ETHOS 2019

Stoves 101

An introduction by Christa Roth
with slides by Dan Sweeney

• Biomass fuels in the household energy mix
• Classification of solid biomass fuel by substance and shape
• Stove designs for different fuel types
• How to apply principle lessons learnt on stove design
• How to evaluate stoves? Who looks at what?
Basic Household Energy Needs

**Thermal Energy** for cooking and heating = Vital for survival

(Electric) Energy for Lighting, Cooling, Communication, Entertainment = Quality of Life

Orders of magnitude of typical energy requirements:

- **Heating stove**: 5,000-10,000 W
- **One hot-plate for cooking**: 500-1,000 W
- **Laptop Computer**: 50-100 W
- **LED bulb (150 lm/W)**: 0.5-1 W
- **Light**: > 80%
- **Radio, TV**: > 80%
- **Small Cooler**: < 20%
- **Computer**: < 20%
- **Phone**: < 20%

Space heating

Cooked Food

Bath water

Safe drinking water

Hot drinks
Make the clean available and the available clean access to 'clean fuels' electricity, gas, biogas, liquid fuels BLEEN (biogas, LPG, Electricity, Ethanol, Natural Gas) 'cleaner’ cooking with available solid biomass fuels

How realistic is this, looking at the magnitude of population cooking with solid fuels?
Population cooking with solid fuels:

Geographic distribution (in %) and regional trends (1980-2010)
• Firewood and charcoal are often from non-renewable sources and getting scarce

Forest degradation = still forest, but degraded

Deforestation = land use change
What are fuel options?

A stove (and other devices for heating or productive use) is coupled to a specific energy carrier / fuel => Multi-fuel stoves are challenging

Stove design starts with the fuel!

Myth: „energy ladder“

Reality:

„Energy shelf“
= parallel usage of multiple fuels and devices depending on the task.

Biomass is here to stay!
Biomass is the best source for thermal energy, it is renewable and can be grown on-farm.
Biomass energy

• Stored solar energy once converted by a plant through photosynthesis

• Renewable (but needs management of natural resources for sustainability)

• Available on demand (unlike other energy sources)

• High calorific value, ideal source of thermal energy (for cooking, frying, grilling, baking, drying, heating, and other productive uses)
Fuel is a form of energy storage

Source

Carrier

Use

Slide by Dan Sweeney
Source  Carrier  Use

Slide by Dan Sweeney
Source

Carrier

Use

Slide by Dan Sweeney
Slide by Dan Sweeney
Technology and Fuels Landscape: Improve use of available fuels and increase access to cleaner fuels

**MORE ACCESSIBLE**
- Pellets
- Briquettes
- Processed Wood
- Biogas
- Ethanol
- LPG
- Electric

**LESS ACCESSIBLE**
- Kerosene
- Coal
- Charcoal
- Wood
- Solar
- Dung

Eliminate use

Improve through stove technology

Scale up production and distribution

Expand Accessibility

Improve through Processing

Improve supply, distribution, affordability

Slide by Dan Sweeney
A good fuel is...

- Readily available
- Intuitive for the user
- Low-cost
- Burns easily in air at a controllable rate
- Produces a large amount of heat
- Does not leave behind or produce undesirable substances
- Others?

Usability

Affordability

Performance
Evaluation Criteria

**Usability**
- Preparation
- Time to cook
- Use is intuitive
- Intended stove type
- Safety
- Fire tending
- Cleanliness
- Aspirational value
- Multi-purpose
- Storage/ stability

**Performance**
- Sustainability
- Fuel consumption
- Pollutant emissions
- Turndown
- Quality control

**Affordability**
- Processing and production
- Transport
- Supply reliability
- Cost to user
- Income generating opportunities
- Incentives, subsidies

**Scalability**
- Availability of material inputs; seasonality
- Production equipment
- Skilled labor
- Maintenance & service
- Cooperation w/ host community
- Existing supply chains
**Fuel types by categories**

<table>
<thead>
<tr>
<th>Substance:</th>
<th>Uncarbonised, natural</th>
<th>Carbonised</th>
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<tr>
<th>Shape:</th>
<th>Log-shape</th>
<th>Small size Lumps / Chunks</th>
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<td></td>
<td>pushed from side</td>
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**Fuel:**
- e.g. FIREWOOD
- e.g. CHARCOAL
- e.g. NUTSHELLS, WOODCHIPS, PELLETS etc.

Other factors with implication on performance in a stove:
- Particle size and particle size distribution
- Density of fuel
- Moisture content
Diversity of processed fuels

Uncarbonised briquettes

Carbonised briquettes
Supply chain management is crucial!

• Fuel supply is most time-sensitive and is needed in the appropriate quality and quantity on a regular / daily basis (unlike stoves)
• Logistical challenges of transport of input materials and product
• Power dependency and requirements for processed fuel production

Both need to reach the user at the same time.
There is (more) money in fuels...
Photosynthesis
By the plant transforming sunlight to create biomass

Combustion of biomass
To release the stored solar energy (photosynthesis reversed)

Products of Complete Combustion=

$\text{CO}_2 \quad \text{H}_2\text{O} \quad \text{HEAT}\quad \text{LIGHT}\quad (+\text{ash})$

Note: $\text{CO}_2$ is a natural ingredient of ambient air, not a risk for human health, but for climate.
How does this translate into useful heat? Where is the best spot for a cook-pot?
How does biomass burn: Stages of biomass combustion
How to apply this knowledge on stove designs?

Can we first define what ‘a stove’ is?
What is a 'Stove' = Heat-Generator

= How to make most heat from a fuel

Factors to optimise complete combustion: „the 3 T’s of combustion“

T ime, T emperature, T urbulence

Fuel Specific re size, shape, moisture content and state of carbonisation:

• Uncarbonised
  • „stick‘-wood, twigs
• Briquettes
• Woodchips, nutshells, pellets
• Charcoal lumps, carbonised briquettes

Heat-Transfer-
structure

= How to get most heat into the pot

Factors to optimise heat transfer: „TARP V‘

T emperature, A rea, R adiation,

P roximity, V elocity

„Form follows function‘:
depending on

• Fuel
• Cultural and human factors
• meal type, type of cooking
• pot-shape, material, size etc.
Design principles of stoves per fuel type

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Fuel: e.g. FIREWOOD
Design principle: Continuous side feed
Rocket stove

Fuel: e.g. CHARCOAL
Design principle: Batch fed
Charcoal stove

Fuel: e.g. NUTSHELLS, WOODCHIPS, PELLETS etc.
Design principle: Batch-fed
TLUD gasifier
Log-shaped fuels: Design principles for firewood stoves

**Rocket stove principle**
Continuous feed, feed controlled

- Improved combustion: burn the smoke and get more heat from the fuel
- Improved heat transfer: more cooking from the heat
A range of firewood stoves to suit different needs and means (Malawi 2007)
Institutional Rocket stoves

With open fire

170 kg

With institutional Rocket Stove

14 kg
School feeding programme
Mary’s Meals Blantyre (Malawi)
Feeding porridge to 330 pupils per pot
Institutional Stoves can be a profitable business:
Example Ken Steel Engineering in Malawi
Char-burning
Carbonised fuel: Design principles of charcoal stoves

- Batch fed: size of charcoal container matters
- Air controlled: needs draft regulation (door)
- Heat transfer through radiation and convection
- (secondary) air and space to burn CO
For all other small-size natural and processed fuels:

Gasifier: gas-creation separated from gas-combustion
Top-lit Up-draft gasifiers: char-making gas-generator below, gas-burner on top
Gasifier:
mini-kiln that turns small chunky biomass into char while cooking!

Gasifier: Batch-feeding of fuel, heat controlled by air regulation
Conventional fires: constant feeding of fuel, unregulated air-supply
Switching from char-making TLUD mode to char-consuming BBUD mode
'TChar': Combing multiple options
Gasifier produces own char on top of a charcoal stove,
for immediate use in charcoal stove while still hot
Interesting co-benefit from gasifiers:

Biochar as soil amendment:

- Carbon-negative thermal energy to further reduce carbon footprint
- Increases water retention capacity and CEC
- Improved fertiliser uptake through longer retention in soil by adsorption

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**The carbon cycle**

Most carbon returns to atmosphere

Green plants use solar energy to remove CO$_2$ from the atmosphere via photosynthesis and store it as chemical energy in biomass. When biomass decomposes or burns, this process is reversed and nearly all CO$_2$ returned to the atmosphere.

**The biochar cycle**

Up to 50% of carbon stays in the soil

Pyrolysis destroys the structure of the biomass. One half of the carbon is converted to woodgas and the other half remains in the created char. If the char is buried in the soil as biochar, most of the carbon stays there and is sequestered as biochar.
aMaizing cooking
example from Malawi
of gasifier dimensioned
to cook 50 liters of
porridge with loose
maize cobs

Easy lighting with one match only.

Nearly smokeless start-up phase.

Ready to put concentrator on after
1 minute, pot on after 1 more min

Steady flames around the pot only
6 minutes after lighting.

No smoke, no refuelling or
pushing of wood.

10 minutes after lighting the water
is already hot enough so that the
women can start adding the flour.
The porridge is ready only 40 minutes after lighting. The flame has gone out by itself, usually without smoke.

The cooks love it!

The char is dumped from the container to cool off and stay as char. It gets sieved: the larger pieces are used as easily igniting charcoal, the fine char will be primed with microbes, then it is ready to go into the soil!
Further reading by GIZ-HERA:

**Manual Micro-gasification:**
cooking with gas from dry biomass

1. Introduction
2. Cooking on ‘wood gas’ from dry solid biomass – How it works
3. Solid biomass feedstock and fuels for micro-gasification
4. Gasifier cookstove diversity
5. Biochar – a by-product of cooking with gasifiers


**Cooking energy compendium**
A practical guidebook for implementers of cooking energy innovation

What is a ‘Stove‘ = Heat-Generator

= How to make most heat from a fuel

Factors to optimise complete combustion: „the 3 T‘s of combustion“
Time, Temperature, Turbulence

Specific for size, shape, moisture content and state of carbonisation:
• Uncarbonised
  • ‘stick‘-wood, twigs
• Briquettes,
• Woodchips, nutshells, pellets
• Charcoal lumps, briquettes

Heat-Transfer-Structure

= How to get most heat into the pot

Factors to optimise heat transfer: ‘TARP V‘
Temperature, Area, Radiation, Proximity, Velocity

„Form follows function‘:
depending on
• Fuel, cultural factors, meal type, type of cooking
• pot-shape, material, size etc.
How to optimise stove design re ‘3T’ for complete combustion

- **Time**
  - extend residential time of combusting gases in the combustion chamber

- **Temperature**
  - Reduce diameter of combustion chamber to keep hot gases concentrated,
  - insulate combustion chamber to maintain heat

- **Turbulence**
  - Increase swirl for better mixing of gas with air
Examples for inclusion in stove design

TIME

Adding Burn Time

TURBULENCE

Fast and Slow Mixing

Fast mixing

Slow mixing

Figures and ideas courtesy of Kirk Harris (US), inventor of the TLUD with currently lowest emissions measured.
Heat transfer

- Radiation – without contact
- Conduction – contact between materials
- Convection – heat transport by hot gases

Knowing heat transfer principles and the ability to apply this knowledge on stove design offers a big potential to improve the performance and safety of a stove.
Points to observe to design a new ‘dreamstove’: What are the crucial parts of a stove that influence stove performance?

- **Functional** parts with influence on performance:
  - Fuel container size (and shape)
  - Air Flowpath:
    - Door
    - (Baffles)
    - Potrests
    - Chimney?
- **Form** mostly concerning convenience & aesthetics, safety:
  - Stands / legs
  - Handles
  - Bottoms
  - Body
  - Others?
What implications does stove design have on production of stoves?

– Which materials are available at which costs?
– Material properties (durability, weight, transportability etc.)
– How many production chains are involved to get to the finished product? What are the bottlenecks in the supply chains?
– What is my vision of scale of business? Do I want to make 100 stoves in a year or 100,000?
– What level of optimization do I need / can I afford? Who can help me?
– ....which other factors do matter??
What does the engineer want from a stove?
What does the user want from a stove?

Nabetha, my husband has brought a very interesting stove from overseas.
The over-improved stove

This is the stove: it charges and answers the phone, goes to the market, makes fruit juice just to mention a few.
Conclusion: a stove should first of all cook!

How does it cook?

Ummh... I haven’t worked that out yet!

Drawing by Henderson Mawera (Malawi), idea & sponsorship by Charlotte Ray, University of Nottingham (2016)
Efficiency vs. Multipurpose

Efficient cooking
With a good fuel-stove combination

Space heating

Provision of light
and other uses

Multi-fuel Stove
with fuel flexibility

An efficient cookstove is often a bad space heater. Compromise can be the enemy of efficiency.
How much 'clean' do we need?

SDG 7: Ensure access to affordable, reliable, sustainable and modern energy for all

- Energy Access
- Energy Security
- Energy Poverty

- Food Security

- Environment, Climate, Management of natural resources

- Health

- Gender

- Local Economic Development

- Employment creation

- Convenience

- Emissions, Security

- Local value adding

- Local ownership

- Empowerment

- Decentralization, local Government

- Poverty alleviation

- Diversity of Development Goals
Health protection: How to determine what and how much people breathe in?

Emissions, Concentrations, and Exposure...

Environmental pollution

HAP

IAP

Stove = source of emissions

Slide based on figure provided by Morgan de Foort, Colorado State University, 2012
A ‘clean stove’ is .. a myth!
Contextualising ‘stoves’ to define quality of CES

Slide based on Dr. Christoph Messinger, GIZ-EnDev
Guiding questions

ACCESSIBILITY:
Can I prepare all my meals with this cooking system when I need it and in the quality and quantity that I need?

HEALTH PROTECTION:
Do I risk my health when using this cooking system?

CONVENIENCE:
Is it hassle for me to use this cooking system?

Slide courtesy of Dr Christoph Messinger, GIZ EnDev
Why people like and use their stoves

Example Peru: High Andes

Cold climate, no natural forests

Save firewood, less smoke, fast cooking, ability to cook upright
Why people like and use their stoves

Example Peru: Coastal area

Climate moderate, windy, dry, no natural forests

Fast cooking, safety, save firewood, clean kitchen, less smoke
Why people like and use their stoves

Example Peru: Amazonas basin

Climate tropical hot and humid, abundant vegetation

Less heat exposure, safety, less smoke, fast cooking, convenience to keep fire going, easy to reignite, ability to cook upright, clean kitchen, save firewood
Summary Example Peru:  
**same stove - different perceptions by the users**

Qualitative ranking of arguments why people like and use the same stove based on visits to 10-20 households per region in February 2011

<table>
<thead>
<tr>
<th>Perceived advantage by the users</th>
<th>High Andes</th>
<th>Coast area</th>
<th>Amazonas</th>
</tr>
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<tbody>
<tr>
<td>Fuel savings</td>
<td>1</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Less smoke exposure</td>
<td>2</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Increased safety, less burns</td>
<td>6</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Fast cooking</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Less heat exposure</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Convenience to keep fire going</td>
<td></td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Easy reignition, saves matches</td>
<td>7</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Ability to cook upright</td>
<td>4</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Cleanliness of kitchen</td>
<td>5</td>
<td>4</td>
<td>8</td>
</tr>
</tbody>
</table>
Convenient (fast,...)
Less smoke
Efficient on fuel use
Affordable and available
Not harmful (safety)
Easy to use and aesthetic (buy beautiful, cook easy)
Robust (durable, strong and long lasting)

This is what users want!
Give users options!!!!