### Background
- Exposure to smoky cooking fires cause 1.6 million deaths each year, **this is three deaths every minute.**
- They claim the lives of more children under five than any other single cause.

### Goals

**Primary goal**
Reduce harmful emissions of carbon monoxide (CO) and particulate matter (PM) which are very detrimental to human health in order to save lives.

**Secondary goals**
1. **Increasing fuel efficiency**
   - Solid biomass fuels are scarce in the developing world and have alternate applications.
2. **Producing Biochar**
   - Biochar is charcoal made from biomass to be added to the soil and has the potential to improve agricultural yields and mitigate climate change.
3. **Electrical cogeneration**
   - Excess heat may be converted into electricity and used for fan forced combustion or indoor lighting.

### Proposed solution
- Two stoves were designed to improve combustion to **save lives**.
- Efficiency and emissions testing compared improved designs to traditional stoves used in the Nepalese Terai.
- Research into stove improvement concepts including biochar production and cogeneration identified their feasibility.
- A partnership was formed with Engineers Without Borders (EWB) to share our work with in-field engineers currently working in the Terai region of Nepal.

**TLUD stove**
- Top-lit up draft (TLUD) stove.
- Uses pyrolysis, (the decomposition of solid biomass in a low oxygen environment), to release volatile gases which combust separately to the solid fuel.
- As a result, the TLUD stove burns almost any solid biomass fuel with low emissions and also produces biochar.

**PHAIR stove**
- Pre-heated improved rocket (PHAIR) stove.
- Pre-heats primary air to improve the performance of a rocket stove, a commonly used improved stove.
- Designed to use wood fuel and be continuously fed.
- Is applicable throughout the developing world.

### Outcomes

**Emission reduction**
The TLUD stove reduced CO emissions to one-eighth of a three stone fire, a traditional stove used in Nepal.

**Biochar**
Cow dung biochar from the TLUD stove was tested and found to have great soil enhancing potential to improve agricultural yields.

**Electrical Cogeneration**
- Fan forced combustion was experimentally evaluated.
- Major improvements were not realised to justify the additional cost.

**Partnership with Engineers Without Borders**
- Improved stove designs were demonstrated to EWB in-field engineers who will take the technology to Nepal.
- Suitability to the Nepalese Terai will be evaluated through continued community engagement and in-field trails.
Engineers Without Borders Partnership

Working with in-field engineers
Through a partnership with Engineers Without Borders (EWB), project members worked with volunteers in the Terai region of Nepal who share a common goal of saving lives.

Three stone fire
The most common stove setup in the Terai is a three stone fire; an open fire surrounded by three stones to support the pot.

Buffalo dung
- The most common fuel type in the Terai is buffalo dung.
- Buffalo dung has a low energy density and incomplete combustion produces harmful emissions.

Stove integration
- Stove designs were demonstrated to in-field engineers when preparing a traditional Nepalese meal.
- These volunteers have arrived in Nepal and will focus on integrating the stoves into the Nepalese way of life.

Implementation of TLUD stove technology will reduce harmful emissions compared to traditional stoves. This will be achieved through;

- Use of a TLUD stove for single-pot cooking with a larger fuel chamber to burn buffalo dung.
- Incorporation of TLUD stove technology as the heat source in a multi-pot cooking structure.

Future work
- The next stage of the project involves in-field trials of TLUD stove technology.
- This will be conducted through partnership with EWB to help save lives and improve quality of life.
**Background**

- Dung is used throughout the developing world as a cooking fuel.
- Common fuels include cow, buffalo and ox dung.
- Dung produces higher emissions of harmful pollutants than other fuels.

**Testing dung**

A TLUD stove was tested with a range of dung fuels including cow, zebra, giraffe, rhinoceros and bison dung.

**Dung cakes in Nepal**

- Dung cakes are made during the dry season (Oct - May) and must last through the wet season (Jun - Sep).
- Buffalo dung is mixed with waste straw and formed into palm sized patties which are then dried out in the sun.

<table>
<thead>
<tr>
<th>Background</th>
<th>Dung fuel temperature profiles</th>
<th>Results</th>
</tr>
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<tbody>
<tr>
<td>Dung is used throughout the developing world as a cooking fuel.</td>
<td><img src="image" alt="Graph showing temperature profiles of different dung fuels" /></td>
<td>Multiple dung types were tested in the dung burning TLUD stove:</td>
</tr>
<tr>
<td>Common fuels include cow, buffalo and ox dung.</td>
<td></td>
<td>- All dung types performed well.</td>
</tr>
<tr>
<td>Dung produces higher emissions of harmful pollutants than other fuels.</td>
<td></td>
<td>- Giraffe dung produced a significantly longer burn time due to ideal size and shape.</td>
</tr>
</tbody>
</table>

**Outcomes**

- TLUD stove successfully boils water with a range of different size and shape dung fuels.
- The simple design is applicable to other areas of the developing world where alternative dung fuels are used, such as mountainous and remote locations.
- A dung briquette maker is being built by Engineers Without Borders (EWB) in the Nepalese Terai and may further improve fuel applicability.
### Top-Lit Up Draft (TLUD) stove

#### The TLUD stove
- Applies existing TLUD technology to stoves.
- Burns almost any solid biomass with low emissions.
- Designed to:
  - Lower harmful emissions.
  - Increase stove efficiency.
  - Produce biochar.

#### Approach
- Preliminary testing with wood pellets.
- Adaptation to dung fuel.
- Development of dung burning stove:
  - Air inlet geometry.
  - Chimney to pot separation distance.
- Final testing:
  - Thermal efficiency.
  - Emissions.
  - Alternative fuel types.

#### Results
Compared to three stone fire, TLUD stove has:
- Improved thermal efficiency.
- One-eighth the carbon monoxide emissions.

#### Operation
- Fuel chamber is filled with round fuel pieces
- Fuel is lit from the top (hence “Top-Lit”)
- Hot flue gases induce buoyant “Up Draft”
- Flame heats the fuel below
- Pyrolysis front begins
- Pyrolysis front releases combustable gases called volatiles
- Volatiles and secondary air mix and combust
- Char oxidisation begins when all the fuel has pyrolysed
- Flame changes colour to blue
- Stove operation is stopped by starving it of oxygen
- Biochar remains behind
Pre-Heated Air Improved Rocket (PHAIR) Stove

Background
Conceptual design which pre-heats primary combustion air to:
- Lower harmful emissions.
- Increase fuel efficiency.
- Work with multiple fuels.

Theory
- Combustion chamber is surrounded by an air channel.
- Buoyancy induces air downwards from the top of the channel.
- Pre-heated air raises combustion temperature.
- Higher temperature increases the reaction rate.
- This results in more complete combustion.

Design Development
Experiments were conducted to find best performing design:
- Varied chimney height and channel gap.
- Water boiling test for efficiency.
- Visual assessment of smoke.

Results
Best performing PHAIR stove was tested against three stone fire and rocket stove:
- PHAIR stove more thermally efficient than three stone fire but less than rocket stove.
- Rocket stove produced more smoke.
- PHAIR stove more efficient with door open;
  - Operating at less than stoichiometric mixture of fuel and air.

Future Work
Concept of PHAIR stove has been proven, but much work is still required:
- Quantification of emissions.
- Testing of more parameters to improve design.
Background

- Biochar is charcoal added to the soil as a soil enhancer.
- It is made from the decomposition of biomass in a low oxygen environment.

Benefits of biochar

- Increased water retention
- Reduced nutrient leaching
- Increased microbial activity
- Increased pH (liming effect)
- Increased soil carbon

Biochar quality tests

- Carbon Hydrogen Nitrogen (CHN) analyser to determine carbon-nitrogen ratio.
- Adsorption capacity test to determine biochar adsorptivity.

Cow dung biochar quality

- Carbon content: 45.0 %
- Nitrogen content: 5.3 %

Carbon-nitrogen ratio (C:N) = 8.5

- Biochar with C:N < 15 make great soil enhancers as they readily mineralise to release nutrients to plant roots to benefit plant health.

Biochar production in TLUD stoves

- TLUD stoves ideal temperature for quality biochar.
- Potential for biochar to be sold to farmers.

Adsorption capacity

- Compared to commercial biochars, cow dung biochar has a reasonable adsorptivity.
- Biochars with good adsorptivity are better able to hold soil organic compounds.
- Soil organic compounds are released to nourish plant roots and benefit plant health.

Carbon sequestration

- Biochars with C:N > 30 more stable in the soil and better at sequestering carbon, such as biochars made from woody biomass.
- Dung biochars contain less carbon and mineralise quickly.

In-field Trials

- Engineers Without Borders (EWB) engineers to conduct field trials in Nepalese Terai region.
- Working with local communities to demonstrate ability of biochar to boost agricultural production.

Images

- Biochar 700μm: http://www.geos.ed.ac.uk/facilities/sem/Biochar.html
- Biochar 50μm: http://www.geos.ed.ac.uk/facilities/sem/Biochar.html
Background

- One in four people do not have access to electricity
- Electricity from Cogeneration may:
  - Power a fan to improve combustion.
  - Provide indoor lighting and phone charging.

Fan forced PHAIR stove

- A fan was attached to a PHAIR stove at 60°.
- Tested over varying fan speeds.
- Minimal combustion improvements.
- Further tests required with forced air directed onto the combustion zone.

Fan forced TLUD stove

- Fan forced primary and secondary air.
- Tested over varying fan speeds.
- Thermal efficiency results are shown below.
- No improvement over natural draft.

Thermoelectric generator

- Generate electricity from waste heat.
- Produced insufficient power.
- Unfeasible due to high cost and poor performance.

Findings

- Cost of cogeneration outweighed benefits.
- Costs will decrease with time.
- Social benefits result from indoor lighting and mobile phone charging.
- Improved stoves may provide a source of electricity for millions living without it.