University of Colorado Boulder

Team
Karl G. Linden
R. Scott Summers
Al Weimer
Al Lewandowski
Rita Klees
Cori Oversby
Ryan Mahoney
Tesfa Yacob
Richard Fisher
Dragan Mejic
Josh Kearns
Sara Beck
Kyle Shimabuku

Solar Biochar Toilet

Fecal Sludge Management Conference
October 29th-31st, 2012
Durban, South Africa
R. Scott Summers
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
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
Solar Team
Allan Lewandowski, Lead
Dragan Mejic
Tesfa Yacob
Chip Fisher

Reactor Team
Chip Fisher, Lead
Dragan Mejic
Tesfa Yacob

Biochar Team
Ryan Mahoney, Lead
Josh Kearns
Tesfa Yacob
Kyle Shimabuku

Integration
Tesfa Yacob, Lead
Allan Lewandowski
Dragan Mejic
Chip Fisher
Sara Beck
Ryan Mahoney

Contact: Principal Investigator Karl Linden, PhD
Karl.Linden@colorado.edu
(303) 492-4798
Concept Sketch
Processes Considered

- Mixed Waste Pyrolysis
- Faecal matter & Urine
- Solid Waste Pyrolysis
- Urine Diverted
- Hydrothermal Carbonization (HTC)

Phase 1 Prototype

Phase 1 Research/
Phase 2 prototype
Energy Required – per person basis

Higher energy req’d driven by the need to heat $\text{H}_2\text{O}$
Concentrated energy transmission via fiber optics can be directed to specific locations to achieve high temperatures. Fiber optics are chosen for their flexibility in delivering concentrated sunlight to a reactor. The reactor can be at a fixed location, and very high temperatures greater than 800°C have been demonstrated with similar systems.
Solar Concentrator - Design Parameters

- Solar system and reactor operates 4 hours/day with 800 W/m² sunlight
- 0.6 m diameter concentrators
  - overall efficiency of 0.46
  - delivers 107 W/dish
- 8 concentrators (2.3 m²) 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

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

Outer chamber design protects fiber ends from smoke and soot

Operates safely with little to no user input

Inner wall coated in reflective surface

Outer wall coated in IR/visible light absorbing surface
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

Preliminary Heat Transfer Model

Reactor runs for 4 hours from 30°C to 750°C
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

<table>
<thead>
<tr>
<th>Property</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface area / Microporosity</td>
<td>Accumulation of organic material, biofilm establishment, retention of inputs and H₂O</td>
</tr>
<tr>
<td>Cation Exchange Capacity (CEC)</td>
<td>Retention and bioavailability of inputs (e.g. N, P, K fertilizers)</td>
</tr>
<tr>
<td>pH / Liming Effect</td>
<td>pH balance &amp; buffering, Al toxicity</td>
</tr>
<tr>
<td>Longevity in soils</td>
<td>Potential for CO₂ sequestration, durability of benefits</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fertilizer / Compost / Biosolids Tests</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nutrient content</td>
<td>Bioavailability of nutrients in the product and application limits</td>
</tr>
<tr>
<td>Environmental Hazard Testing</td>
<td>Heavy metals and pathogens</td>
</tr>
</tbody>
</table>
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

[Diagram showing the transition from Nutrient Rich Waste to Solid, Gas, and Liquid]
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**
  - Evaluate effective analog (physically and chemically)
  - As a starting point use NASA recipe (Wignarajah 2006)

### Dry Mass %

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Properties Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 Yeast (active, dry)</td>
<td>Bacterial debris</td>
</tr>
<tr>
<td>15 Cellulose (cotton balls)</td>
<td>Dietary fiber</td>
</tr>
<tr>
<td>20 Polyethylene glycol (MW400)</td>
<td>Insoluble fiber</td>
</tr>
<tr>
<td>5 Psyllium husks</td>
<td>Dietary fiber</td>
</tr>
<tr>
<td>20 Peanut oil</td>
<td>Fat</td>
</tr>
<tr>
<td>5 Miso</td>
<td>Proteins</td>
</tr>
<tr>
<td>5 Inorganics</td>
<td>Minerals</td>
</tr>
</tbody>
</table>
Other Outputs & Recovery

- Off-gas characterization
- Resource value
- Safety and odor (e.g. H₂S)
- TGA/MS & GC/MS analysis
- Excess heat for urine disinfection
- Water condensation for re-use
- Nutrients (adsorption through biochar column)
- Combustion gas (household use)
- Other Outputs & Recovery
- Safety and odor (e.g. H₂S)
- Resource value
- TGA/MS & GC/MS analysis
Urine Diversion
Process Considerations

Disinfection
- Removal of particulates by filtration
- Thermal disinfection using off-gas 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

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

Locally operated & managed
Scalable
Affordable
Looking Forward

Achieve technical milestones for proof-of-concept

Potential for future field test: Kampala Sanitation Lab
Looking Forward

- Achieve technical milestones for proof-of-concept
- Utilize CU resources
- Low cost, open-source, DIY alternatives
- In-depth market assessment and feasibility analysis
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

- **Difficult to direct light**
- **Significant heat loss**
- **High Temp. flux zones**

Need sophisticated optic devices
No insulation
Dangerous for users

Light Tube
http://www.lsuagcenter.com

Beam Down Tower

Solar Furnace
Concentrated Transmission

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

Light Transmission

Fiber Optics