4C Kiln for Combined Heat and Biochar (CHAB): Introduction

Paul S. Anderson, PhD [Email: psanders@ilstu.edu] [Website: www.drtlud.com] (Version. 2019-01-23)

Preface:

The objective of this document is to make available worldwide the information about the 4C Kiln and related technologies for the creation of char, heat and residual products from diverse biomass.

This document is a loose combination of materials prepared since 2014 in several documents. Expect some inconsistencies, duplications, need for editing, and lapses. This is not a document for beginners. Terms are sometimes used without definitions. Different documents could show conflicting approaches.

Note that the name is now 4C Kiln instead of C4 Kiln.

Future versions of this document should include contributions by those who are reading these pages. Refinement of the materials now would cause further delays.

Introduction:

Whether for reasons of climate concerns, excessive biomass, desire for financial gain, or other reasons, there is a need for an "appropriate" way to make large amounts of charcoal and, if possible, utilize the produced gases or heat. An excellent overview with 50 slides of many methods is provided by Kelpie Wilson on Slideshare at https://www.slideshare.net/kelpiew/flame-carbonizers-for-biochar-in-practice-and-theory . One method or technology called "flame cap" (FC) is utilized in the 4C Kiln.

The conceptual design of a 4C Kiln is essentially a "semi-gasifier" or a "pyrolyzer" that uses the principles of a "flame cap" (FC) char-making device.

A 4C Kiln is not a TLUD (tee-lud) gasifier because it does not have a migratory pyrolytic front (MPF).

A 4C Kiln is not a full-fledged gasifier that would typically consume the charcoal.

Name and Justification (revised from 2014-10-02 wording)

A kiln is somewhat related to an oven or furnace. It can have many shapes and variations. The key shape for FC devices is a "cavity". Flame Cap devices are often shaped as inverted cones or pyramids, or as troughs or trenches. All of them are cavities.

4C stands for 4 words that start with C: Controlled Continuous Covered Cavity. Different from other cavity kilns, this one is Covered (for the most part), can be operated Continuously (or in batch mode), and can be Controlled in various ways in different configurations.

Objectives of 4C Kilns:

To be able to convert substantial quantities of dry biomass into charcoal.

To be relatively inexpensive, long lasting, efficient, and clean (with minimal emissions)

To work with a wide variety of biomass types, perhaps with some modifications of the biomass or of the 4C Kiln itself.

To utilize the heat and any other benefits from the device, when possible.

Notes on Cavity Kiln Characteristics:

Cavity Kilns have oxic pyrolysis (air enters into the top area) and anoxic protection (or collection) of the created char (because air does not get down into the char that is accumulating.) This could be referred to this as Oxic Pyrolysis Anoxic Protection or Collection, or either OPAP or OPAC

Interestingly, there is another OPAP / OPAC device that is well known but is vastly different. The TLUD devices have oxic pyrolysis and the char is preserved/ protected/ collected ABOVE the migratory pyrolytic front in an anoxic environment.

NOT all pyrolysis processes can be simplified into OPAP or APOP or OPOP or APAP terminology, so these are only descriptive acronyms that are *not* intended to be a product or process name.

The cone and pyramid kilns are generally not controlled, not continuous, and not covered. And devices or methods that do have some degree of controlled, continuous, OR covered (but not all three) are not (and have not been) recognized as ways for intentionally making char in quantities other than incidental char with considerable ash.

Technology:

Controlled Continuous Covered Cavity Kilns (4C Kilns) produce charcoal from dry biomass by pyrolytic heat that originates from controlled oxic-flaming (oxygen present) of some pyrolytic gases, with the char being saved in an anoxic (oxygen absent) environment lower in the cavity. The charcoal can be extracted as necessary, allowing continual operation by the addition of more fuel. The heat and any non-combusted gases exit the mostly-covered device in channeled ways and are available for appropriate usage. Control is by the limiting (or facilitating) of the entry of oxygen (in the air) at specified locations, possible because the covered nature of the device. Inert substances (potential ash) are retained in the charcoal or are extracted with the charcoal.

Functional 4C Kiln units, as seen in the first ones built and used:

Mid-year in 2014, the first 4C Kiln was made from a 55-gallon (200 liter) steel drum. Larger and smaller sizes are certainly possible and are discussed later. The specifications below are for a general description, NOT for requirements or precise measurements.

Early written material: File name: Earliest to show photos 2014.docx Selection from:

Trof [4C] Kiln Biochar Maker: **First descriptive document.** 11 June 2014 Paul S. Anderson

This document is intended for use by [ ] when making a new unit in [ ]. It is shown to others only for informational purposes on a CONFIDENTIAL basis. The size shown is a 55 gallon (200 liter) steel drum. Larger and smaller sizes are certainly possible. The specifications below are for general description, NOT for requirements or precise measurements.

This initial design is essentially a “semi-gasifier” or a “pyrolyzer”. It is neither a TLUD nor a full-fledged gasifier. The discussion of operational issues is in a separate document.

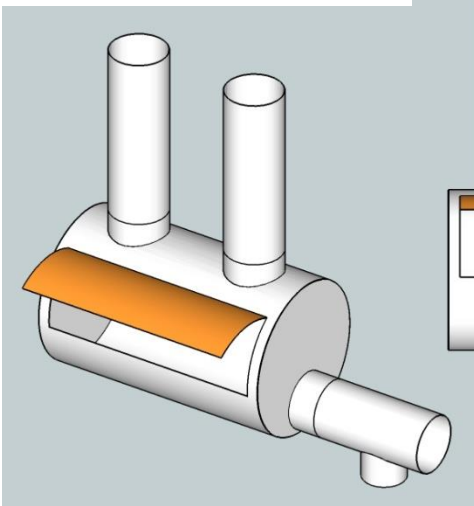
Front (left photo) and Back Views of Trof Kiln Biochar Maker, June 2014

Update (2019) information:
This early 4C Kiln is still operational. The “Trof” name has been discontinued. Approximately ten (10) 4C Kilns have been made.

I, Paul S. Anderson, have invented a process / method / device for charcoal (or char) production. As the char is produced by the heat of flaming pyrolytic gases, the char is saved in an anoxic environment from which it can be extracted as necessary, allowing continual operation by the addition of more fuel. The heat and any not-combusted gases exit the device in channeled ways, available for appropriate usage.

One model for small size.
It can be taken into agricultural fields or woodlands. These are very rough drawings of the size of a 55 gallon (200 liter) metal barrel.   Much smaller is also possible, such as for cooking meals with a single pot.

FIG. 3



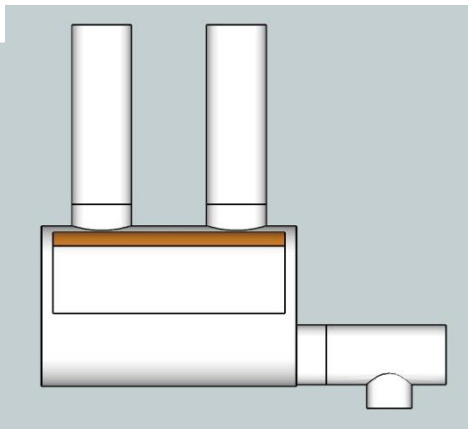


FIG. 4

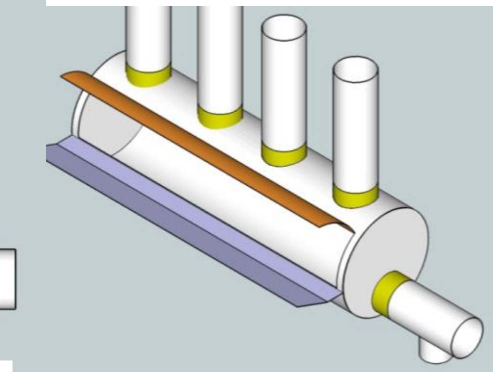


FIG. 5

FIG. 6 Prototype
Note the shelf for fuel feeding.

FIG. 7 Wood used in one session

FIG. 8 (Top)   FIG 9 Door down

One much larger unit with full automation.

Diagram not yet available. To be shown:

a. Size of a large propane tank about 6 ft diameter and 30 feet long. Or the size of a 53 ft shipping container. And even the length of whole trees (easiest to visualize the trunks of pine trees, but other trees can be appropriately trimmed.)

b. Chimneys and char extraction ports, including automated augers.

c. Multiple inlets for forced air (FA) into the region of the fuel, and not into the lower section (except for special port for assisting initial ignition).

d. An automated fuel feeder (appropriate for the types of fuels) to feed at various locations through air-lock fuel hoppers.

e. Appropriate grate to support raw fuel until char or nearly char is able to fall to the lower section for anoxic pyrolysis and anoxic holding until removal.

f. Electronic controls (such as PLC) with sensors and controls for air flows, fuel feeding, char extraction, emissions sensing, weights, alarms, etc.

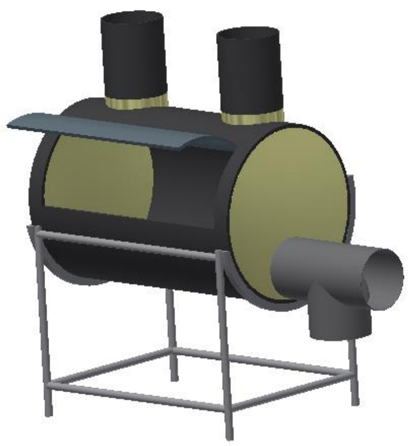
[End]

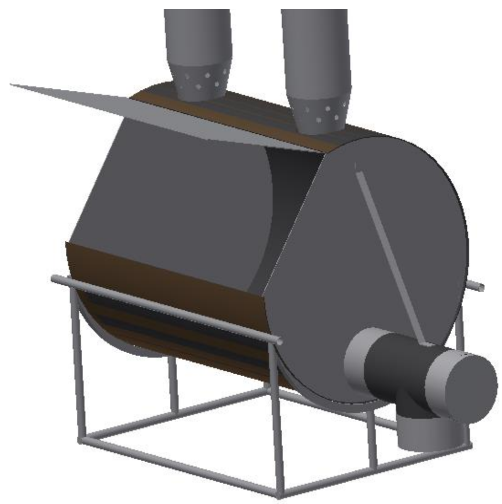
Video of 4C Char-maker Oct 2014 (Recommended for orientation.)

A video of 7 minutes shows operational aspects of a C4 kiln in the barrel size. Here is the link of the video at my YouTube account: http://youtu.be/xzhKD1Zap3c

Size (Note 1):

The 200 L barrel size (Diameter 60 cm, Length 85 cm) is convenient for small volumes and for learning. A somewhat larger one has already been produced (in El Salvador) by cutting and welding of new steel plate in sheets that are 4 x 8 ft (1220 x 2440 cm).





NOTE: Technical drawings as .pdf files with measurements are being placed on the Internet at: www.drtlud.com/resources File names 4CCM signify 4C Char Maker, followed by key dimensions in centimeters. More information will be placed there as it becomes available. Please share your learning experiences and progress, especially via the Stoves Listserv or directly to Dr. Anderson at psanders@ilstu.edu .

Construction (1): (This is the first document about construction. 2014 - Barrel size)

The basic construction consists of cutting and then mounting a hinged door, plus three holes with permanently attached short conduits (or nipples) that are 8 inches in diameter. Two are for vertical chimneys (each with a 2 or 3 foot chimney pipe) and one is on one end for char extraction (with a cap). There is also to be some form of supporting structure to prevent the unit from rolling or tipping. See discussion below for specifications and for suggestions.

Front (left photo) and Back Views of Trof [4C] Kiln Biochar Maker, June 2014

What is shown in the photos is a visual guide, but the written directions below take precedence for construction.

A. Orientation:

1. The barrel is in a horizontal position with a clear front side, back side, and left and right ends.
2. Rotate the barrel so that the welded seam is in the middle of the back side (essentially to keep it out of the way.).
3. Viewing toward the LEFT end of the barrel, consider the circumference to be a clock-face with 60 minutes marked on it. That means that the seam is at the 45 minute mark. (We use this designation later.)

B. Door:

1. The door itself is the remnant of the side of the barrel that is cut out. It is therefore slightly smaller than the actual hole (see further comments in #4 below).
2. The bottom edge of the door is to be at the 16 or 17 minute mark on the circumference of the barrel. (What is shown in the photos is at about the 12 or 13 minute mark. This change means that more metal will be at the top of the barrel for the chimneys. And the change could also benefit the loading of the fuel and the air flows.)
3. The height of the door is approximately 12 inches or 30 cm. I measured along the circumference. Door size will be a variable for possible changes in future units, in part because of different fuel types and loading systems.
4. The width of the door was almost the full length of the barrel, leaving an edge for strength or attachment to the support structure. The door is seldom closed completely because of the need for air to combust the gases from the pyrolysis process. However, because a reasonable seal might be desirable in future operations (such as to preserve the char if extraction cannot be done promptly, or for cooling the char while still inside the unit), consider adding metal strip(s) to extend the door so that it will overlap onto the edge of the barrel when closed.
5. The door is hinged. 3 hinges will be better than the two that I used. What worked very well were some scrap hinges from the centers of garage doors (see photo at right) because the pin (pivot) is off-center and then the ribs on the barrel did not cause binding. A small handle or latch is in the center of the bottom edge of the door, preventing the door from swinging into the inside of the barrel.
6. To hold the door open the correct amount, the prototype uses 2 C-clamps (see in first photo). A better and more adjustable way to set the size of the opening of the door is needed.

C. Chimneys:

1. I used rectangular heating ducts (see photo above) that become 6-inch holes and nipples. Instead, please use 8-inch diameter material directly attached to the top of the barrel.
2. The hole / chimney should be vertical but somewhat off-center toward the back-side of the top of the barrel for two reasons. a. to leave more metal for the top of the door to be secure and strong, and b. to favor the hot gases and flames to sweep toward the back of the barrel.
3. Shown are three top exits. The central one is not necessary. It only shows that the hot gases could be extracted horizontally. The use of expanders / enlargers (from 6 inch to 8 inch diameter chimney segments) is not needed and causes extra cost. But the holes (seen in the expanders) should be in a low segment of the chimney.
4. I found no need for having a damper in either of the chimneys. This simple unit is not fully exploiting the advantages of having carefully controlled air to combust the pyrolysis gases. Future and larger units will have additional features associated with the chimneys.
5. The nipples have their crimped ends pointing upward. Lengths of chimney pipe (black and thicker than the galvanized ducting for heating and air conditioning) are placed on each nipple.
6. Stability of these chimney segments is a significant concern. But because of probable transportation of the unit to different locations or for storage, the chimneys need to be removable. Please discuss with me the options that you could implement support for the chimneys.

D. Char extraction:

1. At one end there is to be a nipple of 8-inch diameter. Leave it circular. In my prototype I squashed the inner end, but it became more difficult to extract the char.
2. It needs a lid that does not leak much air. A handle on the lid/cap is useful but will get quite hot.
3. Extraction occurs when the layer of char in the bottom of the barrel is sufficiently thick, probably between 4 to 10 inches. Any non-pyrolyzed fuel is lifted above this layer so that a hoe or rake or auger or other device can pull the char through the extraction hole. This is extremely hot work, with easy solutions simply costing a bit more money: heat shield, looooooong handle on the extractor, or (best) the insertion of an auger, but it is not always inside because it will get in the way of the needed vertical mixing.
4. Consider the addition of an 8-inch diameter "T" pipe with the leg pointing downward into a safe receptacle for the char. This would require space under the T, which is accomplished by raising the whole unit higher than is shown in the photos. Char extraction will be a way for enhancing the more expensive and larger pyrolyzer units.

E. Support structure:

1. The very first units (not shown) were supported in a bed of dirt or with bricks on the sides to prevent rolling. Totally inexpensive, but too crude. Adding support structures add costs.
2. The small red cart shown in the photos does facilitate movement, but is inadequate.
3. Support structure must be appropriate (such as detachable) for the method of transportation of the unit. (To be discussed.)
4. In addition to simple stability during pyrolysis, there is need for stability during the occasional mixing of the fuel (so that the char pieces fall to the bottom and the raw or torrefied fuel is brought to the top). Currently this is done with a garden fork leveraged against the lower edge of the door frame. Quite simple and easy, but can be quite hot.
5. Consider how the whole unit could be rotated perhaps 90 degrees onto its backside, and then placed upright (chimneys upward), causing the char and fuel to move, with the larger pieces staying on the top. This too is a major way of enhancing the larger and more expensive options. To be considered.

F. Other features:

1. There are many, to be discussed after success with this unit.
2. Do consider having a long shelf perhaps 10 inches wide that attaches (and can be detached) across the lower front of the door opening. It could have a slight slope (maybe 30 degrees) downward toward the open door. Fuel could be placed on the shelf in advance of each addition of fuel addition, to make the addition easier and faster. Larger units could have automated additions of fuel. [End]

Warnings, Safety, and Disclaimers:

Be advised that the 4C Kiln technology can produce vast amounts of heat that can be dangerous to persons and property. Even when further insulation and protection is added to the systems, serious contact burns are possible. In areas of close proximity to the device, the heat has been known to damage the coatings on some eyeglasses. Note: The 4C technology does NOT involve pressurized components such as boilers, so there is not any normal danger of explosions.

Safety is the responsibility of everyone. The author and his associated entities and persons are not responsible for damages and injuries. Keep all combustible materials away from the kilns.

Use Common Sense. These devices involve fire!!!

Construction (2): (Additional notes about construction. 2016 - Barrel size)

Dear …,   5 March 2016

You already have some information (previous document) from me about 4C Kiln construction. I do not have additional specific instructions. Please note the concepts, and the I am confident that you can produce a functional unit for testing.

1. Basic item is a 200-liter metal barrel in horizontal position.

2. The barrel is supported in any functional way. The easiest are a set of simple vertical legs, or to have legs in an "X" form at each end, or to have two longitudinal bars that are attached to or pierce the sidewalls (so that support blocks / bricks / legs can hold up the barrel.

3. There is a longitudinal door cut into one side of the barrel, in an upper quarter. The bottom of the door should not be lower than the widest place of the barrel. And the top of the door is NOT at the top line of the barrel but is perhaps 20 to 30 degrees of arc down from the top. This is so that the hot gases are captured inside the barrel and are directed toward the chimneys. The door has two hinges on the top edge so that it can be opened for the insertion of the fuel. The handle(s) of the door should be at the sides so that the worker is not exposed to the heat when opening the door.

4. Vertical chimneys extend upward from the top of the barrel. Two of six-inch diameter chimneys seem to be about right, but this has not been tested.

5. For simplicity, there is no need to have any extraction "doors" at the ends of the barrel. Just let the barrel fill with char, and then remove the hot char with a shovel during the first usages.

6. Eventually there could also be a tray just to the outside of the bottom of the door. This would be used for placing the biomass fuel there in preparation for faster and easier placement into the C4 kiln when the door is opened.

Because you are probably a far better engineer than I am, I hope that you can prepare a set of drawings that we can discuss. I request simple pdf files or other visuals that do not require that I have the software that was used for making the designs.

Let's see if this is sufficient so that a basic functional unit can be constructed. This should NOT be a major project. Beauty is not important while we evaluate function.

******

Size (Note 2)

Some 4C Kilns are made from existing metal tanks of other sizes:

4C Kiln from a fuel oil tank.

(Made in southern Illinois, USA.) The tall oval shape is good. The plenum added on top might not be necessary. Used for char-making of Miscanthus, a tall reed. This is an example but is not a specific model to be copied in every detail.

C4 kiln by Paul Anderson in use in March 2018 with Miscanthus fuel to make biochar at the farm of Brandy Philips near Centralia, IL.

C4 kiln = Continous, Controlled, Covered Cavity kiln.

(No longer called C4. Please use the 4C name.)

The barrel-size unit above shows how an attached shelf can assist to feed the biomass into a 4C Kiln.

4C Char-maker Kiln 80 - 100,

Size 80 -100 (80 cm diameter and 100 cm long.)

Made in El Salvador by Gustavo Peña for Paul Anderson in2014. Many advantages, but the design still could be better. Anyone intending to fabricate a 4C Kiln from new sheet metal is encouraged to contact Paul Anderson to discuss optimization.

Size (Note 3):
Table to compare sizes of 4C Char-making Kilns:

	A	B	C	D	E	F
	Size >>>> Issue (below vvvv)	55 gallon	~140 < 180 gallon	275 gallon (5 x 55 gal)	550 gallon (10 x 55 gal)	1000 gallon (~ 20 x 55 gal)
a	Diameter / Length	2 x 3 ft		27x44 " x 5 ft (~ 3 x 5 ft)	4 x 6 ft	4 x 11 ft
b	Fuel input (estimates per h)	25 kg ~50 lbs			250 kg 500 lbs (Quarter ton)	500 kg 1000 lbs (Half ton)
c	Char output (w/ 20% yield)	5 kg 10 lbs 1 wheelbarrow (WB)			50 kg 100 lbs 10 WB	100 kg 200 lbs 20 WB
d	Thermal energy output as 70% of total (30% in char) 12 MJ/kg 8 K BTU/lb	300 MJ 83 kW-h 284 K BTU	Almost 1 M BTU (Under EPA interest)	1500 MJ 415 kW-h 1.4 M BTU	3000 MJ 830 kW-h 2.8 M BTU	6000 MJ 1660 kW-h 5.6 M BTU
e						
f						

	A (repeated)	F (with new units)	G	I	J
	Size >>>> Issue (below)	1000 gallon (~ 20 x 55 gal)	2000 gallon (2 x 1000 gal)	4000 gallon (4 x 1000 gal)	To be determined (10 to 20 K gal)
a	Diameter / Length	4 x 11 ft	5ft 4in x 12 ft	5ft 4in x 24 ft	40 ft. shipping container~18 k gal.
b	Fuel input (est. per hr)	500 kg 1000 lbs (Half ton)	1000 kg 2000 lbs (One ton per hour)		
c	Char output (w/ 20% yield)	100 kg 200 lbs (New volume ???)			
d	Thermal energy output as 70% of total (30% in char) 12 MJ/kg 8 K BTU/lb	6 GJ Gigajoules 1.66 MW-h 5.6 M BTU	12 GJ Gigajoules 3 MW-h 10 M BTU	GJ MW-h M BTU	GJ MW-h M BTU
e					
f					

Size (Note 4) and Past Business Notes

Another statement about sizes of 4C Kilns is on the next page. It comes from a document that was written with commercialization in mind, named Business Overview Draft 6, 2014-09-29 provided as a .pdf . Circumstances have changed, the Juntos Energy Inc for-profit corporation was not created, but the vision of worldwide usage of 4C Kilns is still very valid.

Extract from **Business Overview Draft 6, 2014-09-29**

Seven Categories of License Arrangements:

To show the seven categories of license arrangements, the array below has “Size and Complexity” on the X-axis, and “License Arrangements” on the Y-axis. Sizes include Small (volume under 250 liter (<60 gallon)), Medium (250 to < 1000 liter (<220 gal.)), Large (1000 to < 5,000 liter (<1000 gal.)), Mega (> 5,000 liter) and Specialty Units associated with specific operations and applications.

The seven categories of License Arrangements correspond to production sizes of single units, limited production (such as < 10 per day), industrial production, national partners / associates, and the international / world entity. Definitions and terms are subject to change without notice, but changes are not retroactive to existing licenses. See the additional notes for further explanations of the different cells and options.

<table>
<tr><td></td><td></td><td colspan="4">Size and Complexity of 4C Kiln Units</td></tr>
<tr><td rowspan="6">License Arrangements</td><td></td><td>Small Units: Barrel & smaller
(<250 liter (<60 gal))</td><td>Medium units:
(250 to < 1000 liter (<220 gal.))</td><td>Large units:
(1000 to < 5,000 liter (<1000 gal.))</td><td>Mega sizes & Specialty Units</td></tr>
<tr><td>Single-unit production</td><td>1A. DIY users: First license is free. Required registration.
1B. All others: US$25.</td><td colspan="2">2. Innovators & experimenters: Licenses are negotiable and encouraged for the advancement of renewable energy and biochar.</td><td>6. Special entities: Grants & special projects are negotiable.</td></tr>
<tr><td>Limited Production</td><td colspan="2">3. Artisans and small entities: Limited numbers of units produced under license agreements with JE World or with JE National companies.</td><td>To be arranged.</td><td>6. Special entities: Special contracts are negotiable.</td></tr>
<tr><td>Full industrial and commercial production</td><td>4. Industrial manufacturers (incl. dealers & advocates)</td><td>4. Industrial manufacturers (incl. dealers & advocates)</td><td>4. Industrial manufacturers (incl. dealers & advocates)</td><td>6. Special entities: Special contracts are negotiable.</td></tr>
<tr><td>National Partners and Associates</td><td colspan="3">5. Juntos Energy [National], LLC, SA, Inc, LLC: Organized in individual countries with local partners / associates for sharing IP, patent rights, licensing and responsibilities. The various JE National companies are linked together as the Association of Juntos Energy National Companies for collaborative development.</td><td>6. Special entities: Special contracts are negotiable.</td></tr>
<tr><td>Inter-national / World</td><td colspan="4">7. Juntos Energy, Inc: (aka JE World)
Issues licenses, etc concerning IP associated with C4 kiln technology. (JE World is the licensed agent for Paul S. Anderson, originator of C4 technology.)</td></tr>
</table>

Quality of Char from a 4C Kiln

ANALYTICAL CHEMISTS
and
BACTERIOLOGISTS
Approved by State of California

SOIL CONTROL LAB

42 HANGAR WAY
WATSONVILLE
CALIFORNIA
95076

Tel: 831 724-5422
FAX: 831 724-3188

Account No.:
Lab Number No. Acct.#
Batch
0 1
CODE:
Code
www.controllabs.com

Paul Anderson

Date Received:
Sample Id.:
Sample id. Number

Proximate Analysis

	as-Received	Dry Weight	
Moisture	50.51	0.00	percent
Bulk Density	0.340	0.168	g/cc
	21.21	10.50	lb/cu ft
Carbon (C)	41.8	84.5	percent
Hydrogen (H)	1.83	3.70	percent
Nitrogen (N)	0.4	0.9	percent
Oxygen (O -calc.)	0.1	0.2	percent
Ash	5.3	10.7	percent
	100.0	100.0	Sum
Butane Activity	2.9	6.0	g/100 grams

Comments by Frank Shields:

Based on our testing it looks like excellent char. The ash is 10% so reporting on an ash-free basis it brings the carbon much higher in this natural fraction. The butane activity is a mid-ranged based on typical findings on dry wt basis.

The interpretation of the stabilized carbon is from work reviewed when development of a test procedure for this. It was found the H/C ratio molar basis was < 0.7 in old chars found and being conservative it was suggested we only give it 80% as called 'stable fraction'. These values and rating is not 'official' and only best I could come up with based on the info I had at the time.

Interpretation

H/Corg.	0.53	0.53	
Stabilized Carbon	33.5	67.6	percent

The H/C ratio must be below 0.7 for the carbon to be considered stable. And because some may still not be stable we calculate at 80% of the total carbon stable.

Interpretation

Range (based on typical samples received)	Rating relative to biochars
Moisture	High
Stabalized Carbon (est.on H/C Ratio and total dry wt.)	High
Bulk Density	Low to Mid.
Ash	Med. To High
Activity	Low to Mid.

Analyst: Frank Shields

A Division of Control Laboratories Inc.

Table of Char Production Methods and Devices (Revised Draft, 2014-08, PS Anderson)

Aspect / Method	Chapter in Taylor	Batch or Continuous?	Small, Med., & Large	Price comments	Established vs. Newness	Timeframe for impact	Oxic or anoxic char process	Char characteristics
Fire focus		Char production is unintentional						
Matchstick	Chapter 10	Batch	Micro-size	Educational demonstration	Universally known	Only for education	Oxic, with unlimited air	Not analyzed; not important
Forest fires & Grass fires	Not discussed	Batch	Small to large	Destructive (to be avoided)	Natural	No viable benefits	Oxic, with unlimited air	Superficial char on wood
Campfires & Many simple cookstoves (ICS)	Not discussed	B or C, depend on users and devices	Small	Free DIY to $200	Widely known	Not suited for char prod., so low impact	Oxic, with unlimited air	Minimal char, mostly ash
Charcoal focus		Char intended to be eventually burned, but recent interest in use as biochar						
Traditional charcoal making	Not discussed	Batch	Mostly small to medium	Free DIY to $1 K	Ancient use with variations	Destructive of environment	Anoxic or almost anoxic	Low-temp w/ volatiles
Modern charcoal making	Ch. 2	Batch	Medium to large	????	Industrial sizes	Not intended for biochar	Anoxic or almost anoxic	Low-temp w/ volatiles
Retorts	Ch. 10	Batch	Small to medium	Free DIY to $25 K (Adam)	Ancient use with variations	Potential, but not yet proven	Anoxic or almost anoxic	Variable with intended use
Cone kiln	Not discu	Batch	Small to med.	DIY to $1 K	Japan & new	Not yet proven	Oxic	Seems good
Gasifier focus		Char saving is optional and usually ignored						
Some incinerators & industrial systems	Currently not intended for char production		Large size, no biochar apps.	Est. $5 K to $100 K	Existing but not for char	Not intended for biochar	Oxic, with limited air	Minimal char, mostly ash
Gasifiers: TLUD cookstoves	Ch. 11	Batch	Micro and small sizes	Free DIY to $500	1985, with recent progress	Potential, but not yet proven	Oxic, with limited air	Medium to good Adsorp.
Gasifiers: UpDraft		Continuous	Small	$15 K to $50 K	Old and new	Not wide use	Limited air	Good adsorp.
Gasifiers: Most others	Ch. 12	Continuous	Small and medium	$10 K to $250K	Existing but not for char	Potential, but not yet proven	Oxic, with limited air	Most do not make char
Bio-oil focus		Char production is a bi-product, of increasing value						
Slow pyrolysis	Ch. 13	Continuous	Medium and Large	Est. $2 K to $200 K	Old and new	Economic limits	Oxic, with limited air	Depends on unit & usage
Fast pyrolysis	Ch. 13	Continuous	Medium and Large	$ millions	New & experimental	Economic limits	Oxic, with limited air	High mobile matter
Not yet known		(See additional comments by Dr. Anderson)						

Additional Materials

Additional information is provided (mainly as .pdf files) at: www.drtlud.com/resources and identified as 4C Kiln items: They include:

A. Fuels:
  - Bamboo in 4C Kilns

B. Background and previous plans and activities:
  - Business overview 2014
  - Field-scale Pyrolyzer Project Intro 2015

C. Technical Drawings
  - Three files about two sizes, including dimensions
  - Folder with Autocad data files
  - Folder with spreadsheet calculations (preliminary)

D. 4C additional features created by Gustavo Peña (El Salvador 2014)

What is Not Yet Released about 4C Kilns: (Contact Dr. Anderson to save you time and money)

E. More notes about fuel options and variations

F. Designs and notes for much larger units for PBR – Pyrolytic Biomass Reduction

G. Notes on uses of 4C Kilns
  - Hyper-dryer (pre-torrefaction to 150 deg C.)
  - Other applications for use of the heat

H. Comments and calculations and comparisons about cost / benefits of char-making devices. For example, the ROI Air Curtain Burners (40 ft shipping container size) are estimated as handling 10-20 tons per hour of feedstock and 5% biochar recovery. Biochar recovery is expected to increase. Prices are in the $500,000-$600,000 range. What will be the future capacities and prices of devices based on 4C Kiln technology?