RoCC Kiln – Innovator Perspective on a Low-cost Pyrolysis Technology

Presentation on 15 December 2023
To the National Workshop on "Biochar and Bio-resources"
Hosted by CSIR-IMMT, Bhubaneshwar , Odisha, India.
With appreciation to the convenor, Dr. Manish Kumar, for arranging to include this presentation.

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Woodgas International Website: https://woodgas.com

This slide deck is available in the Resources section at the www.woodgas.com site.

Three Key Biochar Production Considerations

- **Biomass** type / size / characteristics (there is no shortage of biomass)
  - **Physical size: Rice husks, chips, straws/stems, twigs, branches, trunk/cord wood**
  - **Origins: Agriculture residues, forest refuse, fuel crops, MSW**
  - **Location / distribution / availability**
  - **Moisture content (MC)**

- **Pyrolysis technology** -- RoCC kiln is the Focus of this presentation

- **Pyrolysis devices** (specific designs) (not in detail in this presentation)

RoCC kilns can be adapted for many biomass types, sizes and shapes

(E = Easy, R = Reasonable, P = Problematic, D = Difficult)

- **Reeds and stems (E)**
- **Brush and small branches (E)**
- **Slab wood and bamboo (E)**
- **Arm-size branches (R)**
- **Cordwood (R)**
- **Mulch (P)**
- **Chips and Pellets(P)**
- **Whole trunks (P) (Allow sufficient time for pyrolysis or prepare cordwood)**
- **Sawdust and rice husks (D)**
- **Full size root balls of trees (D).**

The ability to handle so many different forms of biomass can mean **substantial savings on current pre-processing** of biomass to be disposed.
Example: Eliminate grinding and chipping whenever possible.

The Pyrolytic Technologies (~10) Are NOT Specific to Sizes of Devices

Without oxygen	Limited oxygen	Much oxygen
Earth mound	Gasifiers (various types)	Open-air piles
Retort	Glowing pyrolysis (TLUD)	"Conservation burn"
Laboratory	Flame cap (Cavity kilns)	"Top-down burn"
Adam retort	*Open top:* Pit; trench; trough; pyramid; cone; Kon Tiki; Ring of Fire	Air curtain machines
Auger kilns	*Covered top:* 4C kiln and RoCC kiln	Industrial furnaces
Rotary kilns		Incinerators
		Forest fires

Technical Note:
Not referring to the oxygen that is in every carbohydrate molecule of biomass. [example $C_{12}H_{22}O_{11}$]

Sizes for Pyrolytic Biochar Production

Classified by Orders of Magnitude of input of biomass per 10 hrs of operation

- Laboratory (< 1 kg)
- Micro (1 to 10 kg.)

- Small (10 to100 kg)
- Midi (100 kg to 1 ton)

- Medium (1 t to 10 t)

- Large (10 ton to 100 t)
- Industrial (> 100 t) (>10 t/hr)

Very small quantities of biochar production.
This can become significant when there are tens of thousands of producers organized for biochar collection, which is the case with TLUD cookstoves.

Seven Orders of Magnitude !

Major capital investments in stationary facilities with many support functions (transport, storage, handling, co-products, etc.); viability based on large quantities. These pyrolysis technologies and finances do not scale well to smaller sizes.

Sizes for Pyrolytic Biochar Production

Classified by Orders of Magnitude of *input of biomass* per 10 hrs of operation

- Laboratory (< 1 kg)
- Micro (1 to 10 kg.)

Objectives

R&D /testing
Cooking (TLUD)

Not today

- Small (10 to100 kg)
- Midi (100 kg to 1 ton)
  - (~20 kg to ~200 kg biochar / 10 hrs)
- Medium (1 t to 10 t)
  - (~200 kg to ~2 t biochar per 10 hrs)

Making Biochar in small amounts

Target of 1 t biochar per day = 250 t/yr = 500 t CO2e/yr = $50K

Biochar production & possible co-benefits

This size is best for flame cap / cavity kilns, retorts, and small versions of large systems.

- Large (10 ton to 100 t)
- Industrial (> 100 t)

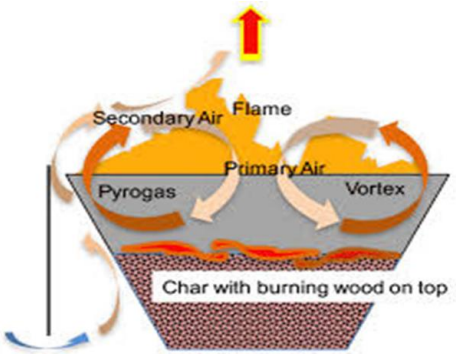
Char/chem/power

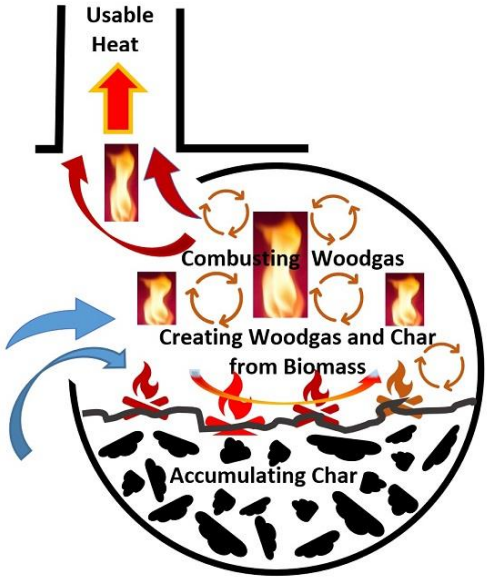
CHP (char secondary)

Not my topic

What is "flame-cap" or "cavity kiln" pyrolysis?

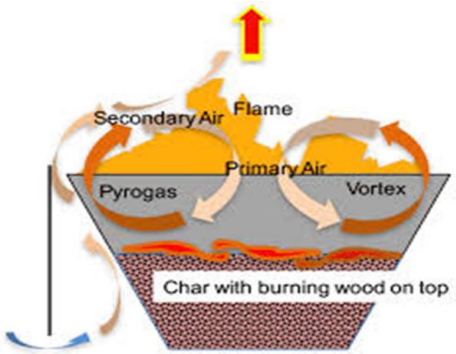
- They are the **same technology viewed from two perspectives**, both of which are essential to define the process.
- **The "cavity"** prevents the entrance of air / oxygen from reaching the biochar that is accumulating in the cavity.
- **The "cap" of flames** prevents (or mostly prevents) the downward penetration of air / oxygen from reaching the biomass or char that is below the cap. Air enters over the lip of the kiln.
- **Other names** are less clear but sometimes used:
  - Flame curtain (dif. from air curtain); Kon Tiki (specific device design)
- **Origins are traced back to Japanese techniques** with contributions by Moxham, Schmidt, Taylor, Wilson, and others. Anderson added 4C kilns in 2015 and RoCC kilns in 2019. He was at IMMT in December 2019; Covid caused years of delay.



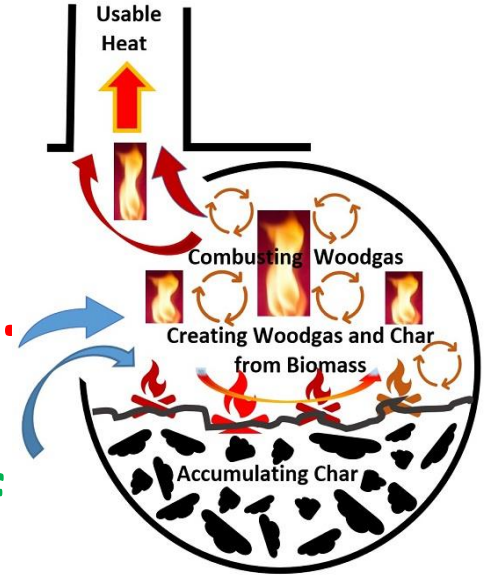


What is "flame-cap" or "cavity kiln" pyrolysis?

- They are the **same technology viewed from two perspectives,** both of which are essential to define the process.
- Pyrolysis is accomplished in cavities with closed bottoms and a cap of flames to create the heating with minimal oxygen present.



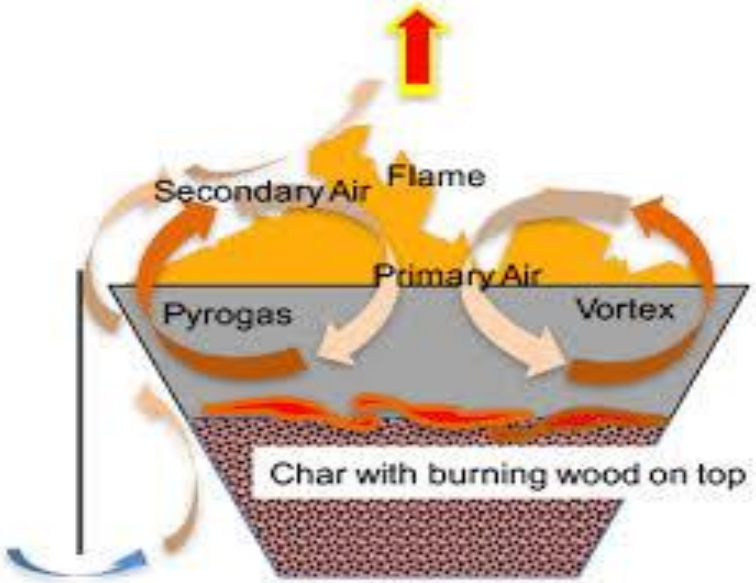
- **The flame cap radiates heat downward to cause further pyrolysis. Radiant heat at flame temperatures over 1200 deg. C causes pyrolysis in the 550 to 700 deg. C range.**
- **Radiant heat does not penetrate through solids; the biomass must "view" the flame. Fuel loading must be gradual and thin.**
- **Some flames convect heat down within branchy biomass, but the combustion is mainly of the abundant woodgas and not of the produced char.** Char burning requires higher temperatures.



- **Very little free ash is created. The inert atoms mostly remain inside the char.**

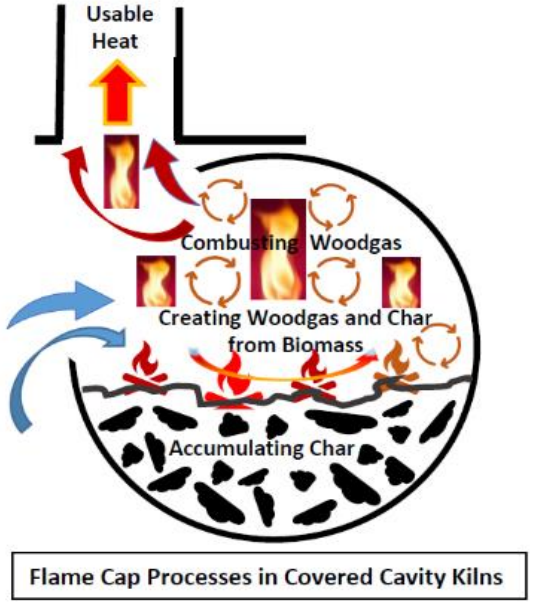
Flame Cap Pyrolytic Biochar Production: Open Top

(*open top* cavity kilns): Pit; trench; cone; pyramid; trough; Ring of Fire; Kon Tiki



Flame Cap Pyrolytic Biochar Production: Covered

(*covered* cavity kilns) "4C kiln" and Rotatable Covered Cavity (RoCC) kilns



Clean Controlled Covered Cavity ("4C") kilns were **not rotatable**. [~ 8 were made during 2015 to 2019.] Not scalable; lacking features for mixing the biomass & biochar. **Discontinued**.

1- and 2-barrel RoCC kilns with "H-frame" support.

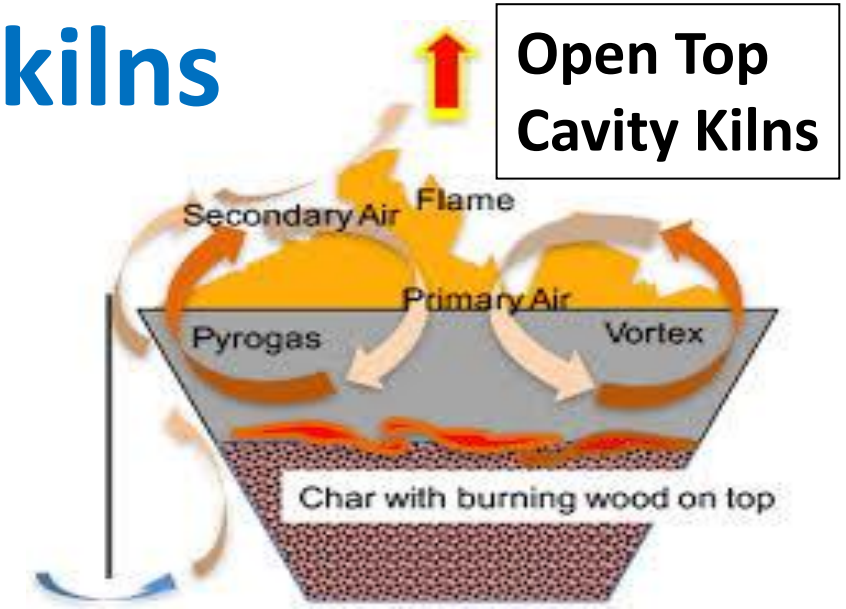
Above: 48-inch (122 cm diameter) x 60 inch length. In California, Feb 2020.

Right: 6-ft dia.(1.8 m) RoCC kiln inside a 20-ft shipping container with mechanical rotation

Comparison of cavity / flame-cap kilns

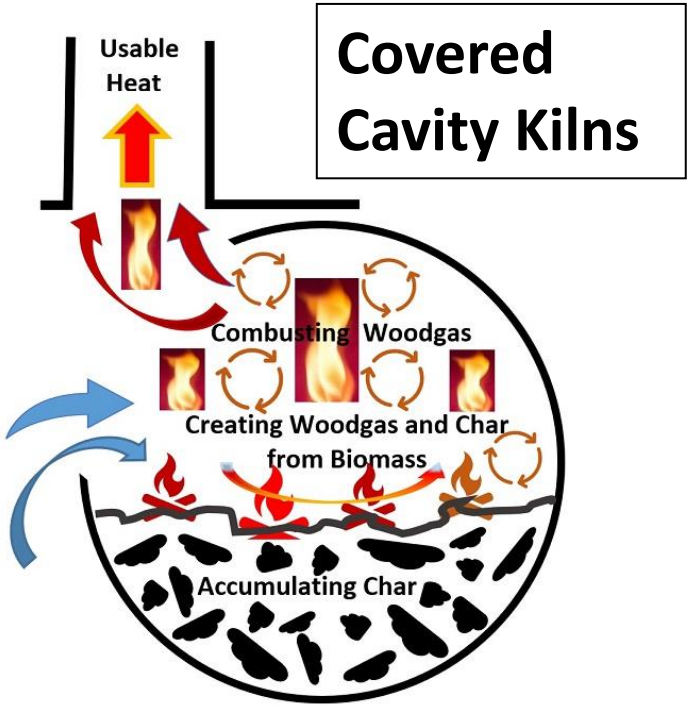
Shared Flame Cap Features

- Heat, flames and emissions rise away from the flame cap.
- Combustion of pyrolytic gases occurs with turbulence.
- Pyrolysis of biomass occurs because of the heat of the cap of flames.
- Char accumulates in the lower areas where oxygen cannot reach because of the cap of flames.



Advantages of RoCC:

- Flame is mostly protected from wind & rain.
- Longer heat retention in the combusting gases.
- Created heat can be directed to uses via chimneys.
- Chimneys can assist with draft but are not essential.
- Rotation mixes the biomass and char to facilitate that all the biomass is pyrolyzed.
- Rotation to easily empty the char.

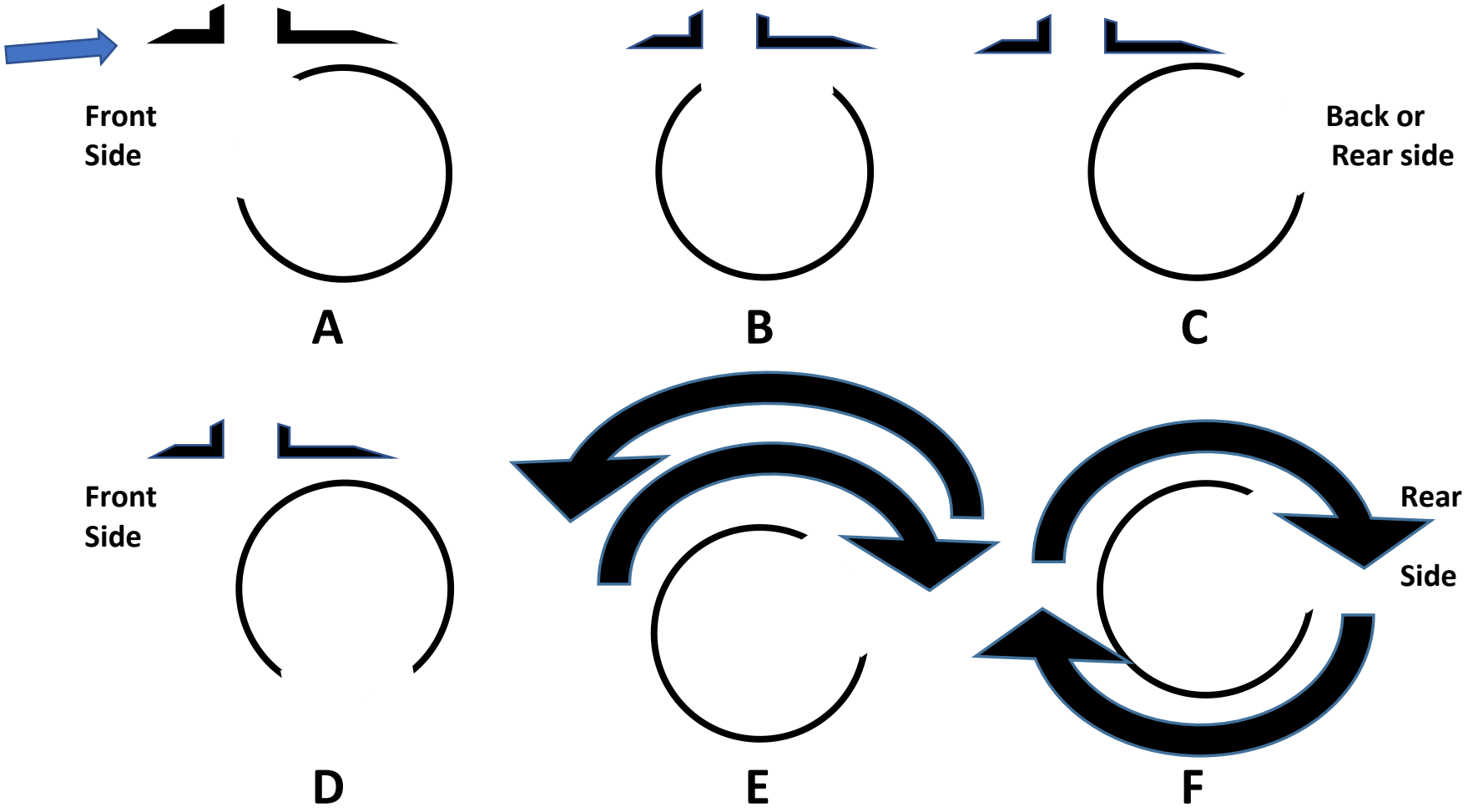


The importance of being "rotatable" (not rotating)

- Rotatable means to be able to be rotated when desired by the operator.
- Rotation accomplishes **mixing** of the contents inside the RoCC kiln.
- The ability to mix is important in flame-cap/cavity kilns **when necessary to "uncover/unbury" biomass that has not been sufficiently exposed** to the heat of the flame cap and is incompletely pyrolyzed.
- **Replaces manual mixing** (from the side with a tool) that is too hot when exposed directly to the radiant heat of open-top flame-cap kilns.
- **Ribs or fins** (such as 10 cm/4 in tall) lengthwise inside the RoCC kilns help assure mixing / tumbling and add structural strength to the cylinder.
- Rotation can be **mechanically facilitated and even automated**, allowing for scale-up to large size RoCC kilns.
- **Positioning of the portal** (opening) is important to facilitate loading, mixing, emptying, and flame control via air flows / winds.

Portal positions on a cylindrical covered cavity kiln

(Figure 6 in an earlier document)



Portal position	Position Name	Purpose	Observations
6A 270 to 350	Shelf fuel feeding	Slide in fuel on shelf	“Normal” position; best flame cap.
6B 320 to 40	Straight up	Slow the fire	Least air entry; “simmer”.
6C 10 to 90	Bulk fuel feeding	Drop in fuel	Short time only; lacks draft.
6D 140 to 220	Straight down	Unloading	Used sparingly for brief times.
6E Roll 240	Rocking back and forth	Tumble w/o dumping	Use common sense; varies w/ fuel type.
6F Roll 360+	Full rotation	Mixing extensively	Subject to conditional limitations.

Some Lessons Learned of What Not to Do

- No need for door to cover the portal (doorway).
- No need for hood and chimneys in most circumstances, but hood and chimney remain an option especially if emissions control or use of heat is desired.
- No need for the grate / bars that can swing into place over the portal. A removeable grate over the portal is possible if desired.
- Use scrap materials when possible for great savings.
- Learn with mild steel; stainless steel is not necessary when learning and is probably not needed for your application.
- No insulation.
- Protective paint and galvanizing do not last.

Further Lessons and Insights

- The accumulating char is not hotter than the temperature of pyrolysis.
- Add raw biomass in amounts sufficiently small that the new biomass does not prematurely insulate or shield (and prevent pyrolysis of) the biomass that is below it.
- The operator(s) are exposed to significant radiant heat if they can "see" the flames. The cover of the RoCC kiln provides significant protection for the operator(s).
- The exposure of the operator to the heat is an important limiting factor to making larger open-top flame-cap units.
- Mechanization is possible for many RoCC kiln processes (including loading, occasional rotations, monitoring, and unloading) , and can cost more than the kiln and frame together.

Additional issues

- NOTE: All pyrolysis technologies are still being improved, so what is not currently available might be possible someday. **Many statements are self-evident; others need objective testing and confirmation.**

- **Size:** Horizontal cylinders (e.g. barrels) hold less biomass and created char than do vertical-wall units.
- **Open-top** diameter size-limit is ~ 2 m; larger becomes harder to to approach when hot unless mechanized.
- **RoCC kilns** can be built larger. Much larger. Already 6-ft diameter by 7 ft long.

Many Options for Cylindrical Pyrolyzer

- **Standard 55-gallon (200 L) steel drum**

- **Cylindrical steel tanks of various sizes** (including RR tank cars)

- **Corrugated steel pipe (CSP)**
  - Strong, economical, industrial product
  - 3 ft to 18 ft diameters; Lengths up to 40 ft.

Further topics:

- **Cost of fabrication:** All flame-cap devices are relatively less expensive than the other technologies. Costs are similar between open and covered models of similar capacity.
  - **Example: A 2-barrel RoCC kiln in Kenya costs less than USD200, with wheels.**
  - The extras for fuel feeding and any automation can cost many times more than the cost of the cylindrical kiln and its frame.
- **Mobility**: Easier to add wheels to RoCC kilns than to open-top kilns. RoCC kilns can be taken to rural sites where the biomass is abundant.
- **Shape of pyrolytic surface:** Rectangular shape favors longer fuel; circular shape leads to overlapping pieces of long fuel.

Costs of RoCC Kilns (in affluent societies)

- **Barrel size (such as 55-gal drum and cylinders up to 3-ft diameter & < 4-ft long):**
  - **Do-It-Yourself (DIY)** for your own use can be **essentially free** if you use scrap, found, or hardware store items.
  - **Purchase ready made (or hire the work) for a few hundred dollars** from a supplier (who is in business for profit and needs a written agreement with the inventor).
  - [NOTE: The H-Frame design needs about US$100 for new materials in America. But labor for preparation (cut, drill, and weld) will cost hundreds more.]
- **Utility size (from 3 to 4-ft diameters and up to 10 ft long):**
  - Many variables, but likely to **cost from 2 to 8 thousand dollars,** but without mechanical operation. The inventor can assist you to locate a supplier (and save).
  - Special arrangements for those making units with features not previously included, such as for heat capture and use.
- **Bulk service size and larger:**
  - Contact Dr. Anderson for special assistance. Consider doing joint research and/or business efforts. Probably used for a heating or biomass reduction project.

The mostly-closed top of RoCC kilns causes:

- **Increased duration of exposure to heat:** The cover causes the created heat to remain longer in close proximity to the biomass being pyrolyzed.
- **Protects against undesired cross winds** and can be positioned (rotated or horizontally turned) to face the winds when that is beneficial
- Permits the cylinder to be **rotated up to 270 degrees** to promote some internal mixing of the biomass and hot char.
- Somewhat more difficult to feed in fuel.
- Partially shields the workers from radiant heat
- Possible less risk of accidental fires, but both open and covered cavity kilns have visible open flames.

Emissions and biochar quality

- **Emissions**: Better combustion leads to cleaner emissions (to be tested)
- **About methane:** ALL fires with open flames produce some methane, but the amount is generally lower in controlled devices, especially when compared with leaving the biomass to decay. Methane release is important, but not sufficient reason to reject flame-cap production of biochar.
- **Biochar quality:** Both open-top and covered flame-cap devices produce biochar of generally good quality in the above-550 degree C range. More testing will help establish the biochar characteristics.

After creation of the biochar

- **Weighing:** Quantification for MRV and CDR carbon credits is by dry weight or by approximations based on volumes. RoCC kilns can have direct weighing of the empty and full kiln cylinders. After dry weighing water or materials or dirt can be added without changing the carbon weighs.
- **Extinguishing by flooding:** A featured aspect of Kon Tiki kilns; Not part of RoCC kiln methods. Such quenching has pros and cons. Once made wet, biochar weights are by dried samples and never fully accurate.
- **Discharge of char:** RoCC can dump straight down. Can have char collection trays, etc. to facilitate gathering of hot char into containment and weighing while totally dry.

Patent IP protection:

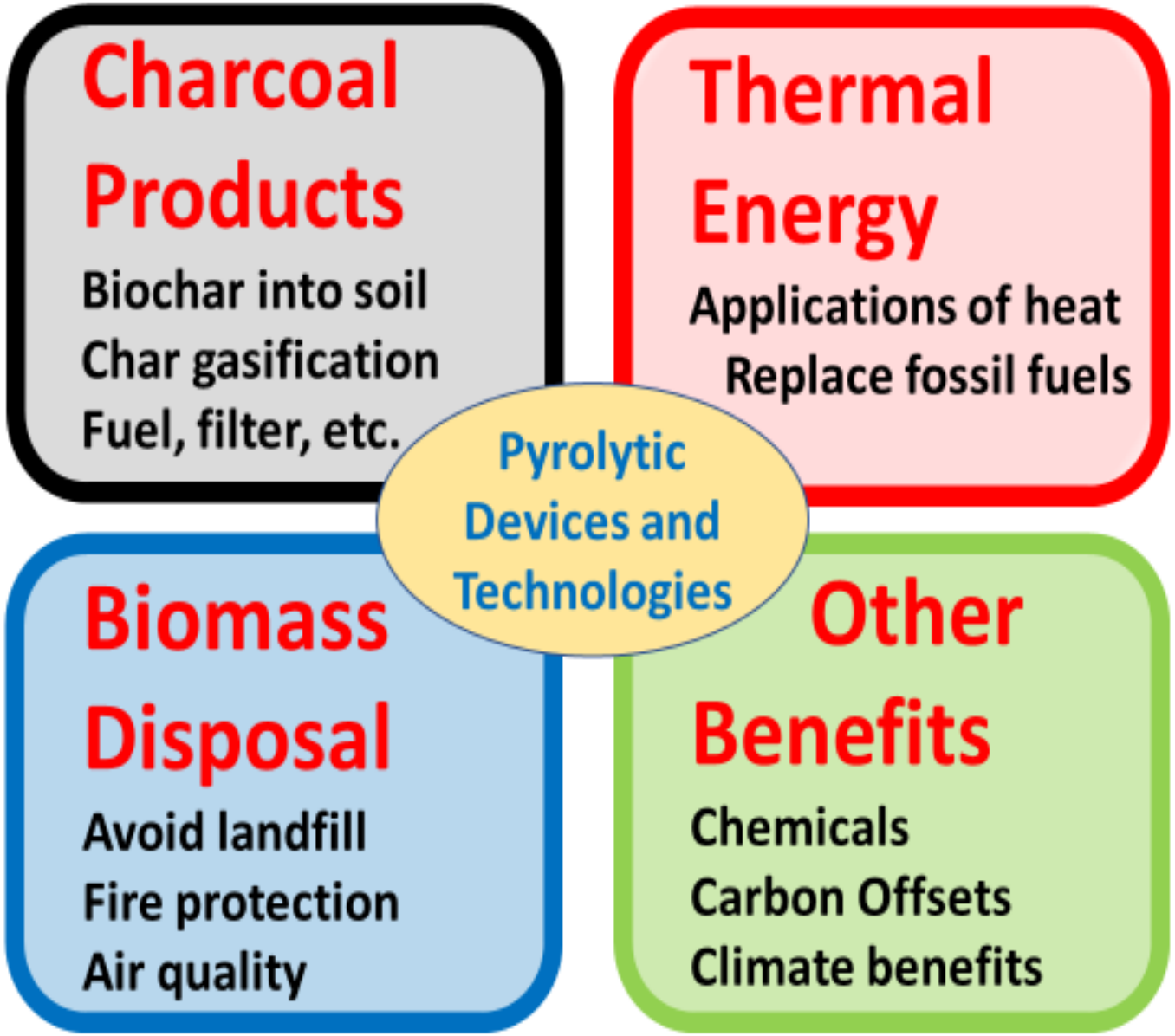
- Open-top (Kon Tiki, etc.) flame-cap kiln designs:
  are totally open for anyone to access and replicate freely.
- RoCC kiln technology:
  is patented in the USA and has patent pending status in Canada and 41 European nations,
  is open for anyone to use in the other countries of the world, but all users are encouraged respect and include in projects the innovators who have paid for the development work and can assist new users to avoid costly discovery efforts.

- **Note: Dr. Anderson is seeking co-workers, associates, partners and owners for development of RoCC kiln businesses in India and other countries**. (Email: psanders@ilstu.edu)

Financial Issues:

Four ways for pyrolysis to be "profitable."

Best if two or more ways are used.

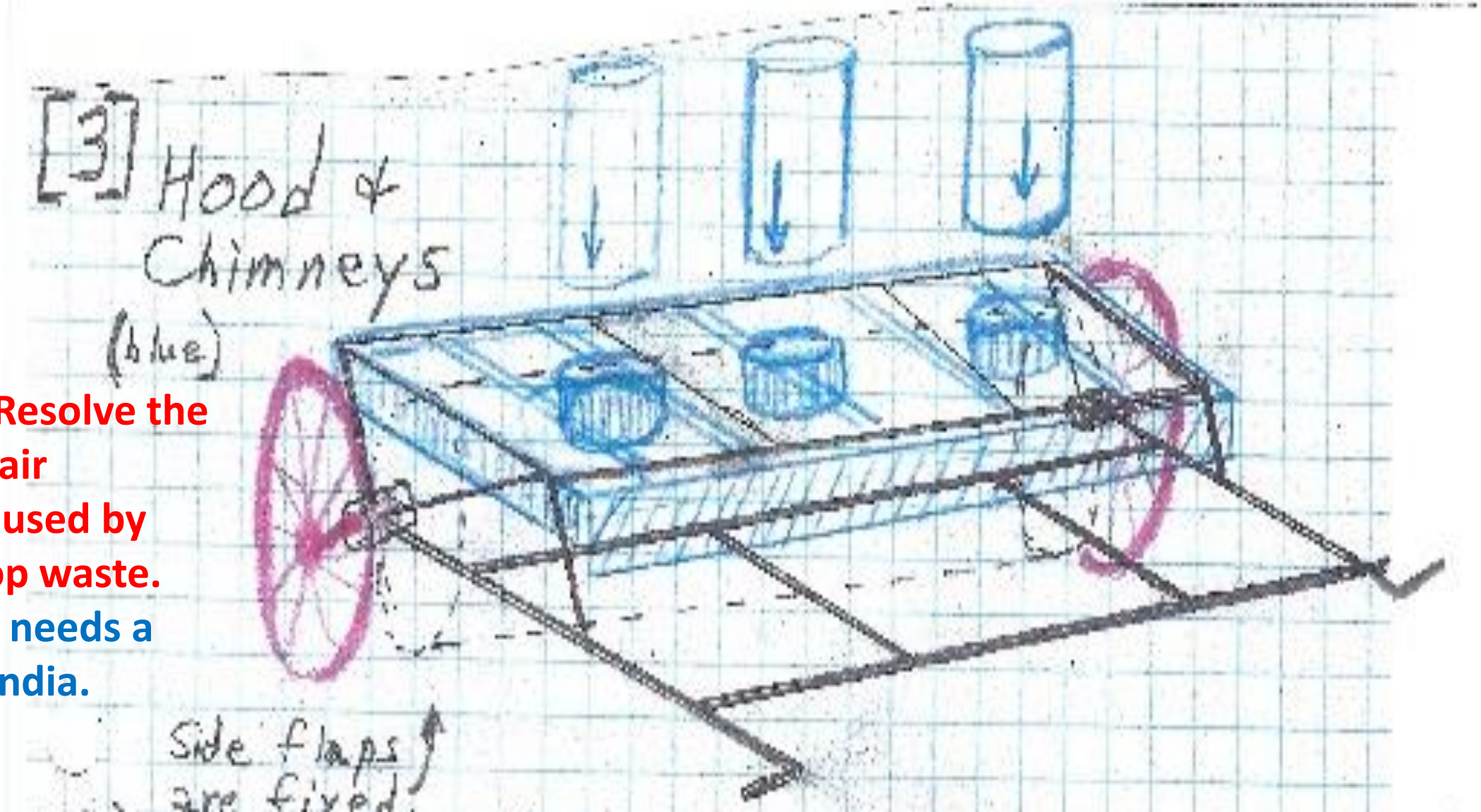


RoCC kiln: Dia. 43-in (1.1 m) x 6 ft (1.83 m); 2023-12-8 Ohio, USA; Cordwood of Ash trees

RoCC kiln: 2-barrel; Bamboo biochar small demonstration; 2023-12-05 North Carolina, USA.

In-field RoCC Kiln for Crop Refuse (Design only)

[A better design in H-Frame is possible for an R&D project.]



Objective: Resolve the problem of air pollution caused by burning crop waste.

This project needs a sponsor in India.

Measured results of RoCC kiln usage

One RoCC 1-barrel-size kiln processes approximately 25 kg of woody biomass per hour, or a quarter ton in 10 hours of operation, yielding about 50 kg of biochar.

50 kg of biochar represents approximately 125 kg CO2 long-term carbon removal and storage (CDRS), which is approximately US$12 gross income from sales of CDRS @ $100 per tonne CO2e to companies that are stimulating CDRS (Microsoft, Shopify, etc.).

In Kenya in one workday one agricultural worker with one 2-barrel RoCC kiln and dry maize / corn stalks produces ~50 kg of biochar (45% fixed carbon) that could obtain ~$10 on the carbon market and is paid ~US$6.

Operational notes

- **Each RoCC kiln has supporting materials:**
  - A list and explanatory document are being prepared currently with seven (7) items.
    - Scale, 20-liter bucket, 200-liter barrel, numerous sturdy sacks, field tools (pitchfork, shovel, etc.), measuring tape, measuring pitcher, notebook

- **All RoCC kilns are owned and controlled by the Kenyan business** that runs the project with signed agreements concerning RoCC kilns and procedures for data collection, carbon financing with CERCS - CharTrac, and operations.

- **Decentralized, locally-focused implementations** of this business model will enable rapid "scale-up by replication." (Franchise model.)

Business possibilities

- You cannot gain from the RoCC kiln technology if you do not embrace it. There are no restrictions to prevent anyone from starting to use the RoCC kiln technology. It is recommended that you stay in contact with Paul Anderson to save your time and money.

- When you (or others) do gain from the RoCC kiln, then part of that gain is to be provided back to Dr. Anderson who holds a patent (pending).

- No RoCC kilns are sold; their production and use are authorized via agreements (such as licenses) that advance the RoCC kiln impacts.

- Dr. Anderson is seeking and expects to identify appropriate associates and partners in numerous countries to maximize the beneficial impacts of RoCC kiln pyrolysis so that all can gain.

- (Continued)

Business possibilities (Continued)

- The business possibilities are available for fabrication of units, management of units (including in projects), any use of RoCC kilns, and the resultant carbon-related benefits that include carbon markets.
- Dr. Anderson seeks impact more than financial gain.

- Contact Information:

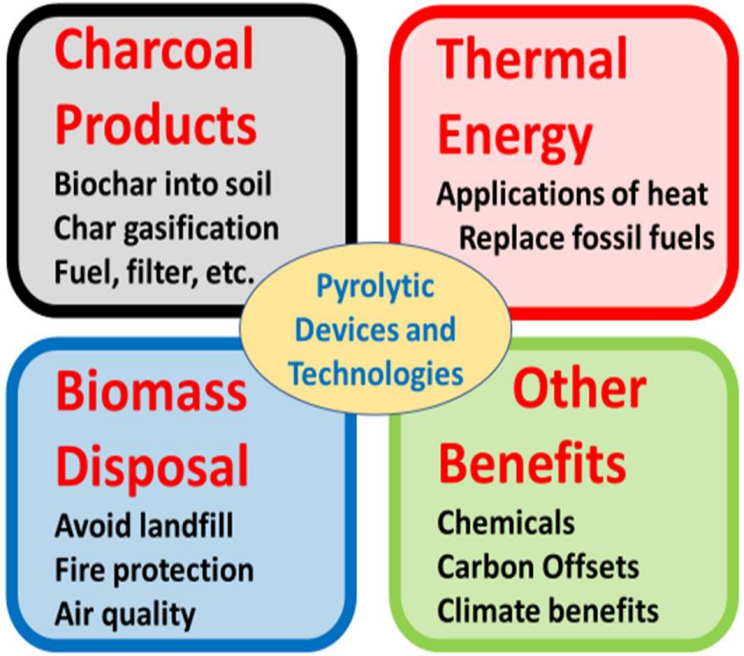
Paul S. Anderson, PhD

Email: psanders@ilstu.edu

WhatsApp & Mobile Phone: +1 309 531 4434 (Central Time USA)

Website for RoCC kilns and biochar white paper:
www.woodgas.energy/resources

Examples of RoCC kiln Business Prospects



- **Manufacturing** of RoCC kilns
  - Incl. future units for thermal energy
- **Research** paid for by outside funding
  - Put Dr. Anderson on your team
- Operate business with RoCC kiln **char production**
  - Produce biochar more efficiently with RoCC kilns
- Collection of RoCC biochar to produce **commercial products**
  - The focus is on final sequestration of the biochar, never to be burned.
- Transactions with carbon units for **carbon markets**
  - Dr. Anderson will use carbon markets to increase the cash flow for growth
- **Other activities** linked to RoCC kiln capabilities

The climate crisis and biochar

- **Biochar and stable carbon removal (sequestration) are in a TRILLION-dollar sector of the world economy in coming years.**

- **Carbon tracking that is necessary for receiving carbon funding for CDRS (on the voluntary carbon markets) is accomplished with CharTrac™ carbon accounting system. Dr. Anderson has arranged this for the RoCC kiln usage that places biochar into soil. (If interested, contact him for further information.)**

- **Please see the many topics presented in "Climate Intervention with Biochar", a 2020 white paper (52 pages) in the Resources section of Dr. Anderson's website https://woodgas.com**

- **Contact Paul S. Anderson at psanders@ilstu.edu**

The remaining 18 slides are provided but not discussed. Most have been present in earlier documents or presentations.

Recommended RoCC Kiln Innovation – "H-Frame"

- **Named for the "H" where the axle stub is supported.**
- **Full details are provided in other presentations.**

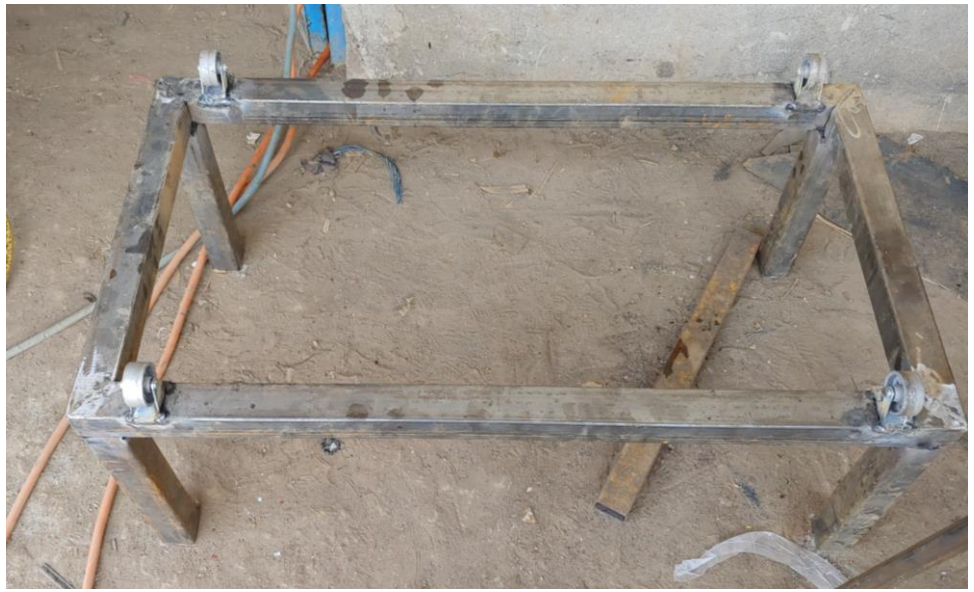
Strong, easy to make, inexpensive, scalable, versatile, mobile.

Three Arrangements for Rotation

- **Rack with support wheels / casters**
- **Rails for rolling**
- **Axle / Axle stubs for rotation and support**

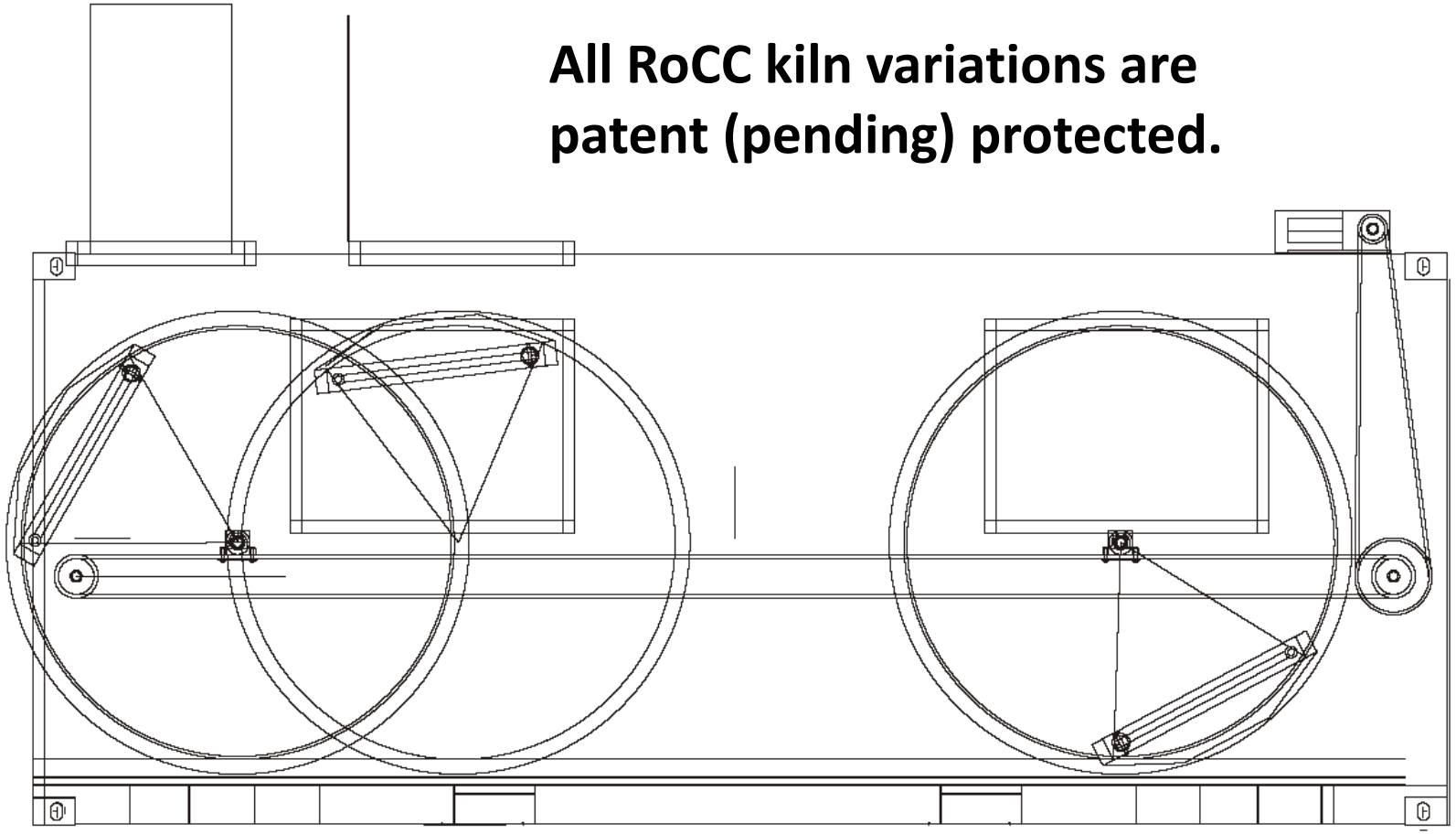
Rack with Support Wheels for Pyrolyzer

- **Welded rectangular tubing with four legs and four steel casters/wheels. ➔**



- **Welded cross bars and casters on improvised legs of concrete blocks. ➔**

RoCC Kiln in Construction: 6 ft D x 7 ft L Inside a 20- ft Shipping Container on rails for rolling



All RoCC kiln variations are patent (pending) protected.

- Constructed in central Illinois with several test runs by May 2021.
- Scale to larger sizes will depend on results and future funding / sales / business associates.
- If interested, write to Paul S. Anderson at: psanders@ilstu.edu

Rails for Rolling

Weight is supported totally on the rails.

The hole in the floor is for dumping the hot char at the discharge end. N.B. The char is not yet ready to dump in these photos.

Axle / Axle Stubs

Having a full-length axle through the cylinder is NOT as good as having only axle stubs which are pipes welded to a firm end-plate that is welded to the ends of the barrel / cylinder.

Support Structure Options

- Racks (shown previously)
- Large side wheels "RoCC n' Roll" (Discontinued and Superseded)
- X-Frames (works well but is no longer the best choice)
- H-Frames (recommended for simplicity, flexibility and size changes)

Latest RoCC Kiln Innovation – "H-Frame"

- **Named for the "H" where the axle stub is supported.**
- **Full details by the end of this presentation.**

Strong, easy to make, mobile, inexpensive, scalable, welded or bolted, versatile, ...

Pieces to make an H-Frame RoCC kiln

The cross-bar of the H has adjustable positions.

Wheels are optional, removable and can be of various sizes for different terrain and heights.

Many options for the handles. The blue pair was borrowed.

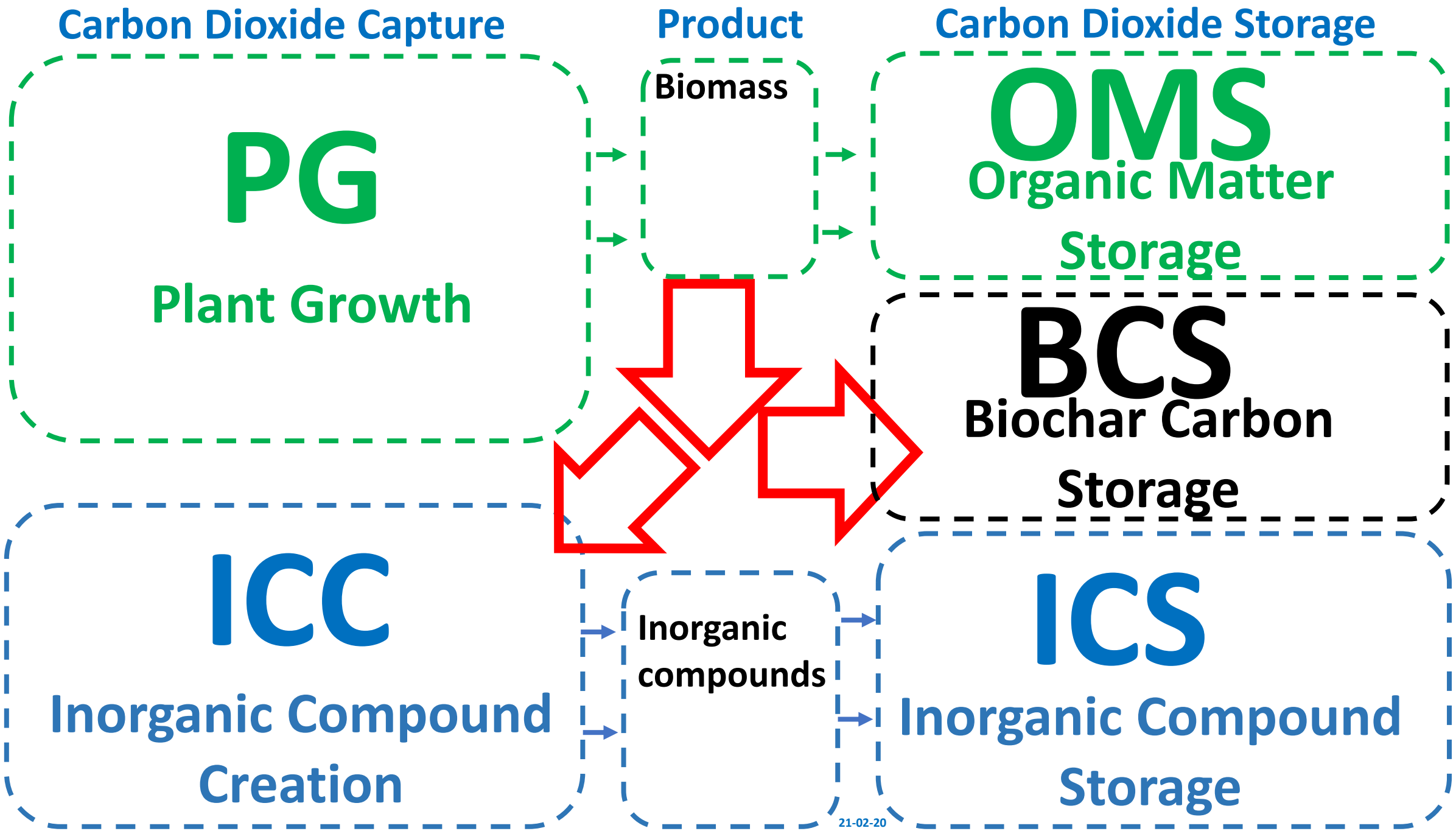
Q: What is the big difference between these two H-Frame RoCC kilns?

A: Same kiln, but the frame is rotated 90 degrees to change the height of the portal from the ground for loading different types of biomass.

Both positions can have wheels for moving through fields.

Kenya --- Comments by Gilbert Mwangi

[Success with rice husk biomass depends on continual feeding in small quantities.]


Carbon Dioxide Capture
Product
Carbon Dioxide Storage
PG
Plant Growth
Biomass
OMS
Organic Matter Storage
BCS
Biochar Carbon Storage
ICC
Inorganic Compound Creation
Inorganic compounds
ICS
Inorganic Compound Storage
21-02-20

Options for Carbon Dioxide Capture and Storage (= Removal = CDR = GGR)

Nature-based capture

Plant Growth (photosynthesis) PG

SOMG

- Forest & woodland growth FWG
- Agricultural crop growth AGG
- Weeds and wild growth WWG
- Ocean biomass growth OBG
- Soil organic matter growth SOMG

[Suffix "G" = Growth and Suffix "S" = Storage]

Biomass

- Woods
- Crop residues
- Invasive weed
- Seaweeds
- Soil organisms

TREES

- Standing trees TREES
- Wood structures WOODS
- Soil Organic Matter Storage SOMS

Organic Matter Storage OMS

Prevent decay

Redirected biomass

Burn to CO_2

Pyrolyze to biochar

BCS

- Biochar in soil BC-SOILS
- Biochar in structures BC-CONS
- Biochar into mines BC-GEOS

Biochar Carbon Storage BCS

Elemental Solid Stable Carbon

Engineered capture

Inorganic Compound Creation ICC

CCE

- Concentrated chimney emission capture CCE

DAC

- Direct air capture DAC

EW

- Enhanced weathering EW
- Carbon concretions in oceans: CCO

Inorganic compounds

- Super-critical Liquid CO_2
- Carbonates

OCS

- Deep geologic storage GEOS
- Constructed structures CONS
- Incorporation into soil SOILS
- Ocean carbon sinks OCS

Inorganic Compound Storage ICS

Engineered inorganic chemical storage

21-01-26

The objective is CO_2 Removal <u>and</u> Keeping it removed.

Long-term Sequestration

Clear winners are plants with Biochar !

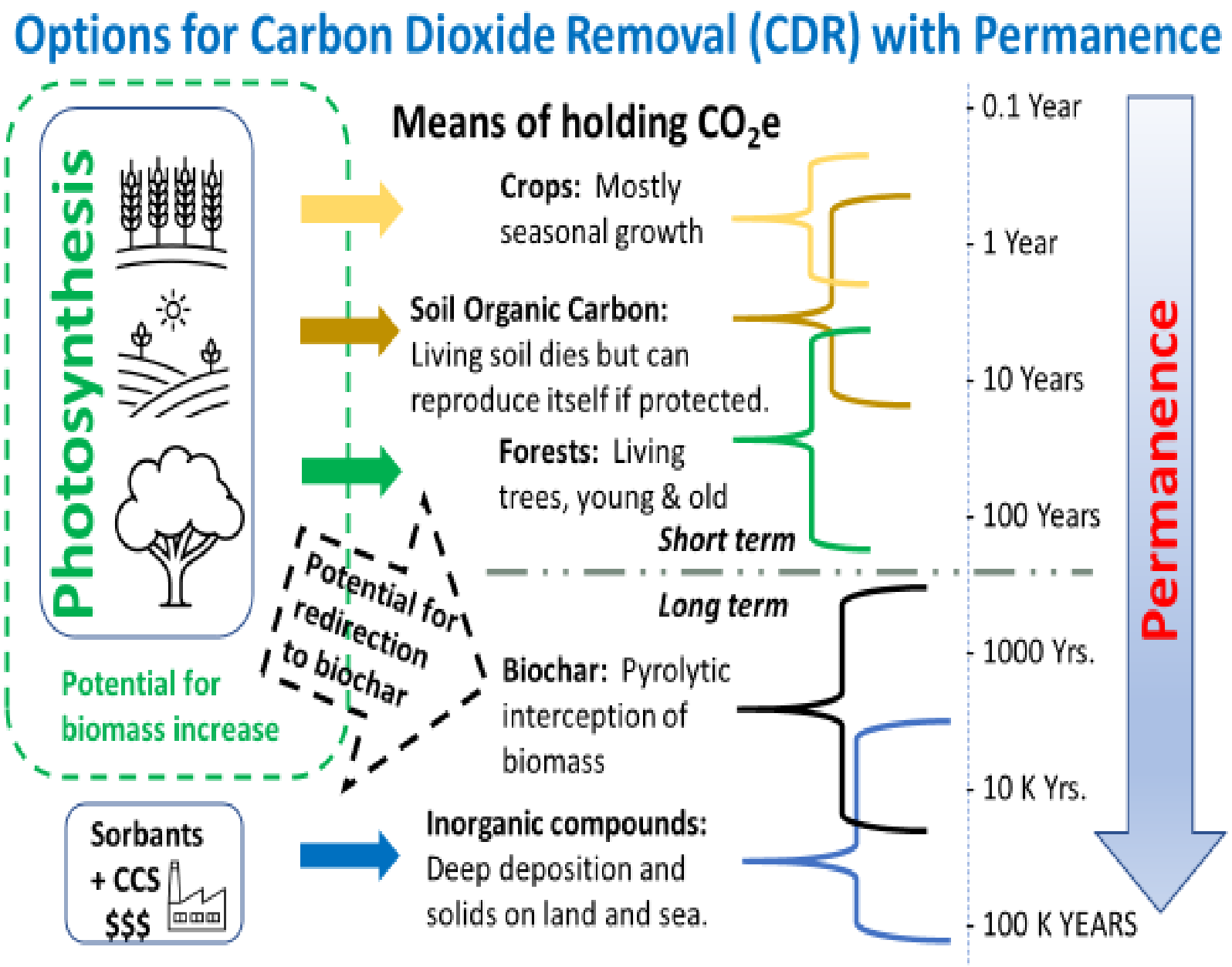


Table of sizes of RoCC Char makers

(New version 2020-02-15; Draft still in need of refinement; Some rounding)
(Based on cylinders; Extrapolations from Column B; Estimated variability of +/- 50%)

	A	B	C	D	E	F
	Size >>>> Issue (below)	55 gallon (Barrel)	~140 < 180 gallon	464 gallon (4x5 ft) (8 barrels) (1.7 m3)	750 gallon (4x8 ft) (14 barrels)	1500 gallon (~ 20 barrels)
a	Dimensions (Diameter x Length)	(D) 2 x 3 ft = 9 ft3	3 x 4 ft (28 ft3) (210 gal)	4 x 5 ft (62 ft3) (464 gal)	4 x 8 ft = 100 ft3 (2.8 m3)	4 x 16 ft= 200 ft3 (~5.6 m3)
b	Fuel input (kg/hr) (extrapolation from Col B)	~25 kg ~50 lbs (~3 - ~2.5 kg/ft3/hr)	~84 kg/hr	180 - 200 kg/hr	250 – 300 kg (Quarter ton)	500 kg 1000 lbs (Half ton)
c	Char output (kg/hr @ 20% yield) [CO2e reduction per hour]	5 kg 1 wheelbarrow (WB) [18 kg]	~16 kg/hr [58 kg]	40 kg [146 kg]	50 kg [~ 183 kg]	100 kg [366 kg]
d	Thermal energy output as 70% of total (30% in char) 12 MJ/kg/hr 8 BTU/lb/hr	300 MJ 83 kW-h 284 K BTU	Almost 1 M BTU (Under EPA interest threshold)	2400 MJ 666 kW-h 2.3 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	K
	Size >>>> Issue (below)	1500-gallon 200 ft3 4x16 ft; 5x10 ftf; 6x7 ft	3000-gallon 400 ft3 11.3 m3	7500-gallon 1000 ft3 28 m3 = 20 ft container	15,000 gal 2000 ft3 56 m3 = 40 ft container	30 K gallon 4000 ft3 113 m3 (RR tank car)
a	Diameter / Length	4 x 6 x 8ft = 200 ft3 (~5.6 m3)	6 x 14 ft or 7 x 10 ft 8 x 8 ft	**8 x 20 ft** 10 x 13 ft 12 x 9 ft	12 x 18 ft 14x 13 ft 16 x 10 ft	10 x 52 ft (RR tank car) 16 x 20 ft
b	Fuel input (estimate per hr) (extrapolation from Col B)	500 kg (Half ton)	1000 kg ~ One ton per hour	2.5 tons per hour	5 tons per hour (~3 - ~2.5 kg/ft3/hr)	~10 tons/hr
c	Char output (w/ 20% yield) [CO2e reduction per hour]	100 kg [0.36 kg]	200 kg/hr [0.73 kg]	500 kg/hr [1.8 t]	1 t/hr [3.6 t]	Estimate 2 tons/hour [7.2 t/hr]
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	30 GJ 8 MW-h 28 M BTU	60 GJ 16 MW-h 57M BTU	~120 GJ 33 MW-h 114 M BTU
e						
f						

Selected Sizes of RoCC Char Makers

(**Revised version 2020-06-22**; Draft still in need of refinement; Some rounding)
(Based on cylinders; Extrapolations from Column B; Estimated variability of +/- 50%)

	A	B Midi Scale	D Medium Scale	E Medium Scale	G Large Scale	I Large Scale
1	**Name & Size >>>>**	**Barrel (Home)** **2 D x 3 L (ft)**	**Utility - A** **4 D x 5 L (ft)**	**Utility - B** **4 D x 8 L (ft)**	**Bulk Service** **6 D x 14 L (ft)** **8 D x 8 L (ft)**	**Container (20 -ft)** **8 D x 20 L (ft)** **12 D x 9 L (ft)**
2	**Volume**	9 ft3 = 0.25 m3 (55 gallon)	62 ft3 = 1.7 m3 (464 gallon) (~ 8 barrels)	100 ft3 = 2.8 m3 (750 gallon) (~ 14 barrels)	400 ft3 =11.3 m3 (3000 gallon)	1000 ft3 = 28 m3 (7500 gallon)
3	**Fuel input (kg/hr)** (Extrapolation from Col B) (Based on volume; less if based on horizontal area of flame cap pyrolysis.)	~25 kg ~50 lbs (~3 to ~2.5 kg/ft3/hr)	180 - 200 kg/hr	250 – 300 kg Quarter ton /hr **~ 5 t / workday** or > 2 cords.	1000 kg ~ One ton / hour **~ 10 t / workday**	2.5 t/hr **~ 25 t / workday** (Probably is high, but certainly at least 10 t/ day)
4	**Char output (kg/hr @** 20% yield) [CO2e reduction per hour]	5 kg ~1 wheelbarrow [18 kg]	40 kg [146 kg]	50 kg [~ 183 kg] (~1.8 tCO2e/day)	200 kg/hr [0.73 t] (~7 tCO2e/day)	500 kg/hr [1.8 t] (~1.8 tCO2e/day)
5	**Thermal energy output** as 70% of total (30% in char) 12 MJ/kg/hr 8 BTU/lb/hr	300 MJ 83 kW-h 284 K BTU	2400 MJ 666 kW-h 2.3 M BTU	3000 MJ 830 kW-h 2.8 M BTU	12 GJ Gigajoules 3 MW-h **10 M BTU**	30 GJ 8 MW-h 28 M BTU

	A	E
1	**Name & Size >>>>**	**Utility - B** **4 D x 8 L (ft)**
2	**Volume**	4 x 8 ft = 100 ft3 (2.8 m3) 750 gallon (~ 14 barrels)
3	**Fuel input (kg/hr)** (Extrapolation from Col B) (Based on volume; less if based on x-sectional area.)	250 – 300 kg **(Quarter ton / hour)**
4	**Char output (kg/hr @** 20% yield) [CO2e reduction per hour]	50 kg [~ 183 kg]
5	**Thermal energy output** as 70% of total (30% in char) 12 MJ/kg/hr 8 BTU/lb/hr	3000 MJ 830 kW-h 2.8 M BTU

Hypothetical scenario with utility-size RoCC Kiln

- Abundant biomass
  - Slabs / refuse wood; urban wood waste
- Need for heat and hot water
  - Apt complex; school; small industry
- Replace fossil fuel
  - Avoid carbon tax;
- Biochar for agriculture
  - Increasing value
- Carbon sequestration
  - Increasing importance

Patents and Business Prospects

- The RoCC kiln invention has international patent pending status with likely coverage until 2040. This protects your interests as well as those of the inventor.
- When there is financial gain based on the RoCC kiln production or use or other activities such as gained carbon credits, some small share should come to the inventor.
- Therefore, there are at this time (06/2021) no up-front fees to become involved with RoCC kilns and receive expert assistance.
- All options are open for business arrangements to be made so that the RoCC technology can become the basis of business for biochar, energy, climate benefits, and more.
- You are encouraged to become informed about how you or your geographic area or field of activities could benefit with RoCC kilns.