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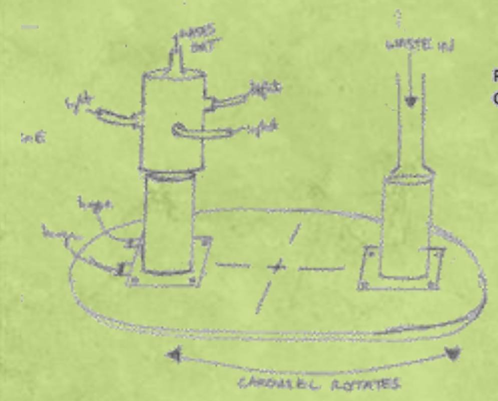
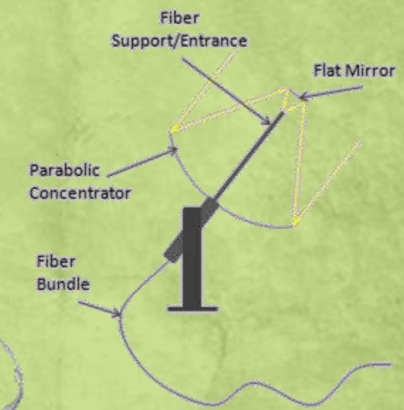
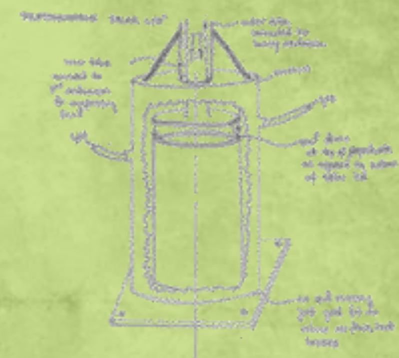






Solar Biochar Toilet

Fecal Sludge Management Conference
October 29th-31st, 2012
Durban, South Africa
R. Scott Summers

The Challenge

Reinvent the Toilet Challenge RTTC- Round 2 funded by The Bill & Melinda Gates Foundation

Condense the sanitation value chain → design a toilet that:

- Is affordable and desirable to use
- Renders fecal waste harmless within a short timespan
- Is self-contained without the need for flush water or electricity
- Produces valuable end products

Our Approach: Technology

Solar energy captured with solar concentrators

Energy is transmitted through fiber optics to a high temperature reactor

Thermally inactivates human waste

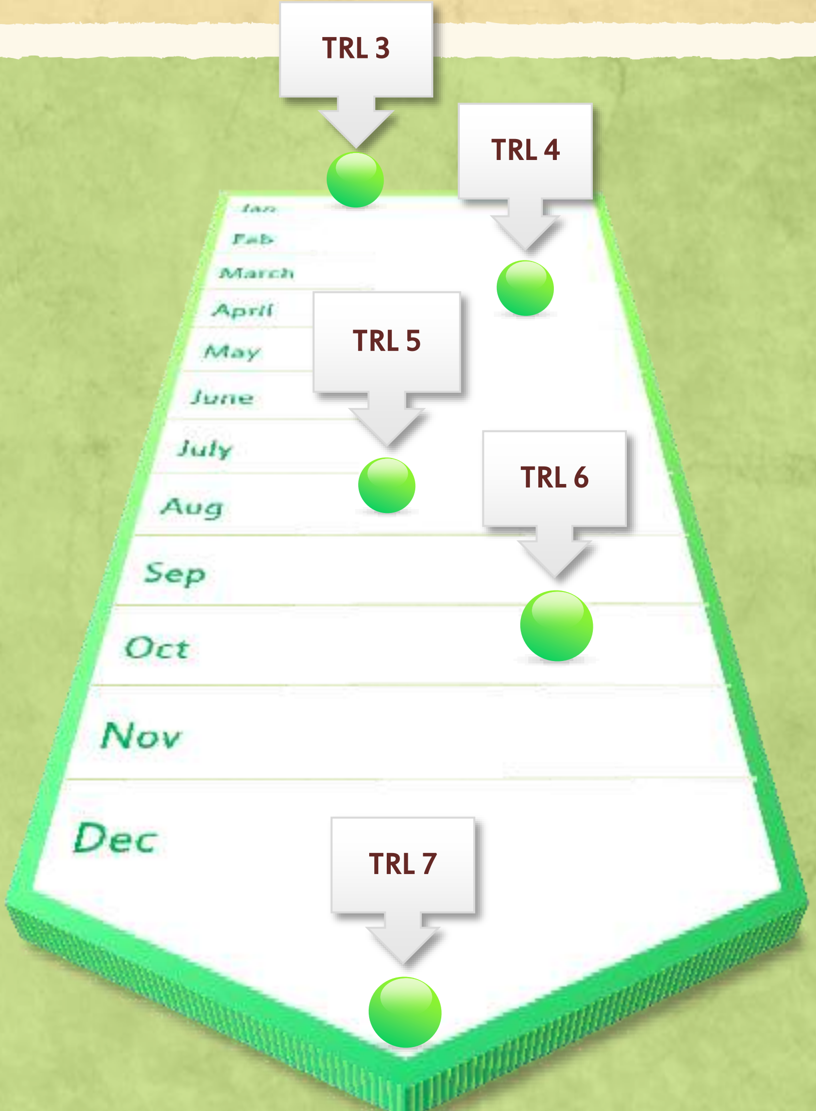
Creates useful end products

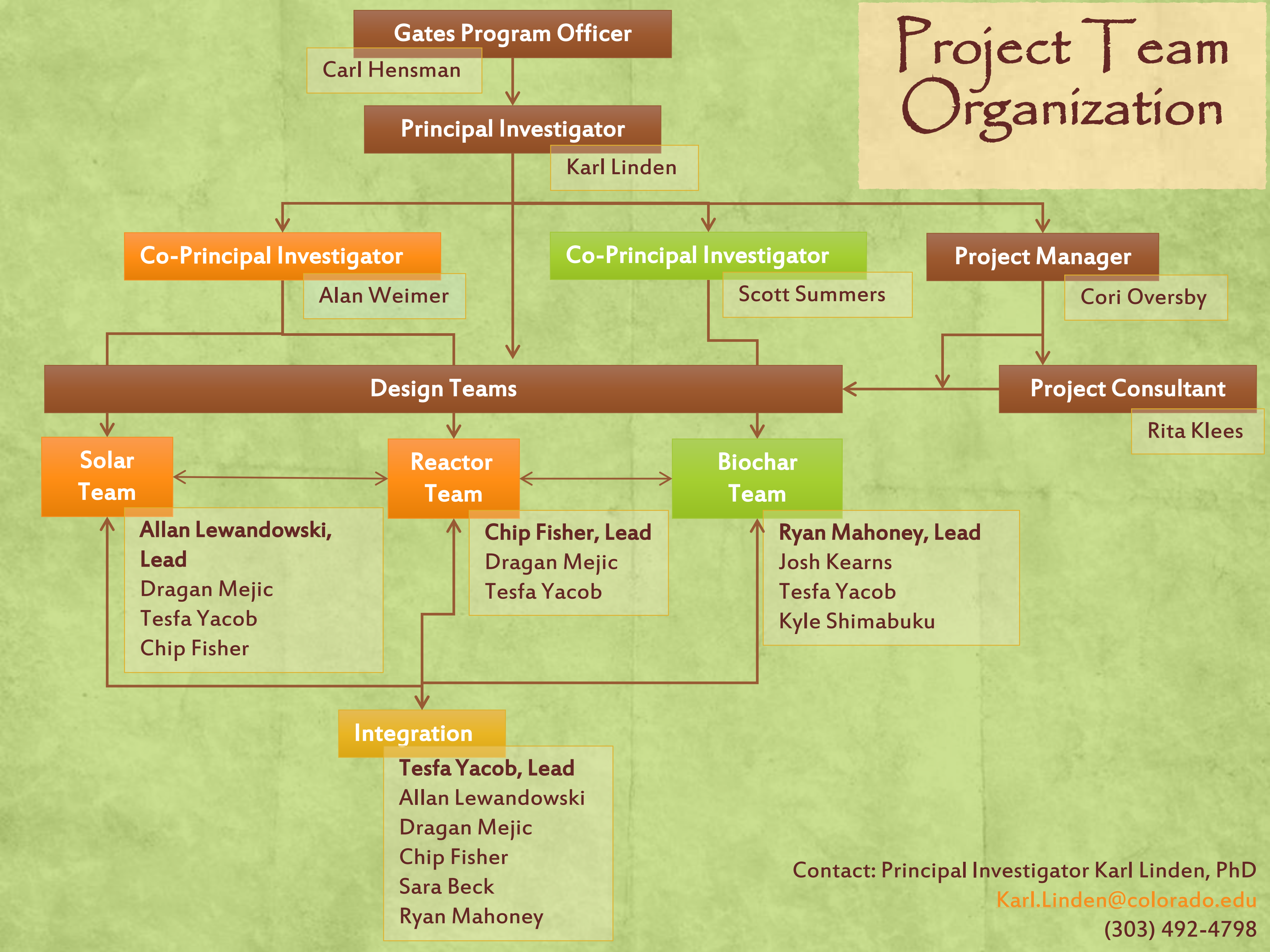
Our Approach: Research Value

- Advance body of knowledge concerning fecally derived biochar
- Advance nutrient and energy recovery from urine and gases released during pyrolysis
- Advance the use of fiber optics for transmitting energy from concentrated solar systems

Project Plan : Technology Readiness Levels

TRL 3	Proof of concept on paper - current
TRL 4	Component validation in lab – Apr 13
TRL 5	Integrated prototype in lab – Aug 13
TRL 6	Prototype used in semi-controlled setting – Oct 13
TRL 7	Prototype used in relevant, slightly monitored setting

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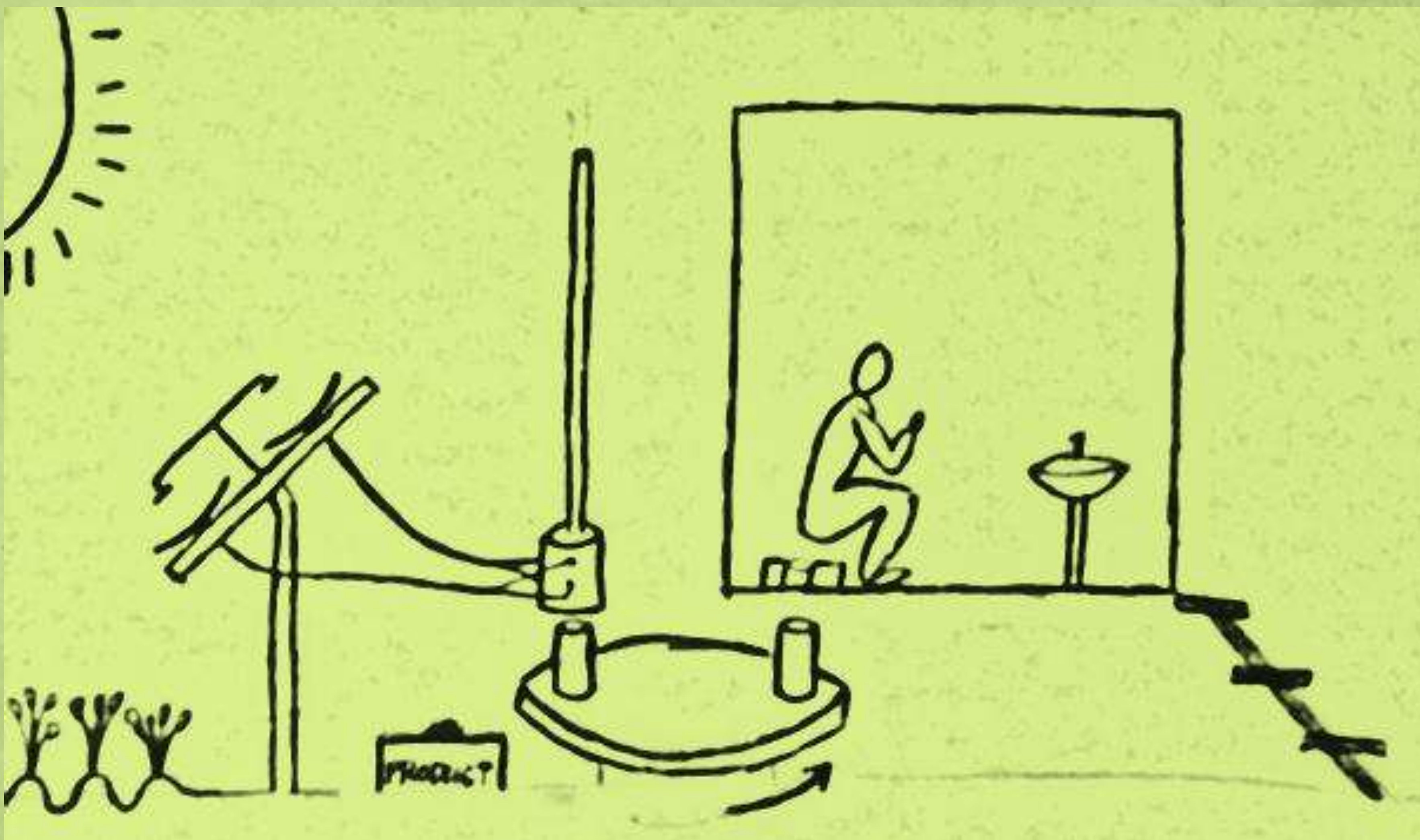
Concept Sketch



Processes Considered

Mixed Waste Pyrolysis
Faecal matter & Urine

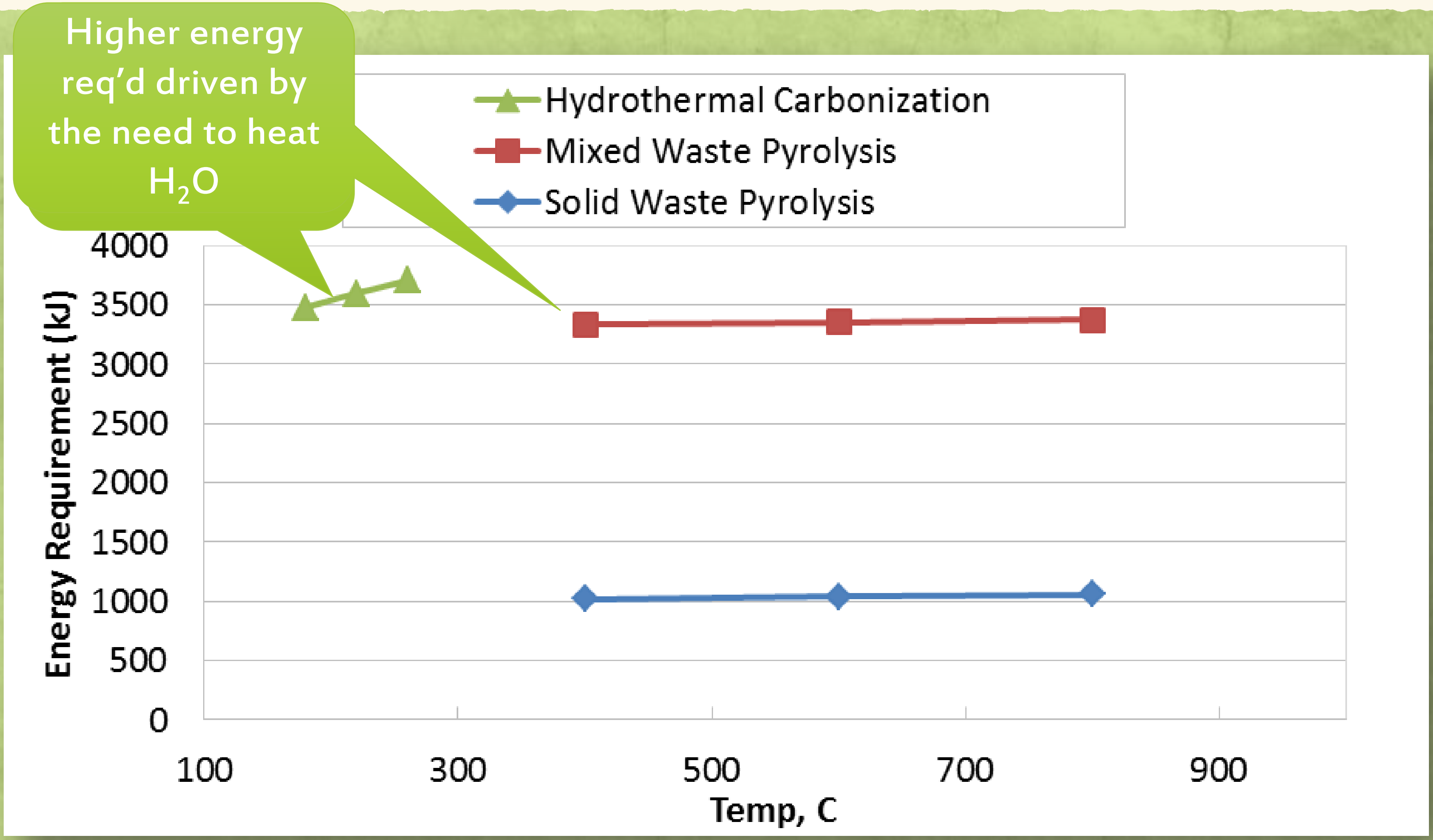
Solid Waste Pyrolysis
Urine Diverted

Phase 1 Prototype

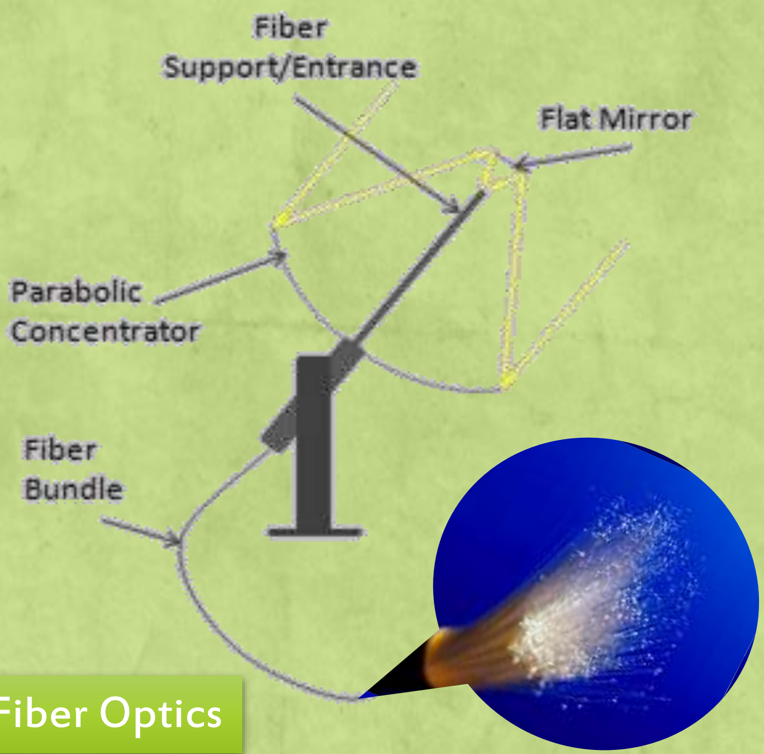
Hydrothermal Carbonization (HTC)

Phase 1 Research/ Phase 2 prototype

Energy Required – per person basis



Solar Concentrator – Concept



Fiber Optics

- Concentrated energy transmission via fiber optics can be
  - directed to specific locations

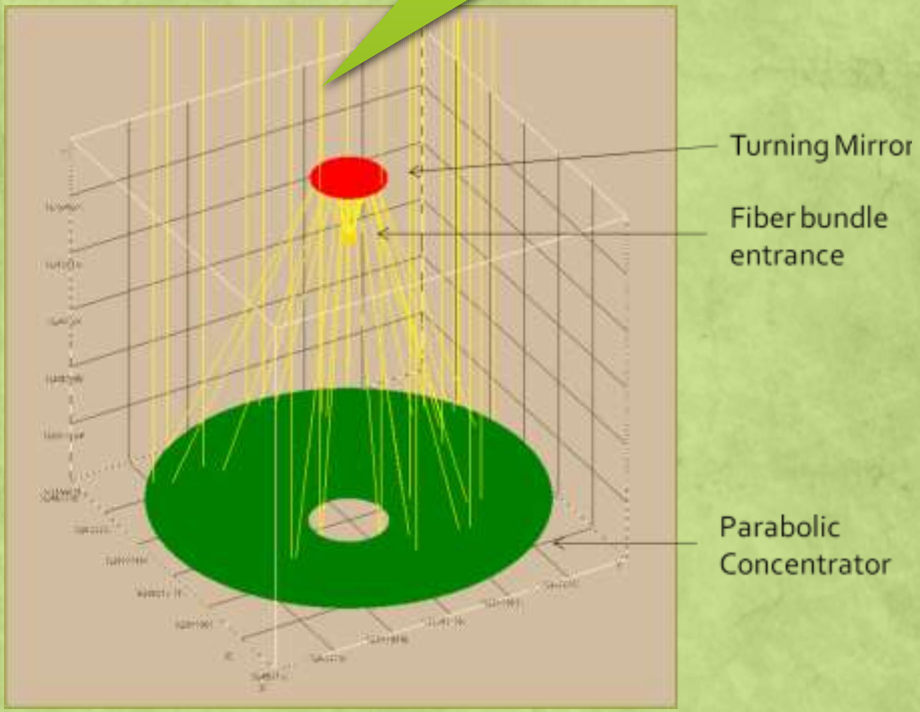
- Parabolic concentrator
- Fiber optics chosen – maximum flexibility in delivering concentrated sunlight to a reactor
- The reactor can be at a fixed location
- Very high temperatures > 800 C demonstrated with similar systems

Source: Nakamura and Smith 2011

Solar Concentrator - Design Parameters

- Solar system and reactor operates 4 hours/day with 800 W/m^2 sunlight
- 0.6 m diameter concentrators
  - overall efficiency of 0.46
  - delivers 107 W/dish
- 8 concentrators (2.3 m^2) and 8 fiber optic bundles needed to deliver assumed energy requirements
- Serves 4-12 individuals based on wet or dry prolysis

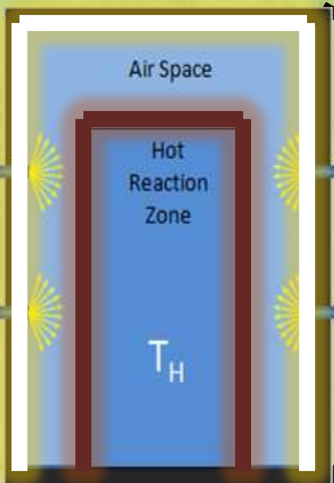
Ray tracing results

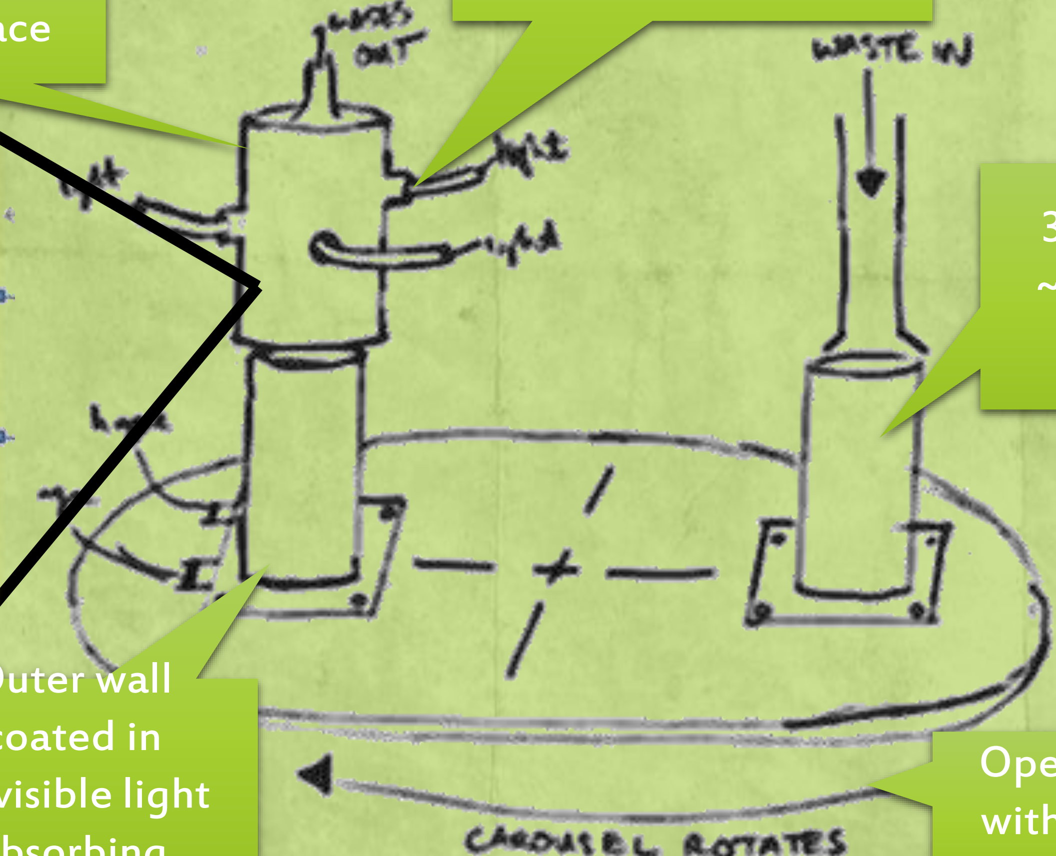


Reaction Chamber - Batch Design

Inner wall coated in reflective surface

Outer chamber design protects fiber ends from smoke and soot





316 Stainless steel: ~ 20 cm dia ~1 atm, 300-750°C

Outer wall coated in IR/visible light absorbing surface

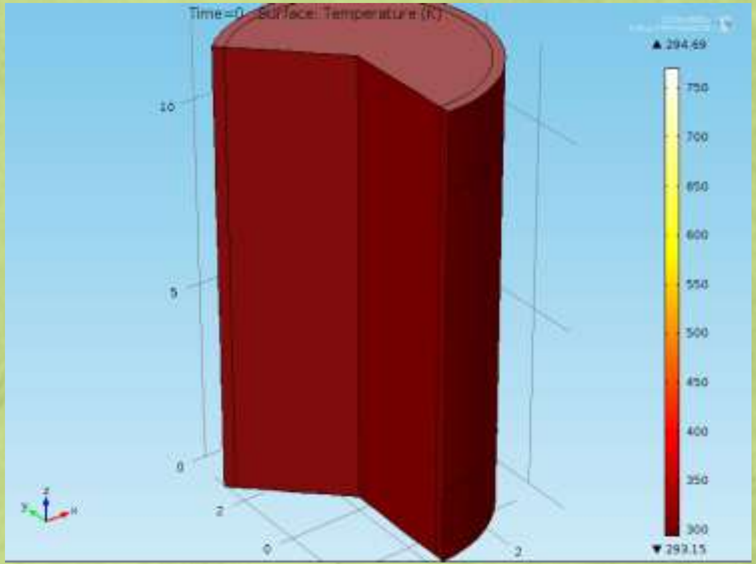
Operates safely with little to no user input

Heat Transfer - Modeling

Future Modeling Will Incorporate:

- Phase change: water to steam
- Radiation exchange between inner and outer walls
- Configuration of sources of concentrated light from fibers
- Shape of material inside the reactor

Reactor runs for 4 hours from 30 C to 750 C



Preliminary Heat Transfer Model COMSOL

Our desired product: Biochar

What do we mean by *biochar*?

"The carbon-enriched solid product of thermal biomass decomposition consisting largely of condensed aromatic (graphitic) zones that when applied as a soil amendment (1) imparts agronomic benefits and (2) is recalcitrant over a long timescale."

Biochar Characterization

Property	Function
Surface area / Microporosity	Accumulation of organic material, biofilm establishment, retention of inputs and H_20
Cation Exchange Capacity (CEC)	Retention and bioavailability of inputs (e.g. N, P, K fertilizers)
pH / Liming Effect	pH balance & buffering, Al toxicity
Longevity in soils	Potential for CO2 sequestration, durability of benefits

Fertilizer / Compost / Biosolids Tests	
Nutrient content	Bioavailability of nutrients in the product and application limits
Environmental Hazard Testing	Heavy metals and pathogens

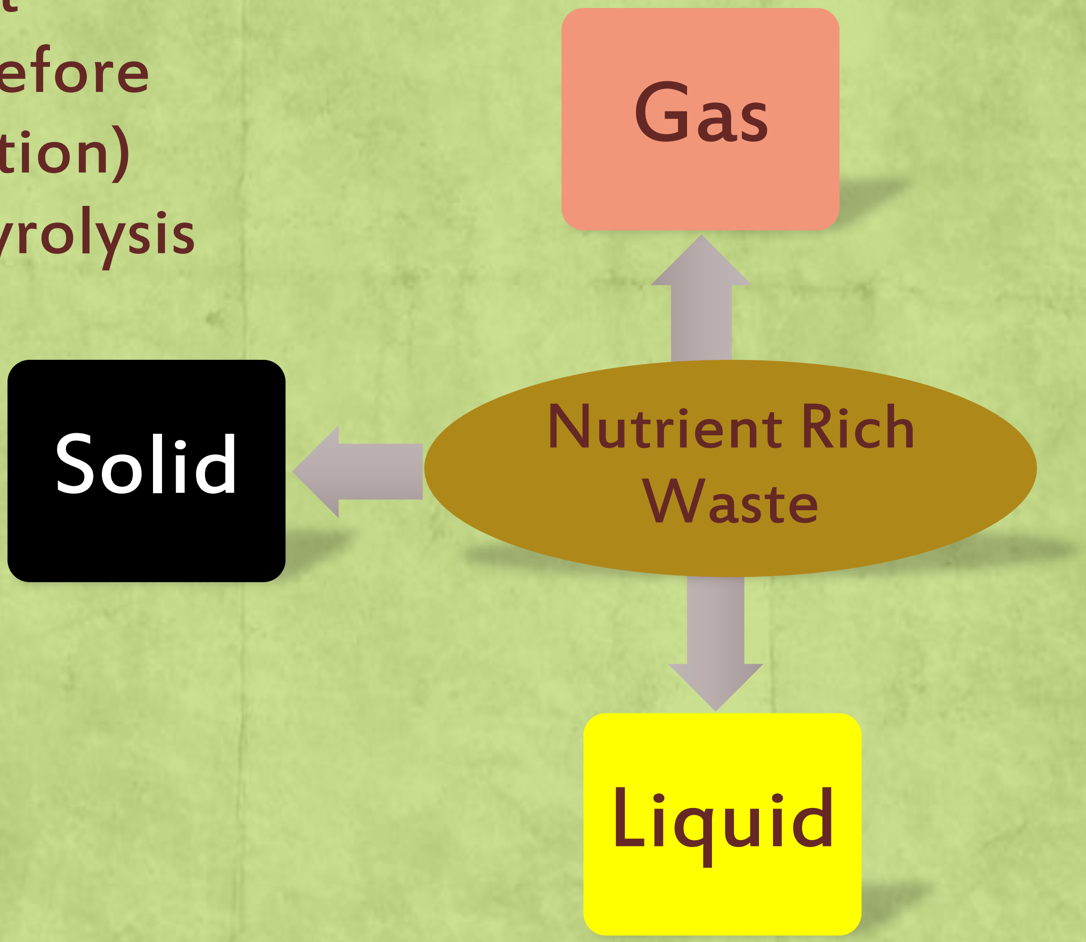
Biochar Characterization

Lab testing will:

- Verify waste stabilization
- Inform consistent & robust testing of all biochar / amendment parameters
  - International Biochar Initiative
  - US Composting Council
  - Collaboration with RTT Grantees
- Determine optimized reaction conditions to produce a product with agricultural value
  - Compare dry and wet pyrolysis with hydrothermal carbonization (HTC)

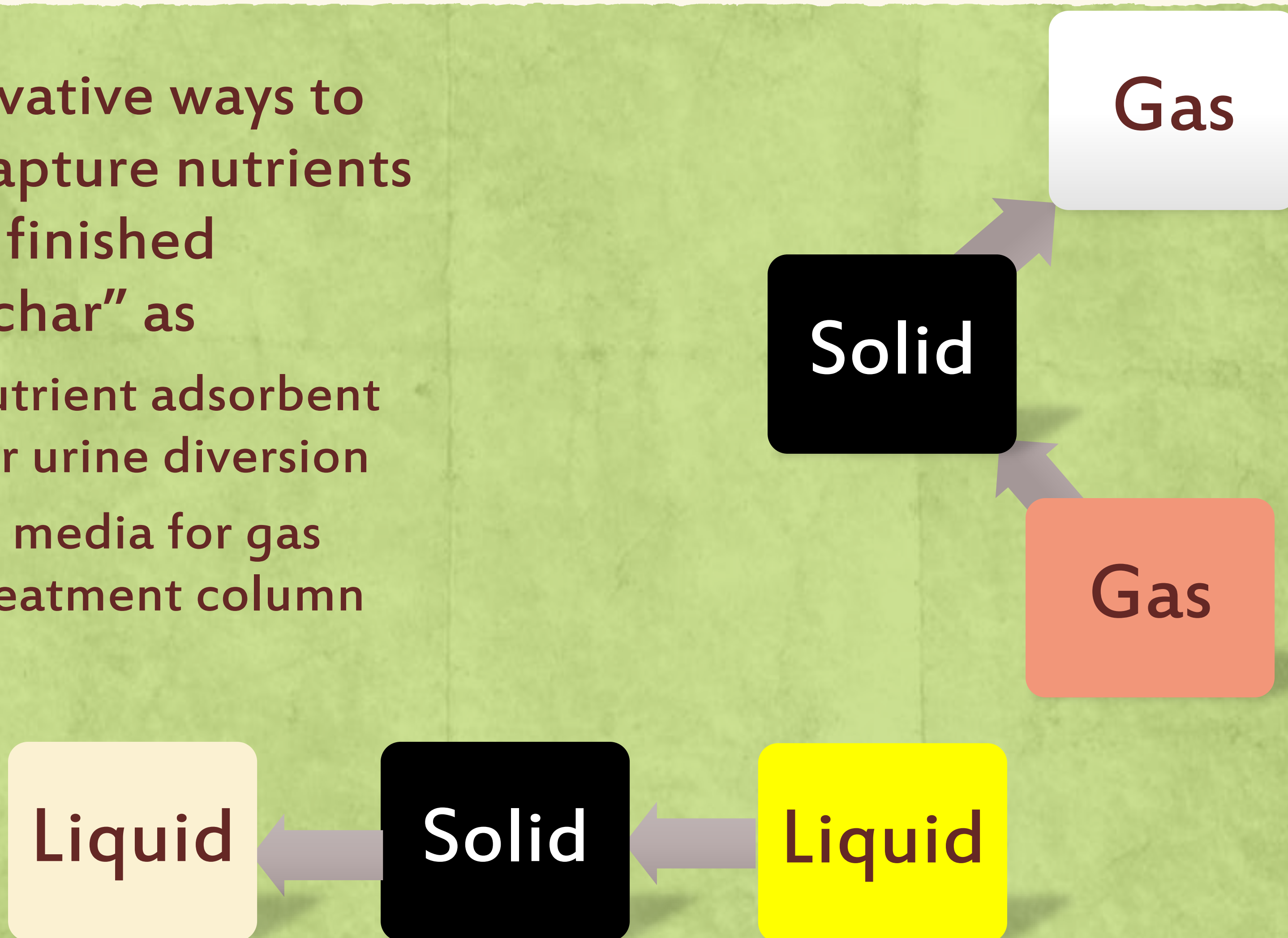
Biochar Characterization

- Strict nutrient accounting before (urine separation) and during pyrolysis



Biochar Characterization

- Innovative ways to re-capture nutrients with finished "biochar" as
  - nutrient adsorbent for urine diversion
  - as media for gas treatment column



Biochar Characterization

Lab characterization will be performed on both:

Human Fecal Waste

Synthetic Fecal Waste

Based on properties of the biochar

- Evaluate effective analog (physically and chemically)
- As a starting point use NASA recipe (Wignarajah 2006)

Dry Mass %	Ingredient	Properties Simulated
30	Yeast (active, dry)	Bacterial debris
15	Cellulose (cotton balls)	Dietary fiber
20	Polyethylene glycol (MW400)	Insoluble fiber
5	Psyllium husks	Dietary fiber
20	Peanut oil	Fat
5	Miso	Proteins
5	Inorganics	Minerals

Other Outputs & Recovery

Off-gas characterization

- Resource value
- Safety and odor (e.g. H_2S)

TGA/MS & GC/MS analysis

Excess heat for urine disinfection

Water condensation for re-use

Nutrients (adsorption through biochar column)

Combustion gas (household use)

Urine Diversion Process Considerations

Disinfection

- Removal of particulates by filtration
- Thermal disinfection using off-gas (heat exchanger/condenser design)
- Alternative disinfection (e.g. UV)

Nutrient Recovery

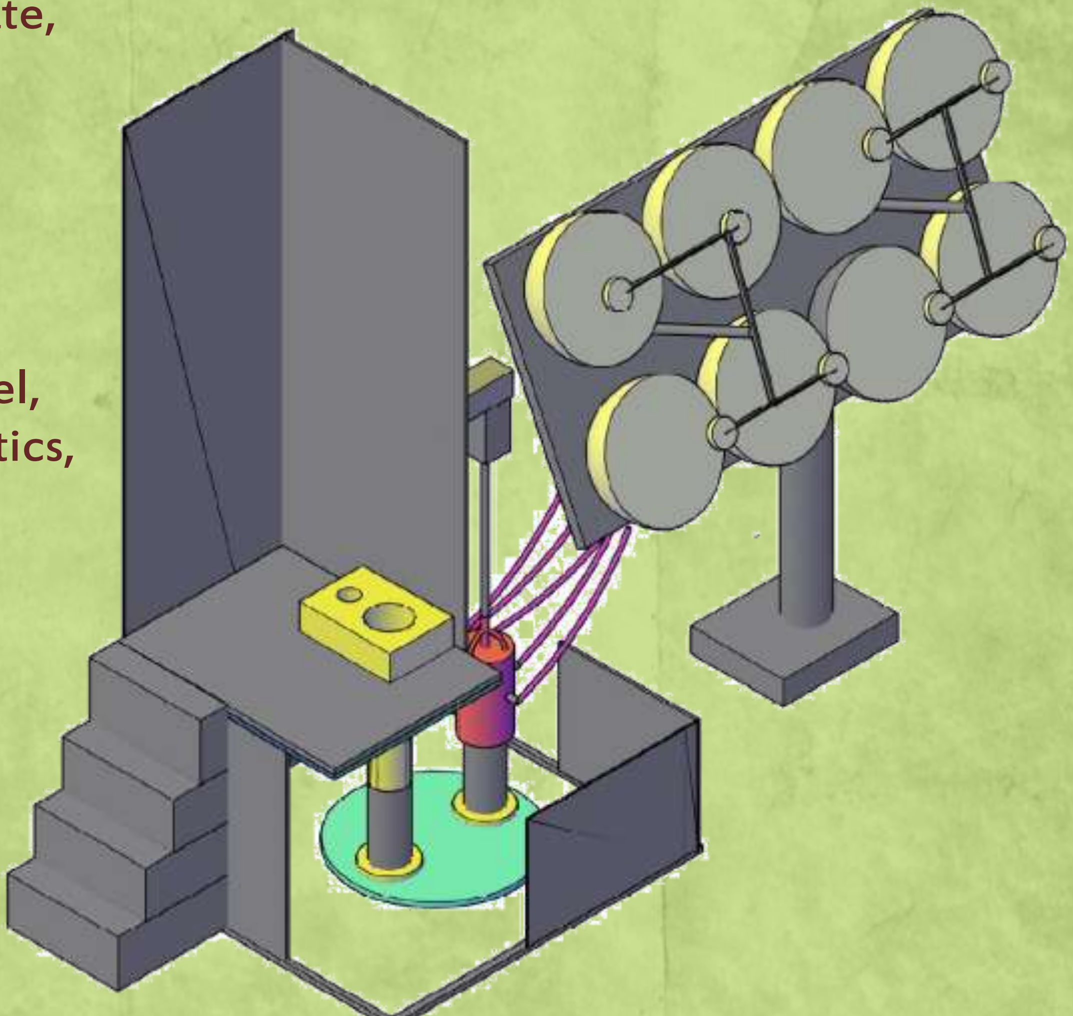
- Recovering N and P nutrients from liquid using packed bed (e.g. Biochar, MgO)
- Adsorbing NH_3 evaporated during thermal disinfection using biochar packed bed

Plan for use/proper disposal of remainder liquid

Comparison of energy consumption and nutrient recovery with mixed waste pyrolysis

From Lab Bench to Prototype

- User compartment (squat plate, urinal, hand wash station)
- Tracker and collectors
- Solar panel and battery
- Mechanisms: rotating carousel, moveable reactor lid with optics, product removal
- Gas and urine stream process units
- Product storage
- Instrumentation and control units.



Risks/Mitigations

Preventive Measures	Risks	Contingency
Insulate reaction compartment	Instantaneous solar flux increases heats in user compartment	Emergency closing mechanism at the fiber optics aperture
Properly contain exhaust gases	Presence of noxious gases	Implement a treatment step to adsorb the noxious gases
Treat fecal sludge using pyrolysis	Insufficient solar thermal energy for waste stabilization	Increase number of solar concentrators, decrease capacity, divert urine
Disinfect urine with heat or UV treatment	Not enough energy in pyrolysis gas or UV treatment not appropriate	Utilize extra energy from collectors (if present), increase storage capacity for time disinfection (6 month), consider chemical disinfection

Looking Forward

Achieve technical milestones for proof-of-concept / prototype

Sanitation problem solved

As a diverse team with extensive experience in the WASH sector – we understand that…

Looking Forward

Achieve technical milestones for proof-of-concept

Potential for future field test: Kampala Sanitation Lab

water for people
everyone | forever

Looking Forward

Achieve technical milestones for proof-of-concept

Utilize CU resources

Low cost, open-source, DIY alternatives

Mortenson Center in Engineering for Developing Communities
UNIVERSITY OF COLORADO **BOULDER**

In-depth market assessment and feasibility analysis

Leeds BUSINESS

Solar Biochar Toilet

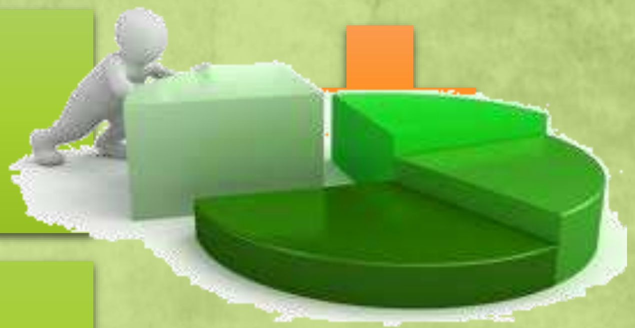
Questions/Discussion

Like us on facebook!: http://www.facebook.com/SolarBiochar

Website coming soon…

Looking Forward

Achieve technical milestones for proof-of-concept



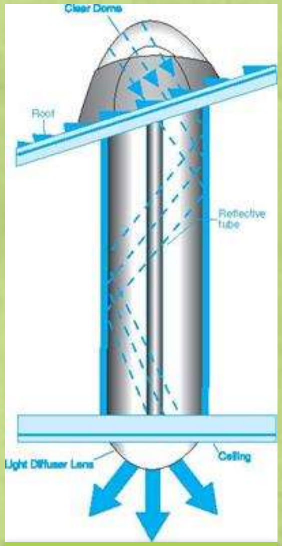
Leverage R&D efforts

Advance the forefront of biochar research

- Characterization protocols
- Sorption properties
- Nutrient retention and availability
- Conditions needed

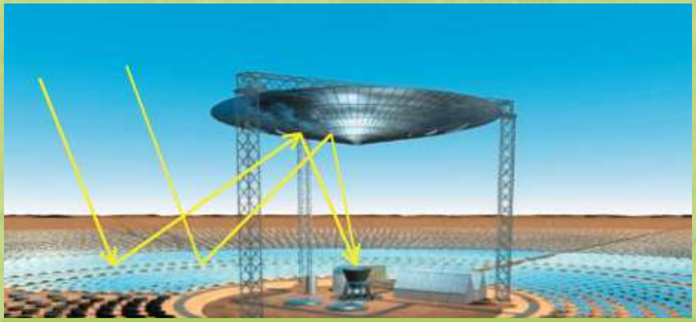
Light Transmission

Opt. 1 Direct Reflection



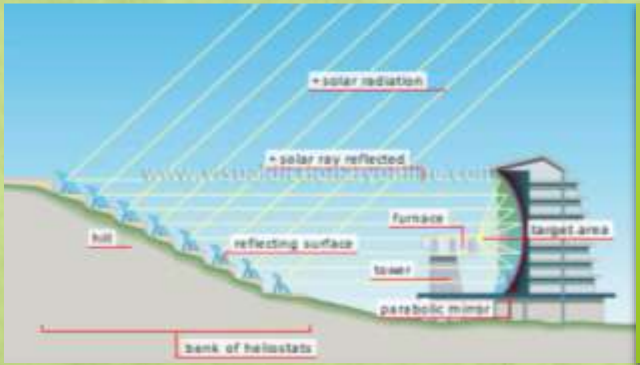
Light Tube

http://www.lsuagcenter.com



Beam Down Tower

http://www.gov-online.go.jp/pdf/hlj_ar/vol_0019e/28-29.pdf



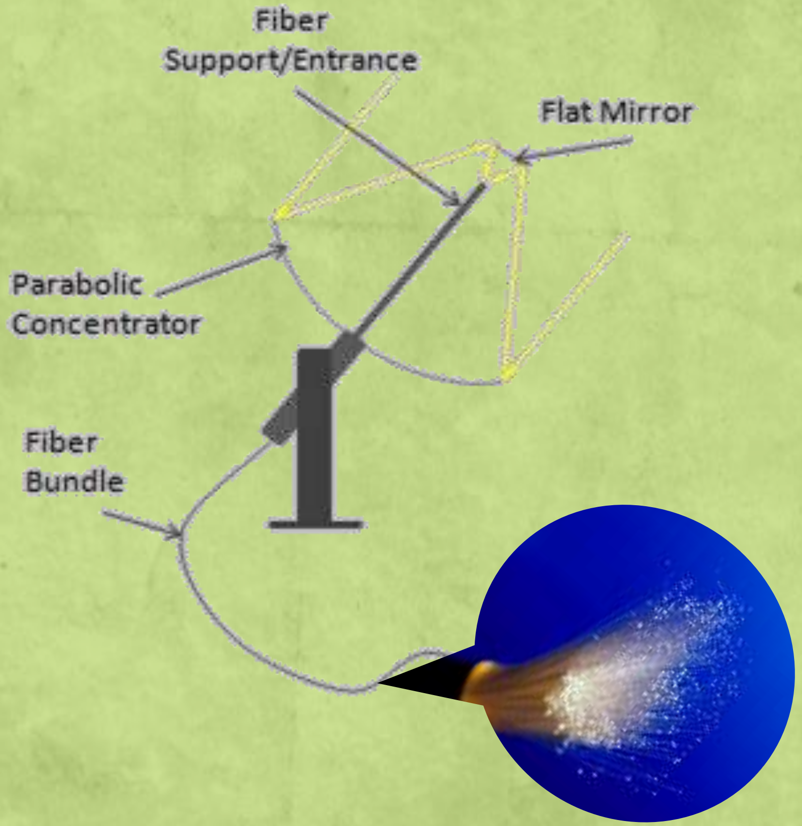
Solar Furnace

http://visual.merriam-webster.com/energy/solar-energy/solar-furnace.php

- Difficult to direct light → Need sophisticated optic devices
- Significant heat loss → No insulation
- High Temp. flux zones → Dangerous for users

Light Transmission

Opt. 2 Concentrated Transmission



Fiber Optics

- **Easy to direct light** → Reactor can be insulated → Underground reactor possible
- **Highly efficient** → High temps can be achieved
- **Safe heat transmission** → Less danger areas for users