Introduction to the Rotatable Covered Cavity (RoCC) Kiln for Medium-size Production of Pyrolytic Biochar and Thermal Energy

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Topics to be covered

- **Pyrolysis for profit** and other worthy objectives. Why you are here!
- **Gap in the "middle-size" ranges** of pyrolyzer technology.
  - This presentation covers major but not all technologies and devices.
- **Flame Cap** pyrolysis with **open top** and **covered cavity kilns.**
- **Deficiencies**, and overcoming them with a "rotatable" cavity kiln.
- **Major components** of rotatable covered cavity **(RoCC)** kilns.
- Examples of **sizes of RoCC kilns** and expectations from each.
- Business issues: **Patents, prices, opportunities** as you define them.
- RoCC kilns for **climate intervention strategies**
- And it is all becoming **available now and worldwide.**

Numerous Profit Centers from Pyrolytic Char Making

What are YOUR interests?

There are opportunities for each business activity & geographic area.

Charcoal Products

Biochar into soil
Char gasification
Fuel, filter, etc.

Thermal Energy

Applications of heat
Replace fossil fuels
Energy for life

Pyrolytic Devices and Technologies

Biomass Disposal

Avoid landfill
Fire protection
Air quality

Other Benefits

Chemicals
Carbon Offsets
Climate benefits

Original: Paul S. Anderson 2019-03. Text changes and color added 2020-02.

Profit Centers from Pyrolytic Char Making

Discussion:

1. Pyrolytic Biomass Reduction (PBR) values may be sufficient.
2. Pyrolytic Carbon Capture and Sequestration (PyCCS) can include all four centers.
3. Use of "wasted" heat can justify action in all the other centers.
4. Not all benefits are monetary.
5. Charcoal is stored energy.
6. **Only ONE needs to have profit.**

Original source: Paul S. Anderson 2019-03
This earlier version has more details of options:

Charcoal Products

* **Standard uses**
  - Fuel, filter, substitute material
* **Biochar into soil**
  - Multi-purpose amendment
* **Char gasification**
  - Engine-quality gases
    - Mechanical & electrical power

Thermal Energy

* **Applications of heat**
  - Cooking (TLUD stoves)
  - Industrial heat
  - Space heating
  - Crop drying, etc.
* **Often a "free" by-product**
* **Replace fossil fuels**

Pyrolytic Devices and Technologies

Pyrolytic Biomass Reduction & Disposal

* **Tipping fees & avoid landfill**
* **Forest fire protection of homes**
* **Agriculture necessity**
* **Air quality by emission reduction**

Other / Misc.

* **Co-products**
  - Chemicals
  - Marketable biomass/compost
* **Carbon Offsets**
  - When additionality occurs
* **Climate benefits**

Pyrolytic Technologies for Dry Biomass Fuels

Without oxygen	With limited oxygen	With much oxygen
Retort	Gasifiers (various types)	Forest fire
Laboratory	Flaming pyrolysis	"Conservation burn"
Adam retort	Glowing pyrolysis (TLUD)	Air curtain machines
Rotary kilns	Flame cap (Cavity kilns)	Industrial furnaces
	Open top: Pit; trench; trough; pyramid; cone; Kon Tiki	Incinerators
	Covered top: "4C kiln" and RoCC kiln	

Technical Note:
Not referring to the oxygen that is in every hydrocarbon molecule of biomass.

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)

Sizes for Pyrolytic Biochar Production

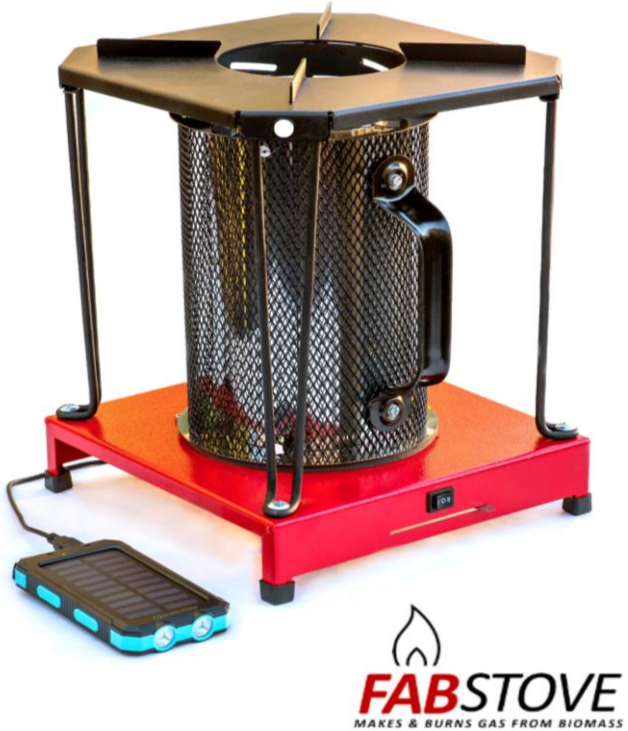
Classified by Orders of Magnitude of input of biomass per 10 hrs of operation

	Objectives
• Laboratory (< 1 kg)	R&D /testing
• Micro (1 to 10 kg.)	Cooking
• Small (10 to100 kg)	Making
• Midi (100 kg to 1 ton)	Biochar
• Medium (1 t to 10 t)	To be determined
• Large (10 ton to 100 t)	Char/chem/power
• Industrial (> 100 t)	CHP (char secondary)

Sizes for Pyrolytic Biochar Production

- 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)

- Cookstoves for heat; char is secondary
  - TLUD (Top-Lit UpDraft) make very good char.
    - Residential & institutional stoves



Forced air (FA)

Natural draft (ND)

Sizes for Pyrolytic Biochar Production

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

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

Making Biochar

- Medium (1 t to 10 t)

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

TLUD barrels:

Singles or multiples

Retorts:

Adam Retort

Sizes for Pyrolytic Biochar Production

Flame cap (*open* cavity kilns):

Pit; trench; cone; pyramid; trough; Kon Tiki

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

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

Making Biochar

- Medium (1 t to
- Large (10 ton to
- Industrial (> 100

Sizes for Pyrolytic Biochar Production

Flame cap (*covered* cavity kilns):

4C = Clean Controlled Covered Cavity

- Laboratory (< 1 kg)
- Micro (1 to 10 kg.)
- Small (10 to100 kg)
- Midi (100 kg to 1 ton)

Making Biochar

- Me… 0 t)
- Lar… 100 t)
- Ind… t)

Sizes for Pyrolytic Biochar Production

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

Size	*Objectives*
• Laboratory (< 1 kg)	R&D /testing
• Micro (1 to 10 kg.)	Cooking
• Small (10 to100 kg)	Making Biochar
• Midi (100 kg to 1 ton)	
• Medium (1 t to 10 t)	To be determined
• Large (10 ton to 100 t)	Char/chem/power
• Industrial (> 100 t)	CHP (char secondary)

Basically missing except at high prices.

A major gap in the available sizes of pyrolyzers.

Gap to be filled by RoCC kilns.

Sizes for Pyrolytic Biochar Production

Rotary Kiln

Air Curtain for Biomass Reduction w/ less biochar

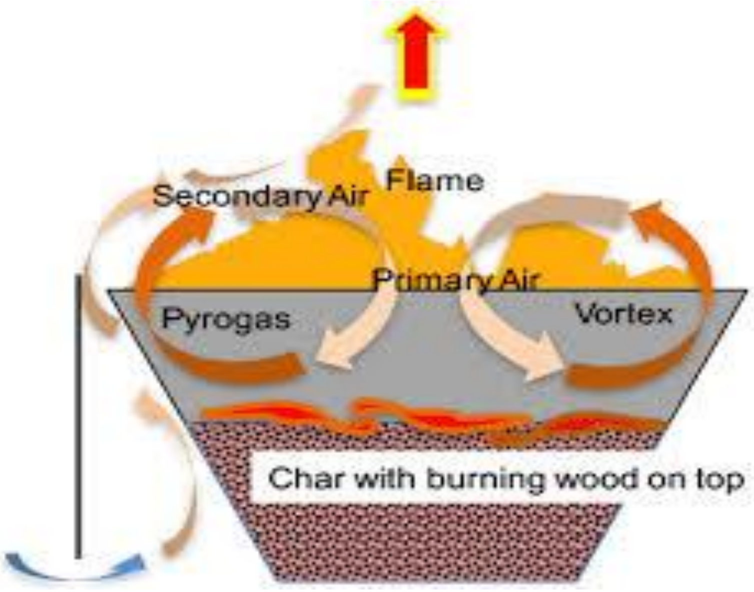
Industrial furnaces for heat with char in the ashes.

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

Char production is secondary

Evolution of the RoCC kiln

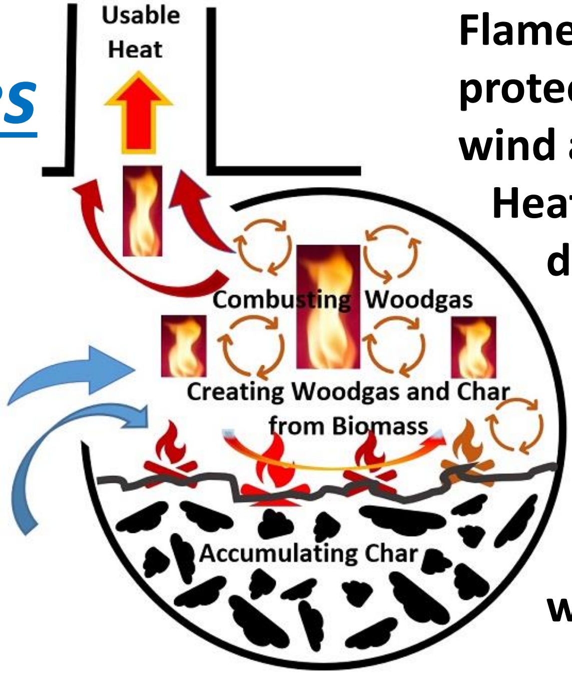
- Flame Cap (aka Flame Curtain) pyrolysis technology is accomplished in cavities with closed bottoms.
- Classic Flame Cap occurs in cavities that have open tops.
- "4C kilns" are covered cavity kilns that have increased enclosure, but they were not rotatable. [~ 8 made between 2014 and 2019]



Open Top Cavity Kilns

Shared Flame Cap Processes

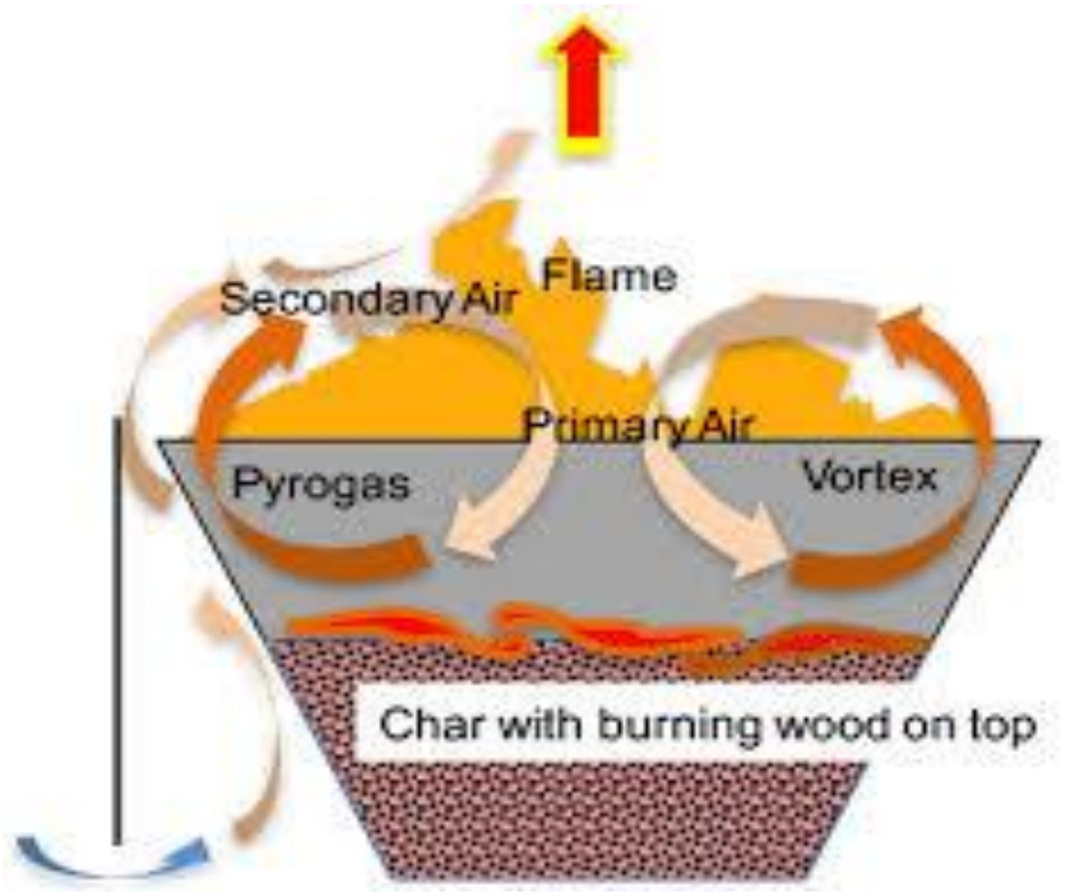
- Heat, flames and emissions rise away from the flame cap.
- Combustion of pyrolytic gases occurs with turbulence.
- Pyrolysis of biomass occurs because of the heat of the combusting gases.
- Created charcoal accumulates in the lower areas where oxygen cannot reach because of the cap of flames.



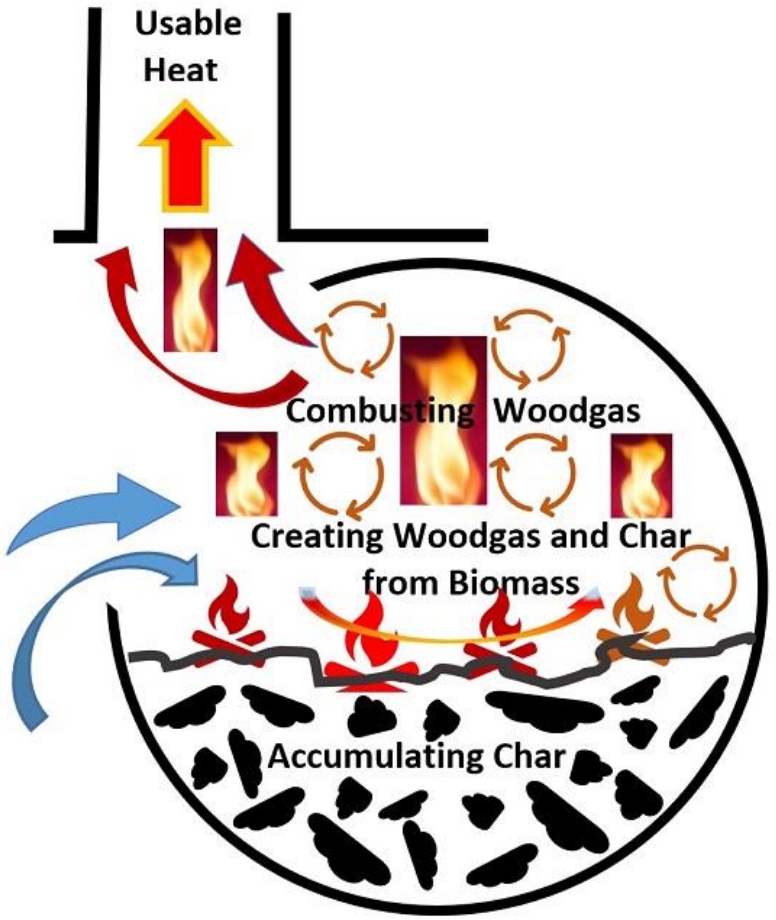
Covered Cavity Kilns

Advantages:
Flame is protected from wind and rain.
Heat can be directed to uses via chimneys that assist with draft.

Diagrams of Open and Covered Cavity Kilns



Flame Cap Processes in Open Cavity Kilns



Flame Cap Processes in Covered Cavity Kilns

Deficiencies of Static Cavity Kilns

- **Several deficiencies are found in classic and 4C flame cap cavity kilns.**
  - **Fuel input is gradual** and requires attention of the user.
  - **Possible incomplete charring** if some biomass fuel becomes buried.
  - **Lack of control of air flows.**
  - **Do not readily scale up for much larger sizes.**
    - Exceptions include the "Turtle" (flip-able half cylinders).
  - **Can become too hot for the operator** to approach without equipment.
  - **Extinguishing and extracting the hot charcoal** become difficult as size increases.

Solutions included in the RoCC kiln designs:

- **Tumbling of the biomass** is possible as the kiln is **rotated when needed**.
  - Let gravity do the work of mixing and exposing the raw and torrefied biomass.
  - Rotation of 240^{o} is possible because it is a covered cavity.
- Have an **open portal** for fuel & air input and emissions & char output that can be placed in different positions for different purposes (explained below).
- **Moveable grate** (prongs/fingers) to help select what is discharged. Door to cover portal is possible for special cases, including 360^{o} rotation.
- **Fuel loading** by horizontal shelf (front) or vertical drop (rear, incl. bins and hoppers).
- **Unloading downward onto slide or into container .** Gravity does the work.
- **Chimney(s) are separate the** from the kiln; place them on a detached hood.
- Utilize **standardized materials,** such as industrial corrugated steel pipe (CSP) that has many diameters and plenty of length.

This allows for additional benefits

- **Scale** from < 2-ft to > 16-ft diameters, and lengths appropriate for the biomass and desired output of biochar.
- Be either **portable or stationary.**
- Is compatible for **addition of sensors** and air control.
- Have **directional control of the emitted gases and heat** which can provide additional value.
- The **operators are less exposed** to direct fire and radiant heat.

The *Rotatable* Covered Cavity (RoCC) Kiln

is an innovation in late 2019 that shows **how to:**

- Facilitate **fuel delivery faster** and more plentiful and with possible **automation.**
- Assure **complete charring** of the biomass.
- Attain **better control** over the air flows, emissions and availability of heat.
- Have **nearly continuous** operations as well as **batch** operations.
- Be sufficiently **low cost** with low maintenance and low labor requirements.
- Be able to **scale to much larger sizes** and volumes.
- Facilitate the **extracting and extinguishing** of the hot charcoal.

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)

Different RoCC kilns span the size ranges from Midi to Large with many options to cover the mostly empty Medium size range.

Sizes of RoCC Kilns: Midi

(100 to 1000 kg/day biomass input)

Barrel-size kilns:

Upper left is front view in Illinois, USA.

In Kenya, lower left is front view and below is rear view when not in the normal operational position.

38-inch (970 mm) Diameter x 48-inch (1220 mm) Length unit in India.
Front view at right.
Rear view below.

Sizes of RoCC Kilns: Medium

(100 to 1000 kg/day biomass input)

Size shown is 4- ft (1.22 m) diameter by 5-ft (1.52 m) length

Sizes of RoCC Kilns: Large (10 to 20 tons or more per day of biomass input)

RoCC kilns the size of shipping containers can be made with industrial, strong, economical corrugated steel pipe (CSP) with up to 18-ft diameters.

1:16 Scale Models

1:16 Scale Models

Major Components of RoCC Kilns

- 1 Cylindrical pyrolyzer (with portal)
- 2 Rack to hold pyrolyzer
- 3 Frame for hood / chimneys
- 4 Hood and chimneys

The rack and frame can be combined in some units.

Auxiliary Components of RoCC Kilns

- 5 & 6 Loading shelf and Discharge slide
- 7 to many: Mechanization, Instruments, Handles, Mixers, Prongs/fingers, Air controls, Insulation, Heat extraction, etc.

Cylindrical Pyrolyzer

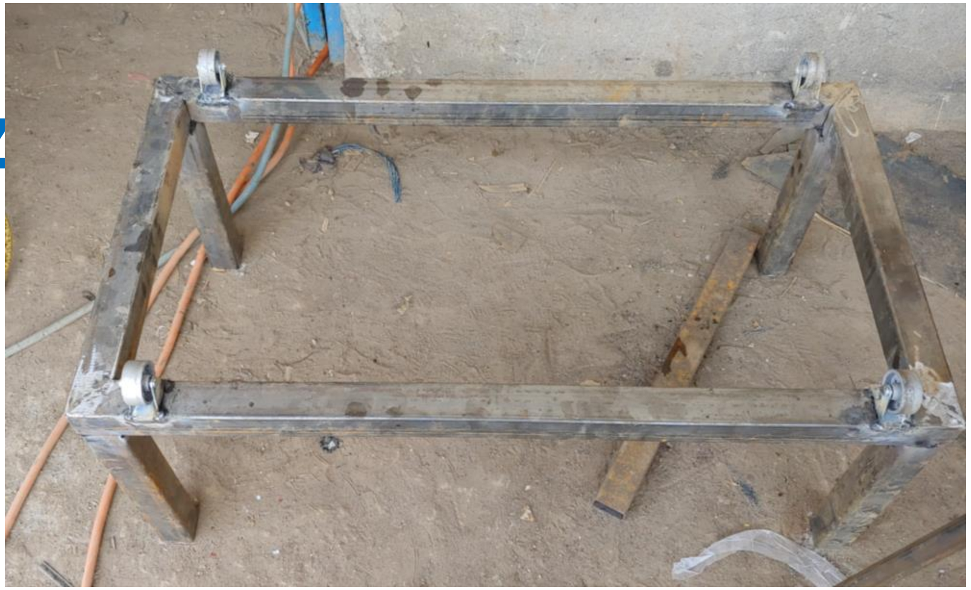
- **Cylindrical steel tanks of various sizes** (including RR tank cars)

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

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

Rack for Pyrolyz

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



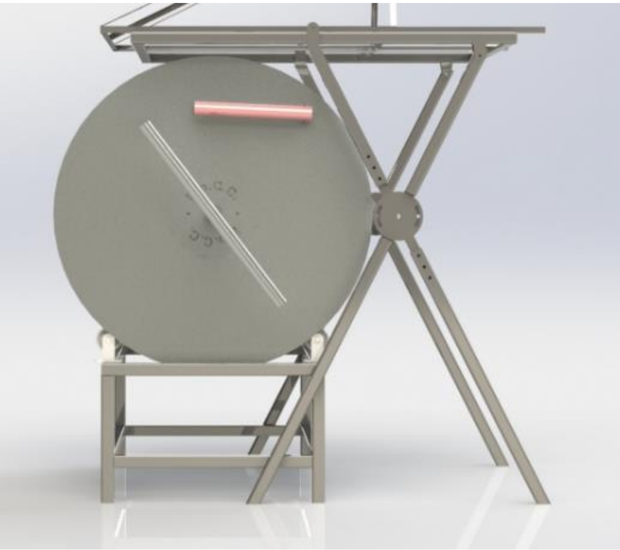
- Welded cross bars and casters on improvised legs of concrete blocks. ➔

- "I" (eye) rack
  - Currently being fabricated; not shown.
  - Shape of letter I with extended bottom for base and top to include an integrated frame for the hood.
  - Made of I - beams for industrial strength and lifting with forklift.

Frame for Hood/Chimney

- Box frame

- "X" frame



- "I" (eye) frame
  - Currently being fabricated.
  - Shape of letter with extended top and bottom. I
  - Made of I - beams for industrial strength.
  - Integrated with rack for cylinder.

Hood / Chimney

- **Flat Hood w/ simple chimney**
  - (Slides on top of frame)

- **Hood w/ simple sides**
  - (Slides on top of frame)

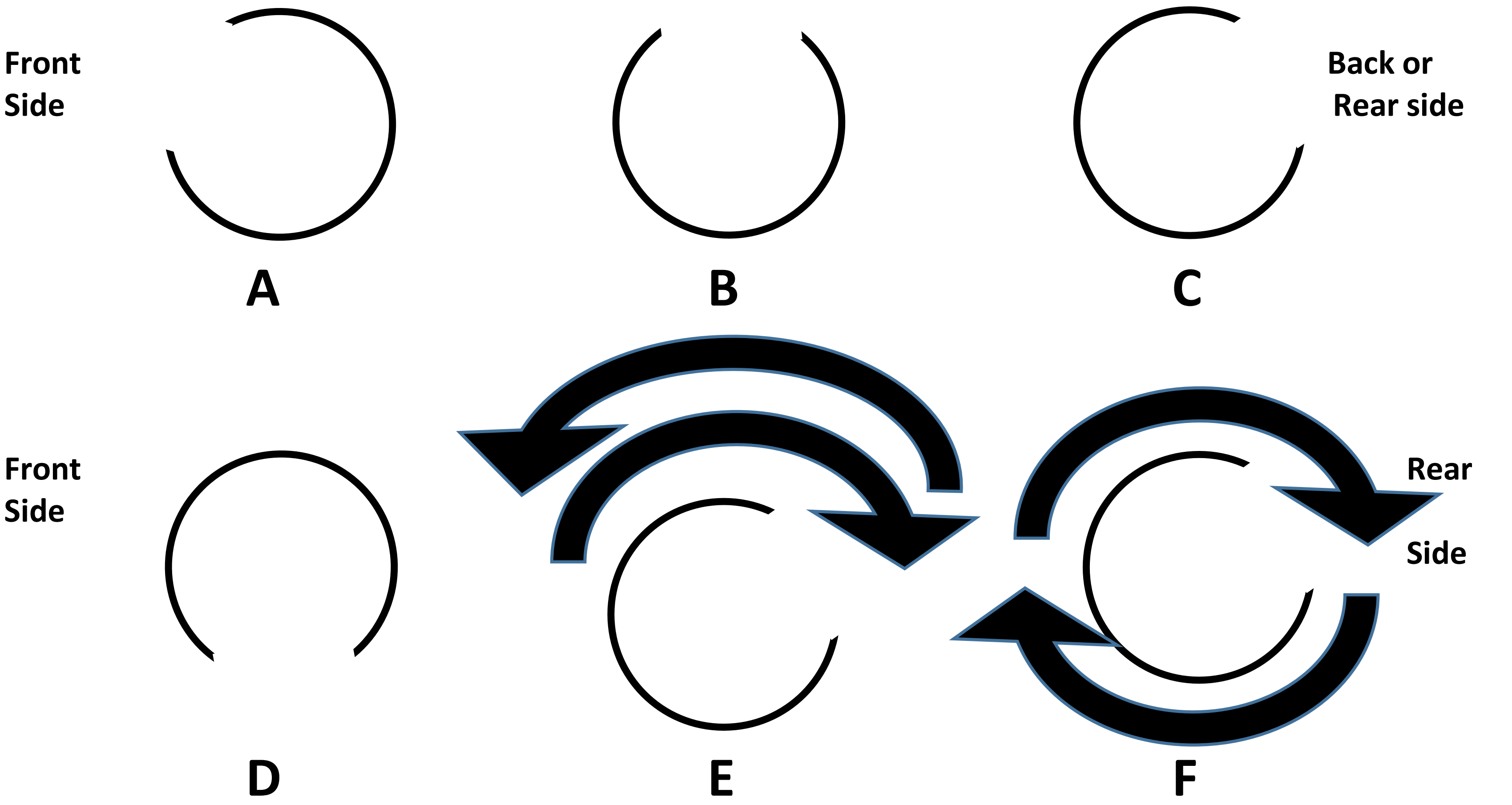
- **Raised hood w/ increased volume**
  - (Slides inside of frame)

Loading Shelf and Hood Define the "Front." Discharge Slide or Collection Box is in the "Back."

Front

Back or Rear

Portal positions on a cylindrical covered cavity kiln



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.

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

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

- Sawdust (P)
- Mulch (R)
- Chips and Pellets(R)
- Reeds and stems (E)
- Brush and small branches (E)
- Arm-size branches (R)
- Cordwood (R)
- Slab wood (E)
- Whole trunks (P) (Allow sufficient time for pyrolysis)
- 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.

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%)

Being revised, but still useful as a reference document.

	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

Hypothetical scenario with utility-size RoCC Kiln

	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

- 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

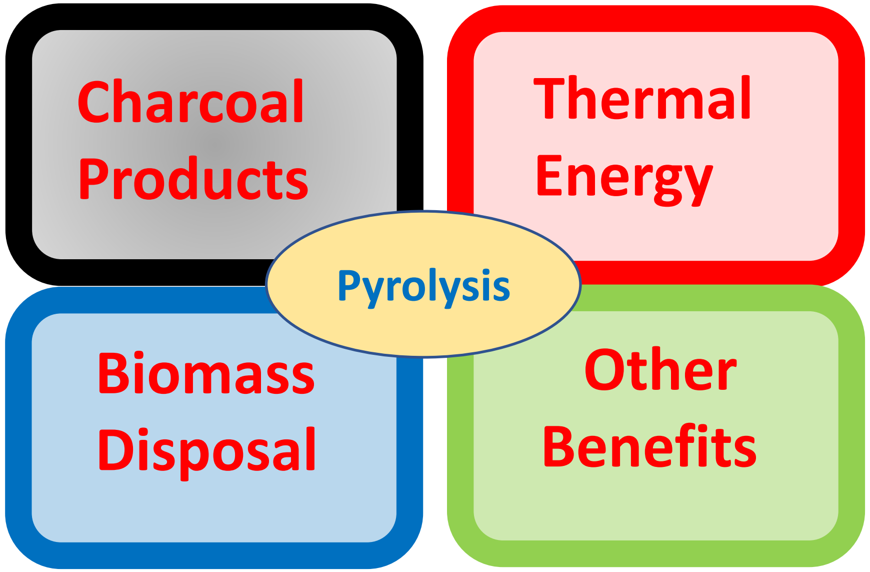
- The RoCC kiln invention has international patent pending status with likely coverage until 2040. This protects your interests as well as those of the inventor.
- When there is financial gain based on the RoCC kiln production or use or other activities such as gained carbon credits, some small share should come to the inventor.
- Therefore, there are at this time (06/2020) 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.

Costs of RoCC Kilns

- **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: A less expensive variation should be available by 1 August 2020.]
- **Utility size** **(from 3 to 5-ft diameters and up to 10 ft long):**
  - Many variables, but likely to **cost from 5 to 10 thousand dollars.** The inventor can assist you to locate a supplier (and save you much expense).
  - 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.

RoCC kilns for climate intervention strategies

- Abundant biomass is widely and often thinly distributed.
- Biomass pyrolysis delivers many benefits.
- Decentralized biochar production as a highly appropriate, accessible, reasonably priced major climate tool for carbon dioxide removal (CDR).
- Major accomplishments can come from the small contributions of many individual efforts.



All is becoming available now and worldwide.

- **Needed:** The world needs renewable energy, biochar for agriculture, biomass removal, and carbon sequestration for climate intervention efforts.
- **Possible:** Pyrolysis / biochar production with affordable medium-size appropriate technology is now possible.
- **Accessible:** Access to the technology is willingly shared with those who want to be part of the activities.
- **Opportunities:** The ownership (and rewards) of potentially profitable activities in local and regional areas are available around the world.
- **Why not?** If or when there is another technology that can fill the gap for medium-size pyrolysis units as well as or better than the RoCC kiln, we should all endorse it. But while you are seeking or waiting, the RoCC technology is available for your consideration.

SUMMARY:

- The Rotatable Covered Cavity (RoCC) kiln technology and devices help fill the massive gap in size and cost options for small and medium biochar operations such as for farms, woodlots, and community places generating “refuse” biomass.
- Possible scale-up to very large sizes. This will depend on need, financing and engineering.

Resources about RoCC Kilns

- ***RoCC Kiln Manual*** **(Version 2020-06-24 has important updates). Available at www.woodgas.com/resources.**

- **Introductory video (4 minutes) available on YouTube: Link is via www.woodgas.com/resources . A GaiaVideo production by Rocky Thompson who maintains a copy on Vimeo.**

- **Direct access to Paul Anderson who provides instruction and support for those who undertake to make and/or use RoCC kilns. Email to: psanders@ilstu.edu**

- **Demonstrations are possible as more units are with users.**

Contact Information

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Websites:

www.woodgas.com (Site of **Woodgas Pyrolytics, Inc.,** home of RoCC kilns)

www.drtlud.com (Site of materials about TLUD micro-gasifier stoves)

www.JuntosNFP.org (Site of non-profit efforts about stoves and biochar)

Active with the Biochar discussion group. Join at: main@biochar.groups.io

-- End of Webinar presentation –

Four extra slides below help visualize the volume and energy associated with 1 ton and 5 tons of dry biomass.

Visualizing a ton of biomass (1 ton => 200 kg biochar)

- Many variables can cause high variations in estimates:
  - Moisture Content (MC), branches vs. trunks, hard/soft woods, compaction
- **Wood chips**, dry 380 kg/m^3. Therefore, 1 t = ~2.6 m^3
- An average **seasoned cord of hardwood** weighs more than 2 tons!!
  Unstacked = 200 cubic feet (5.66 m^3).
  Therefore, 1 t = 2.7 m^3 1 t = ~ a half cord
- **Both chips and cord wood: 1 ton = fits in the bed of a full-size pickup truck.**
- Could double these volumes if low density biomass, but pyrolysis could be much faster.

Visualizing 5 tons of biomass (5 ton => 1 t biochar)

- Many variables can cause high variations in estimates:
  - Moisture Content (MC), branches vs. trunks, hard/soft woods, compaction
- **Wood chips**, dry 380 kg/m^3. Therefore, 5 t = 13 m^3
- An average **seasoned cord of hardwood** weighs more than 2 tons!! Unstacked = 200 cubic feet (5.66 m^3). Therefore, 5 t = 14 m^3
- **Both chips and cord wood: 5 tons = ~ 2/3rd full 20 ft. shipping container.**

Visualizing 20 tons

- 20 t = 10 cords = tri-axle load of wood.

  or a loaded 40 ft. shipping container.
- Could double these volumes if low density biomass.

Energy content of 1 ton of dry biomass

- Dry biomass has about 16 mJ per kg.
- Allow 6 mJ/kg to be remaining in the produced char plus some loss.
- 10 mJ/kg x 1 ton = 10 k mJ (10 gJ = gigaJoules) released per 200 kg of biochar produced.
- 10 gJ = 0.9 million BTU = 95 therm = 2800 kWh

- Average house uses 40 therm per month in winter. Allowing for only 50% thermal efficiency, approx. 1 ton of biomass could heat a home for one month in a cold climate (Estimate because of many variables.)
- Further discussion about heating with biomass instead of fossil fuels.

Energy content of 5 tons of dry biomass

- Dry biomass has about 16 mJ per kg.
- Allow 6 mJ/kg to be remaining in the produced char plus some loss.
- 10 mJ/kg x 5 ton = 50 k mJ (50 gJ = gigaJoules) released per 1 t biochar.
- 50 gJ = 4.7 million BTU = 473 therm = 14,000 kWh

- To be considered: Heating of schools by use of the RoCC kiln technology and local biomass, with biochar output.