?)

Other than that, contacting the Firies might be good politics. They were very friendly at the NCN Show, and impressed with the mystery spark arrestor on our prototyping kiln.... except our flue gases were pristine, clear and shimmering... how wonderful.
So that's: Design Brief Essentials 1 -7
Now all the little details

<u>Low-cost low-emission Charcoal Kiln preamble.</u>
This kiln is fundamentally different to a pottery kiln in that it is firing a fuel load, i.e. not a damp mass of clay and bricks, for up to 12 hours at 1300 deg C. We are firing some thin-walled pyrolysis drums containing a fuel load, and giving @20% more heat than needed, once pyrolysis is started, and for just a few hours at high temperatures, but not more than one hour, at ~800 deg C outside the drums and ~ 500 C inside. This is a much lighter duty cycle than for a pottery kiln, so we can expect good longevity.
<u>Particulars of the design by elements.</u>
The Particulars might include: flues/chimneys/stacks, fibrecrete, flue controls, cyclones, kiln walls, structural bracing, doors & loading access, floor, sheathing/skinning, hearth bricks, pyrolysis drums, steel cylinders, saggars, bourry boxes as priming fireboxes, shelves, ducts, lids/roofs, air pre-heat, sensors, manual air controls, servos/actuators and control devices, climbing kilns.

So one by one, starting at the hot end.

<u>The Flue</u>. I personally think here lies the secret. Draught, for free.
Probably best to try to find some 8 - 10 inch stainless flue at a Tender centre. For a 1 cubic metre kiln I am assuming a generous 250mm dia. flue tube equivalent. A bulk find and purchase

of used 8 - 10" tube would be a godsend for pyrolysis units too. Flue tube is portable, and light and extant, and allows the welding/rivetting on, of damper butterflies, and diversions to flaring nozzles, pre-heat chambers etc, after the draught is well established. Heavy tube is indicated at control areas. Action: Whyralla Rd Stove shop. Tender centres. Tip shops.
Failing this, mild steel tube of similar dimensions, but the lifetime is likely to be shorter - offset by availability, price. Action: scrap dealers/farm sales.
Failing this a cheap tube bending machine can be made to use scrap sheet. An interesting option might be car roof/van side sections, rolled into pipes. I want to build one of these for my workshop anyway, but can't find the link or file. It is just a "sawhorse" made of two large round pipes with a small ~ 3mm gap, to feed sheet into and bend by hand.
A Chimney, may be available as a unit from a scrap/farm sale, but presents a transport issue above 8 metres in length. Avoid Asbestos Cement.
A Stack could be built from firebricks at the hot spots, and commons, and rendered for draught tightness. See the bourry box picture below.
Fibrecrete flues are a definite possibility, made in sections with flanges that bolt together. At the very least, High temperature sections of flue that also change direction are ideal places to use fibresteel cement. A standard refractory mix I use for firebox repair is 1 part lime, 2 parts sand, 1 part cement,1/4 part fibresteel. The entire length of chimney could have a refractory slurry, or firebrick lining, for a permanent installation.
[Fibresteel was an Australian invention by AWI (Aust Wire Ind.) bought by BHP, bought by ?Metalcorp, Habib Drive. ~$40/20kg box.]
Fibrecrete allows mass production of specialized shapes and sections of kiln furniture, and is available in stainless steel fibresteel (7x price). Mild fibresteel has good stability as general concrete and firebox cement applications. 10" of fibrecrete is used in bulldozer factory floors. Many roundabouts, e.g. Lismore's, are one pour of fibrecrete and no reinforcing mesh. It is used in explosive testing factories, and shotcrete pools. It has an expected lifetime in a waterproof 3:1 mix of hundreds of years, and is free of "concrete cancer" issues. As it is neither metal nor cement, fibrecrete doesn't cut well with metal or stone cutting devices and is used for thermic-lance-proof strongrooms. I have cast it, rammed it, hammered it into moulds and rendered it, with gloves, as a ferrocement skin from floor, to right over the top plate, as an integrated "cyclone bolt". Astonishing stuff. I have one experience with forgetting a slot in a casting, and having to machine it with a diamond saw. I now call it permacrete. I am not a fibrecrete salesman, I just respect it a lot. Definitely a "good to the 7th generation" material.

Flue Controls are essential for balancing the air inputs, and for shutting the kiln down for a soak period, or opening wide open for a cooling cycle. Butterfly damper valves require inserts, but allow easy rotational control. Sliding dampers are easier to construct and probably install/service, without moving the flue. Kiln shelf can be used as a sliding shutter in steel guides, otherwise flat cast iron fuel stove leftovers, or just heavy scrap steel (25mm) to control distortion-sealing issues.

Cyclones precipitate particulates by cyclonic centrifugal motion. Maybe centripetal force on the gas, and centrifugal on the solids?? Cyclone filters are used in the woodgas conversions of IC engines, and can be as simple as a metal garbage bin with a top entry port on the tangent and an exit point on the bottom axis. To clean take off the lid to sweep out the soot when it's cool. If things went well it shouldn't be necessary... but the action can also be used to pass the hot gas over a heat exchanger for hot water, and to cool the exit gases below 800 C for NOx issues. (what temps do they *start?*) As cyclones in woodgas operate on suction from the intake manifold, sealing will be opposite to a 'pressurised' cyclone from the kiln exit. Pressure-cooker type flanging? The garbage bin on the right in this pic is the cyclone:

http://www.intergate.com/~mlarosa/images/woodgas/monorator-goo.jpg

Fibrecrete and or sliding shutter devices could divert the exit gases from direct-to-flue during start-up, to direct-to-cyclone when hot (?10 mins into burn?) Some fun days of design there...
I make my hot water using wood, due to low solar insolation in the wet season, and I have successfully used a firing chamber of 3 truck brake drums, each in 5/8" cast steel x 20" dia x 12" high. A slab of 3/4 plate makes the lid. It contains 20 turns of 3/4 copper tube, as heat exchanger by thermo-syphon, to the hot tank. It was designed to boil 50 gals in 1 1/2 hours, for a birthing bath, which it does, still, for 20 years later. It has been rebuilt three times, using the same drums, coil, and stainless flue, different bricks and fibrecrete. Creosote builds up and burns off in the normal firing cycle. It would make an ideal 30 - 50 year cyclone-cum-water heater. Max Graham has 20 brake drums he'll sell for a song…

<u>Kiln Walls</u> of firebricks will have the lowest thermal conductivity for the cost, and so present the best insulation. Wall construction is going to be defined by the decisions on access. Side access is possible via arches that are bricked up for each firing, a traditional well-proven method; above a metre gets tricky with stability. "Space wool", "Durablanket", AlOx, and exotic insulation will add efficiency but at much greater cost. They are harder to fix and fragile. They may however be justified in a bourry box preheater lid on hinges:

http://www.sidestoke.com/JohnJames/Kilnscan5b.jpg

That way the preliminary fire is super-efficient, and can capture charcoal, after it is shut down.

<u>Structural Bracing</u> in dry brick walls over a metre is needed, by steel framing and strapping, especially at the hot (moving) end, and for the stack itself. Framing is absolutely essential for lateral forces on the walls, if a fixed roof of a catenary arch in compression is used. Less important if a steel-framed flat, hinged or sliding lid is used, that has it's own support system, such as a jib, or tracks, or hinges, or axle-posts. The bottom course of bricks needs to be especially well laid and mortared.

<u>Doors</u> are days of design. Any swinging door will have to have in-ground footings and diagonal bracing, not impossible for the convenience factor of loading-unloading cycles, and good for a permanent kiln. A light door (one human limit lift ~ 40 kg) can be made in steel and durablanket. Expensive but could contain the fixed, expensive stainless steel controls and servos. I could see it being lifted off pin hinges, and taken away for servicing, modification, updating, security. Doors could also slide, if too massive for hinges, and I have two 6' lengths of railway line as prototype possibilities, that could also manage the whole load, with doors. Then I see a flip-flop design possibility, that could allow cooling, and then loading the next batch, while the main chamber stays hot, firing the alternate load, sliding a bit like two drawers in a matchbox. (not really:) KISS will win here. It may look like this!:

http://farm3.static.flickr.com/2248/2136783613_1eb4588fd2_m.jpg
or this
http://www.studiopotter.org/articles/img/art0010j.jpg

Kiln Floor needs a moisture barrier membrane 150mm below the soil, under the kiln floor, can be almost any scrap polythene and laid in many plies, to stop up holes and cracks. Directly below the kiln floor should be a thin layer of screeded-level crusher dust, on top of a thin sheet of steel, old signs, corro, or even a dedicated fibrecrete slab and footing.

Sheathing or skinning could be expensive. It is not essential and mudding will stop a lot of smoke. Sheathing could hang off the framing steel in panels. [Old signs, corro; a cheap option may be to brick up the inside of a skip, or some ancient washing machine bodies might make great small kiln jackets to brick up inside. Also ancient fridges and giant freezer bodies might be great. Sometimes they have re-useable fibreglass insulation batts, and not styrofoam. Everything with paint needs to be burned in a very well established hot fire with extra air. Don't tell the EPA I said that]
The advantage of a skin is the control of air entering the whole kiln via intentional ports or tuyeres, and through the unintentional interstices in the walls. This airflow rate can then be damped or fan boosted. In addition, as the air licks over the brickwork, it is pre-heated for the main intentional entry points. A third advantage is that, on start-up, the inevitable few minutes of smoke is captured and fed into the firebox. Skinning will be an issue in the burbs, not on the simpler farm systems, though skinning does then allow a further cladding in glass-wool or even fire-resistant timber like ironbark and turpentine flitches. KISS rules. Mudding works if you have lots of labour.

Hearth bricks need to be pyroclastic ("plastic") firebricks for the hottest areas, and 'commons' for wall sections not under stress, and for chimney stacks above ~2 metres. Some commons from older kilns, esp SE Queensland, are quite good at high temperatures. Bricks with frogs, not holes, preferred. Some very high temperature soft bricks to carve might be good at $10 ea, for spy holes and special applications. A low-firing high-grog raku clay body could bisque fire into bricks with the temperatures we are developing, and the kiln might be able to replicate at least some of its own low temperature brickwork zones. There is no reason why, if it was designed well, that it couldn't be used when hot to do higher temperature firings in a dedicated non-charcoal section.

Pyrolysis chambers
Our plan is to have sealed pyrolysis chambers to make sure we get maximum yields, and can burn the off-gases with oxygen-rich air. Two methods present themselves and they are not mutually exclusive. The Show firing had both the Folke Guenther Inverted Drum barrels, and dedicated pyrolysis vessels, in mild and stainless, with fitting lids and nozzles. the FGID drums did not get disturbed by stoking, but weights or other constraints might be good.
The smaller vessels could be placed on end, on their side or in small voids. The surrounds of the vessels could be packed with newspaper and firewood in cut lengths to suit the firebox height, thus minimising stoking. This would shorten firing times and lessen the load of the firing overseer. I am estimating the filled volume of the kiln to be 2/3 pyrolysis vessels and 1/3 voids, filled as much as practicable, with fuel and kindling.

The first thought failed so far: truncated SS beer kegs. Great steel, and small ones are about the right size; there's hope if we can contact someone inside Carlton United Brewery, and pull their climate change heart-strings, for damaged drums.
Second thought is of using capped s.steel flue sections for good surface area to volume ratios, that also copy in miniature, the remarkably successful Russian kilns, the EKOLON, the POLIKOR, and mobile POLYEVKA.

http://www.repp.org/discussiongroups/resources/stoves/Yudkevitch/charcoal/ekolon.html

http://www.repp.org/discussiongroups/resources/stoves/Yudkevitch/charcoal/photo2.html

http://www.repp.org/discussiongroups/resources/stoves/Yudkevitch/charcoal/mobilkiln.html?owner=bioenergy-spb

My experience with open firing of FGID 20 litre oil drums, was that attendance and continuous stoking the fire was necessary, in excess of 2 hours, to ensure the centre of the drum's load was charred. I think at 35cm the dia. is too large for the surface area, and an ideal size of cylinder would be in the 20 -30 cm dia range. (8 -12 inch flue pipe for e.g.) Filling the pipes would best be by hopper and chips. Another fuel process though. Chunks of wood in the 50mm range is ideal, or long sticks, if straight sticks in metre lengths are accessible, eg bamboo, scantling. There is a long stick gasifier extant.
Steel cylinders conduct better, but stainless steel lasts longer, maybe 100s of firings. Steel is accessible and old machinery sales could turn up suitable tube. However rust will allow air access, and ruin the efficiency, so sound pipes are needed.
A Saggar is a piece of pottery kiln furniture that is essentially a ceramic box with ceramic lid, allowing the pots inside to be fired with different conditions to rest of the kiln. Inclusion of carbon ensures a reducing atmosphere for some glazes for example. As the conductivity is poor and the costs high, it is unlikely to be a practical pyrolysis chamber, except at the high temperature end, or using convivially produced thin-walled versions. They have the advantage of stacking, and batch-style pre filling.
Metal saggars, that is, biscuit tin-like pyrolysis vessels could be purpose built, and have legs that allow stacking and good gas exit and flow-through.
I used kiln shelf stand-offs to space tins in the Show firing. Bricks fragments cut with a bolster would be fine.
A consideration with pyrolysis tins is the expansion of the fuel load. We pyrolised the Australian Master Tax Guide at the show, in a biscuit tin. We had to make it do something useful to justify its footprint. As if to copy its creators, it puffed itself up, expanded the tin, popped the lid and self-combusted. How apt. About 30% was recovered, the rest, ash. It was the only failure. So tins need a positive cliplock, or self-tappers. This would help in coping with loading stresses.

Bourry boxes are really what we're building in a sense. A bourry box kiln has a dedicated firebox, with hinged top-load lid, that pyrolises wood and feeds the woodgas and air into the kiln in an easily controlled fashion. This site also shows a reinforced stack and double-bourry kiln that is exquisite.

http://www.sidestoke.com/JohnJames/doublebourry.html
The difference is that a lot of our fuel in our 'bourry box' is enclosed in tins, and only the woodgas will be used, leaving all the charcoal behind, while the other fuel wood in the box will be consumed, powering up the pyrolysis. It seems that a good bourry box can conserve any leftover charcoal not used in a pot firing, by closing the chamber down. So it seems like a good idea to add a bourry box, at least as a pre-heater of the main chamber, and so allow continuous stoking without disturbing the setting. This would also minimise heat variation when stoking, and also allow stopping down when pyrolysis finishes, or core temps reach 500C. It may well turn out to be the main chamber heating process.
FGID pyrolisers rely on a flat surface, with good refractory nature. I have stacked drums on kiln shelf [stable to 1200C], with good result. Expensive. We can definitely fire high grog terracotta shelves for pyrolysis vessels to sit on, and I am thinking we are channeling the Pre-Columbian Indians here, as large amounts of shards are found in terrapreta, as if they are some essential part of the process, hehe. Some TP folks have suggested platters as sources of these shards.
Cast iron base plates work too. Old barbeques.

Ducts, and complex custom cast fibrecrete floors are possible, with drums set on a firing ring, allowing gases to exit at nozzles, inside [or outside!] the kiln. Months of fun...
With Tuyere-supplied air, driven by a good stack draught, high efficiency designs can be fine tuned, fairly simply. Almost rocket science, but still accessible. Anyone having used a chip heater knows how well tuyeres work, even simple cones. A shower on a Sydney Morning Herald.
Rock science:
http://www.wealdeniron.org.uk/Images/Excav/7.JPG

Rocket science:
http://rocketdynearchives.com/images/643_saturn5_F1_tuyere_Rocketdyne_archives_boeing_ssfl_santa_susana_field_lab_nuclear_laboratory.jpg

The Lid and Roof options will come out of decisions on loading and access. Cheap reliable, extant designs use a fixed chamber roof arch, usually a catenary. This is easily generated by an upside down hanging chain, or a la Gaudi, and the Sagrada Familia (oh my), using plaster-soaked muslin, allowed to set while hanging in the dimensional constraints. It is very easy an accessible and I ave done it with cotton mosquito net.Or maybe The bricks are set on formwork shaped from this template, later removed, and rely on the self-supporting arch of bricks, rarely keystones, and usually lateral bracing/collar ties.
A lid removed means quick cooling, if desired. If the lid is a flat slab it could hinge up, or be raised by pulleys, or tackle or jib, or slide or roll on rails or guides, or swing on a pin. This allows top loading of drums and fuel, and allows walls to be substantial and structural, rather than having bricked up side entries. A disadvantage is the total mass of filled, unfired drums will have to be small enough to allow handling... 30kgs... or maybe the jib again? Or maybe low walls to load over? The top end EKOLON used travelling cranes to handle 20 tonnes per load. KISS.

Pre-heated Air is a great boost to efficiency, by burning all those Poly Aromatic Hydrocarbons.

Hot air allows the firewood in the main setting, the char gases in the pyrolisers, and the fuel in the bourry box to burn better. Apart from the cladding mentioned above, it is possible that parts of the kiln will become too hot, and need ducts built below or within them to allow “cooling” air to circulate before entering the kiln. I'm guessing these will be at the flue end, and the walls and floor in that area. If NOx and temps above 800C are to be problems, especially with crystobalite in sugar cane or bamboo, then cooling may be essential. Unlikely, really, unless the kiln is in continuous batch mode.
Manual Air Controls are manifold (ha), and some could connected by simple, adjustable link-rods. A few come to mind: simple slides with slits, rotating discs with holes, venturi inserts with different outlet nozzle sizes, a simple fire door with ratchet latch, down to a hole with a brick stuffed in it. KISS rules again. Bricks are hard for fine motor control...

Sensors are essential for QC, and can be bought cheaply at Jaycar, where multimeter pyrometers are $30 each. I suggest 3 meters be used and separate probes could be bought at about $10 and the 'wandering' meter used on them, with 2 dedicated probes and meters one at the firebox exit zone, and at the top centre of the kiln. Jaycar meters have an inbuilt thermocouple to read ambient air when the probe is off. Non-contact IR thermometers will be essential for trouble shooting thermal leaks.
CO monitors from wreckers or Jaycar can be installed at the very top of the flue exit, CO alarms in the workplace. Research needed there.

Servos can be simple actuators like car door lock solenoids, good in safety design. Slide controls allow for actuators using worm drives found in eject mechanisms in CD players. Rotating controls allow for use of stepper motors and simple logic controls and position sensing. Very likely that a tuned kiln could be set up on a picaxe chip for $2.50. Someone else's PhD, probably already out there. KISS might make the use of thermostatic springs, now in use in fuel stoves, a real possiblity.

The Climbing Kiln is the next logical efficiency step, and the next kiln to be built would ideally be on a pad, just up-slope, in the next shed... and so on. I wish we had the culture to produce the ambience of the traditional noborigama, anagama, or jagama kilns:
http://flickr.com/photos/17228033@N00/3629194

Climbing kilns are also known as dragon kilns, and this view inside might show why:
http://bp1.blogger.com/_Qubu6A_-eDs/Rn-fMJYIR6I/AAAAAAAAAWM/94akb_ndhv4/s1600-h/kiln.jpg

They use rising, sometimes sinuous, chambers, connected so as to capture the flue gases and use them to pre-heat the upslope chambers. Dragon kilns are as long as 200', and are clearly a preferred, convivial, community kiln, with centuries of proven efficiency in Japan and China. We could do events and build Aussie versions in corrugated iron, and cook pizzas and chapattis on the kiln lid, while crews stacked green biomass in solar tunnel-kiln dryers, for next seasons Chapatti Char-Party, and the cyclone heated the hot tub… Harhar.
End rave.