ETHOS 2019

Stoves 101

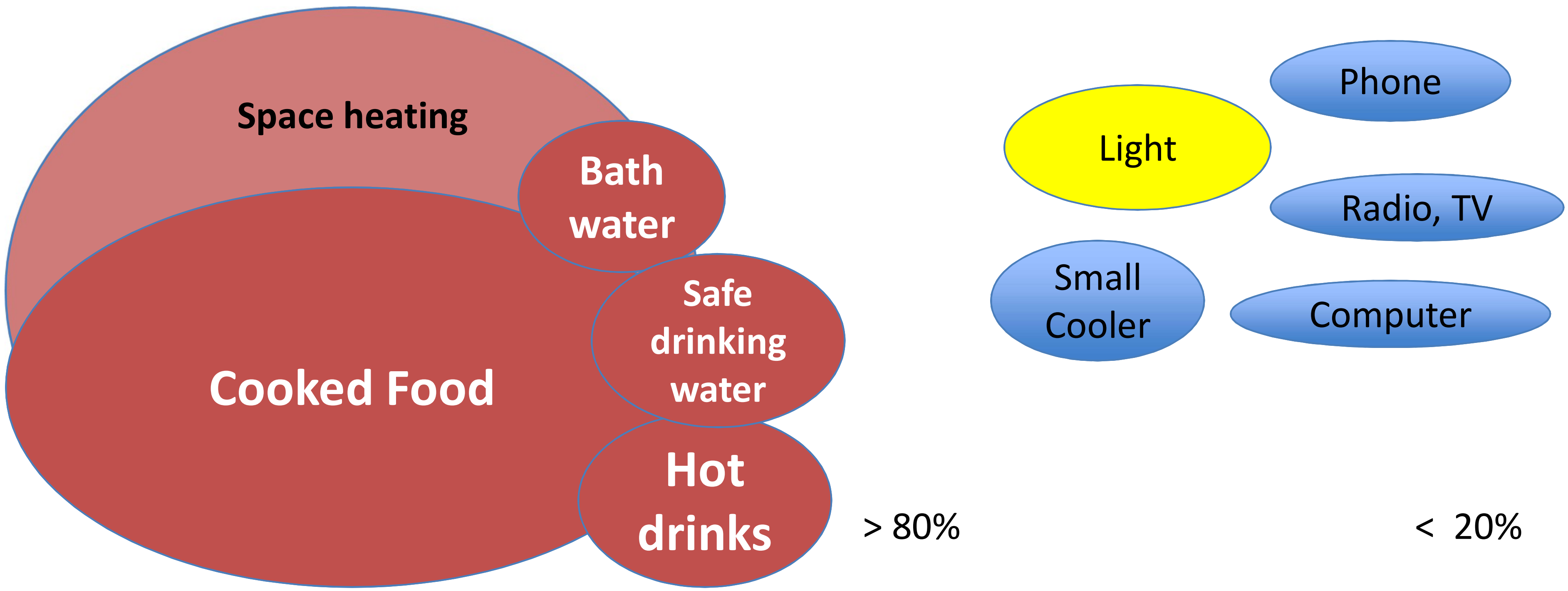
An introduction by Christa Roth
with slides by Dan Sweeney

- 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	Laptop Computer	50-100 W
One hot-plate for cooking	500-1,000 W	LED bulb (150 lm/W)	0.5-1 W

Make the clean available and the available clean

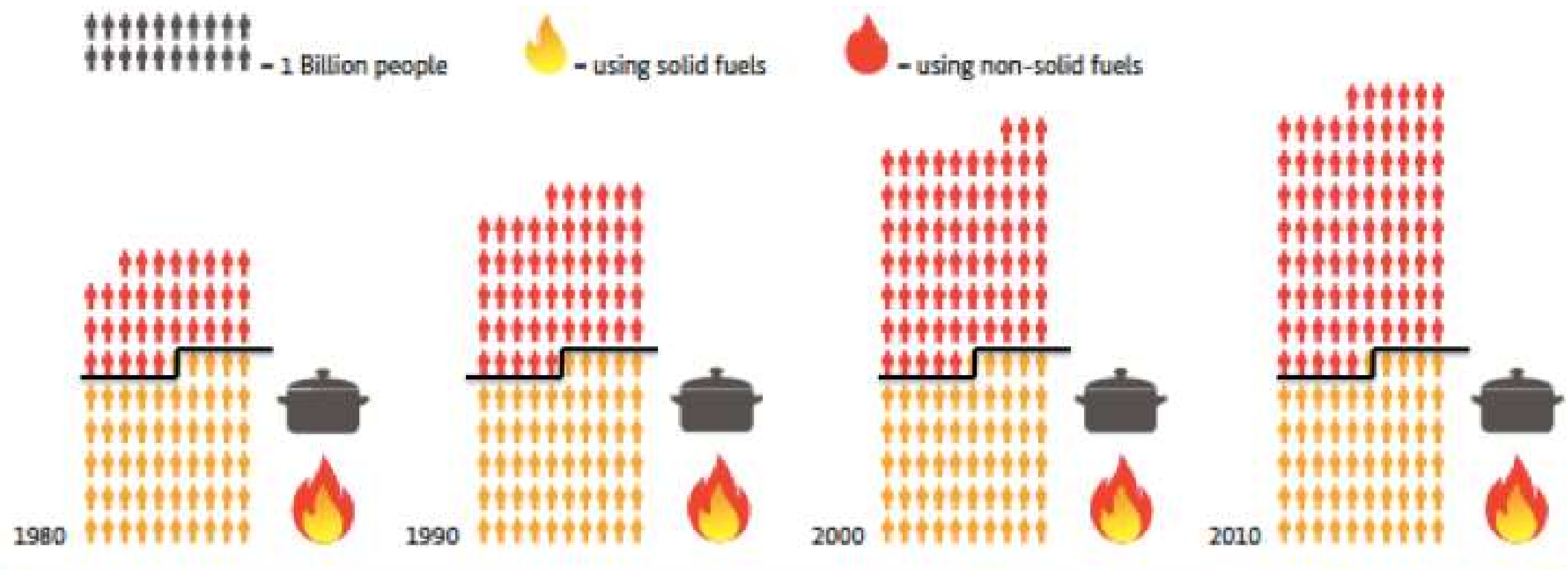
access to ‚clean fuels‘

electricity, gas, biogas, liquid fuels
BLEEN (biogas, LPG, Electricity, Ethanol, Natural Gas)

‚cleaner‘ cooking

with available solid biomass fuels

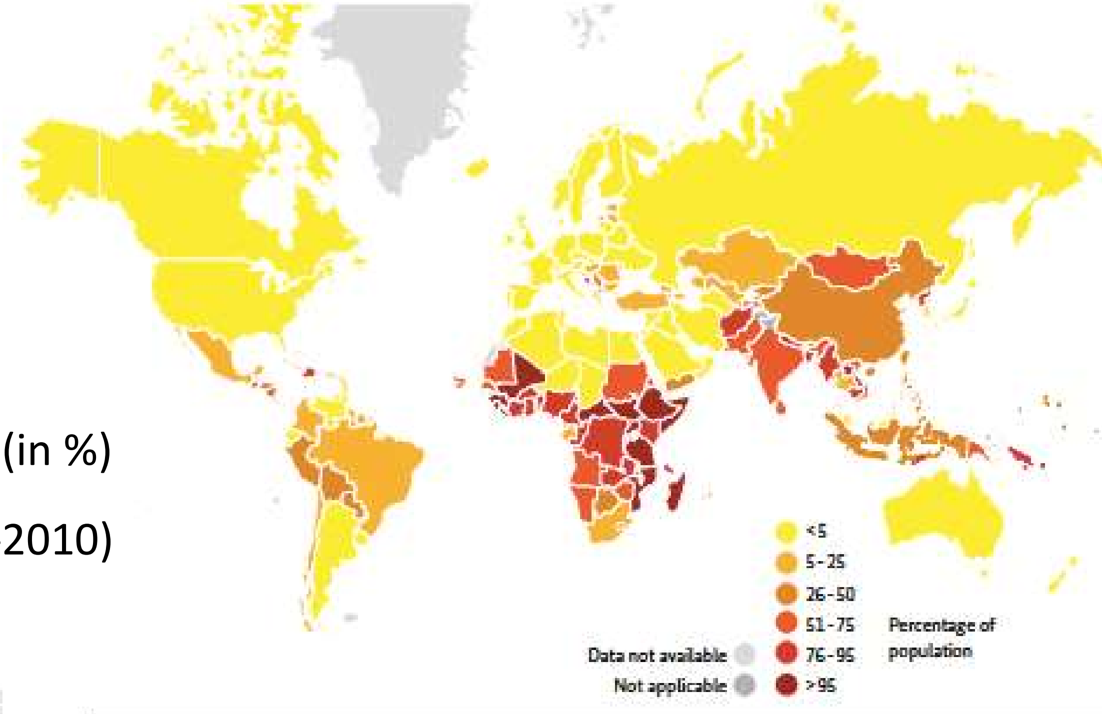
How realistic is this, looking at the magnitude of population cooking with solid fuels?

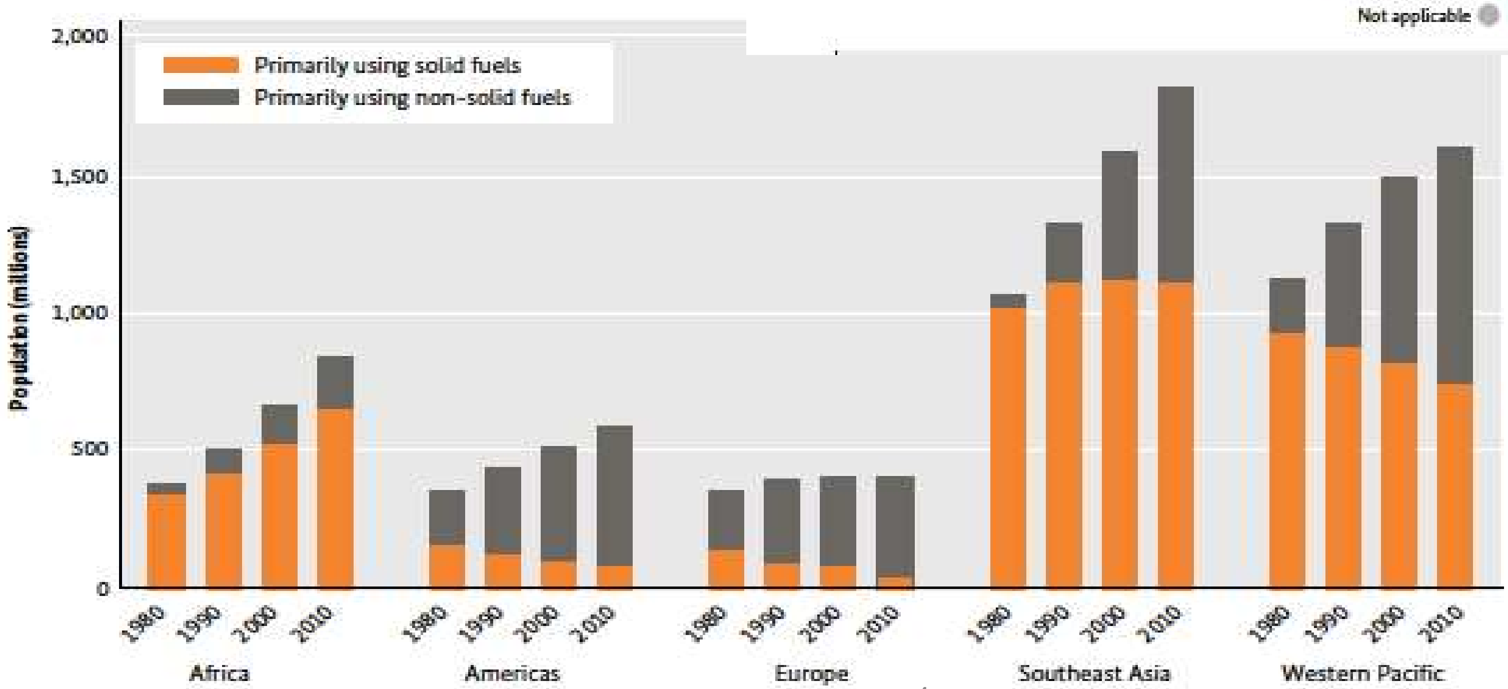


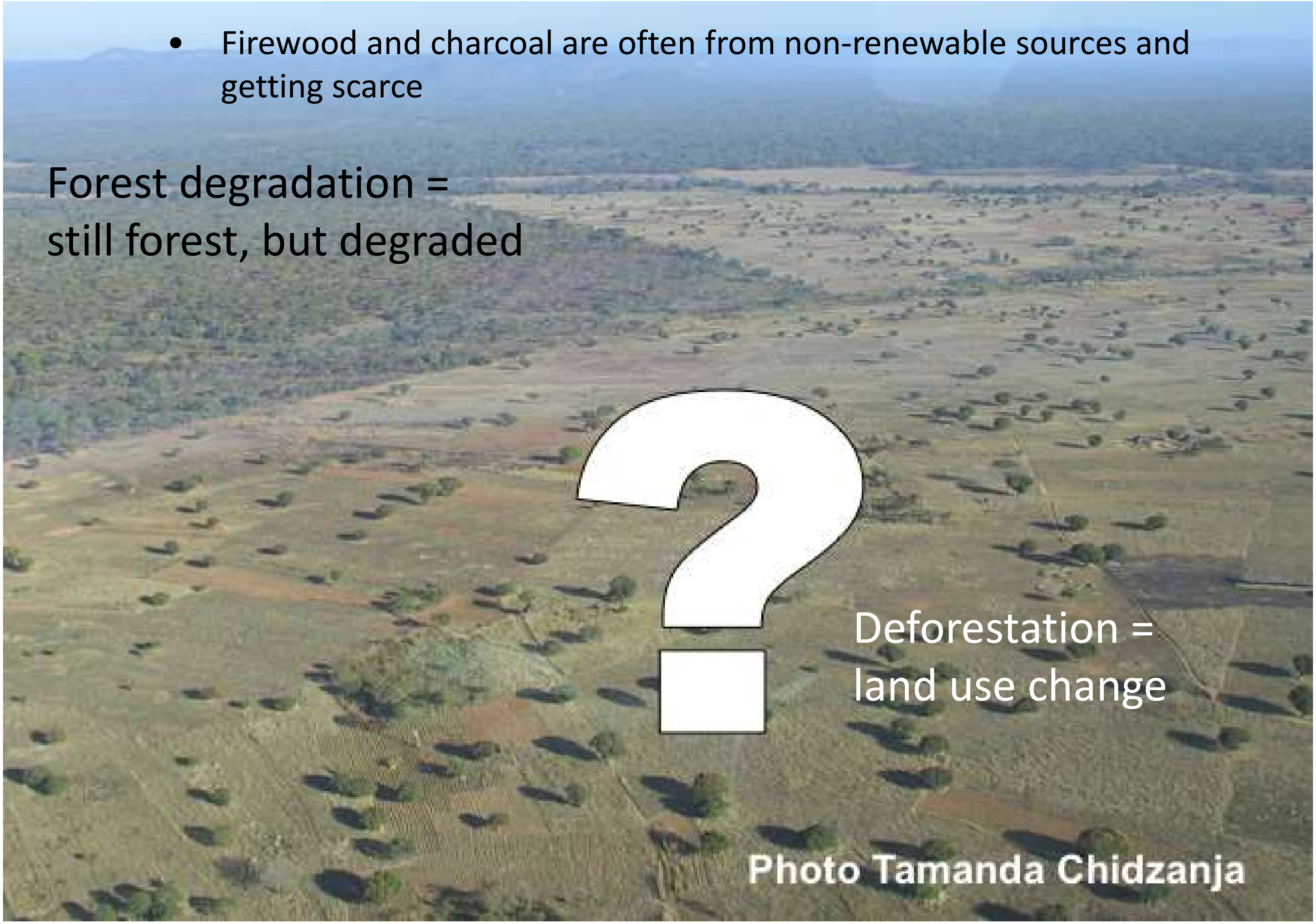
Source: Adapted from WHO and Bonjour et al. (2013)

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
Photo Tamanda Chidzanja

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“

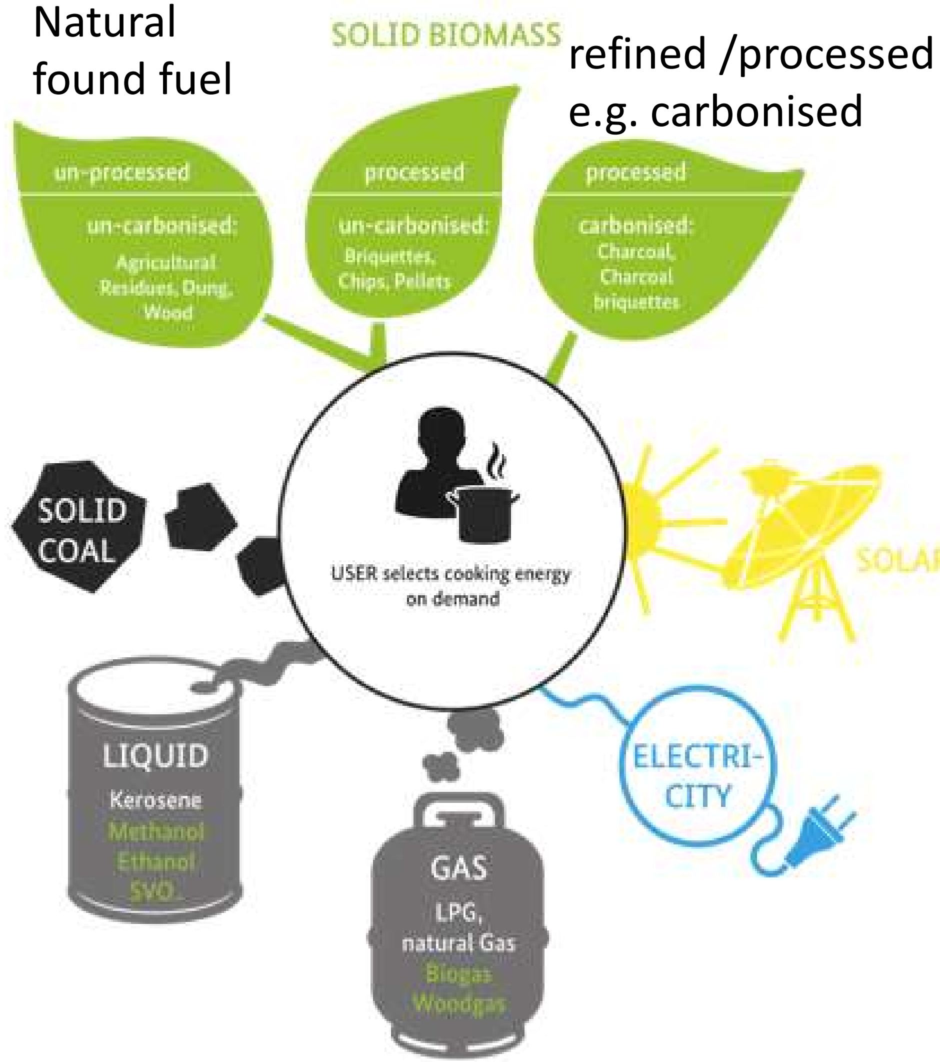
Reality:

‚Energy shelf‘

= parallel usage of multiple fuels and devices depending on the task.

Natural found fuel

refined /processed e.g. carbonised

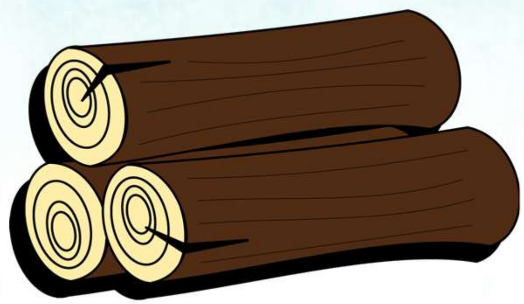


Biomass is here to stay!
Biomass is the best source for thermal energy, it is renewable and can be grown on-farm.

Biomass energy

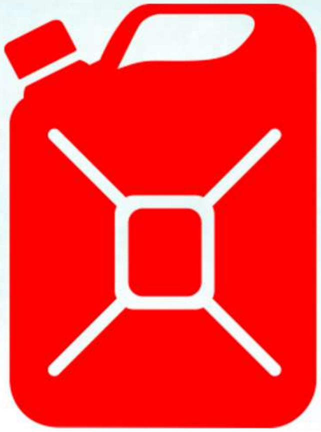
- Stored solar energy once converted by a plant through photosynthesis
- Renewable (but needs management of natural resources for sustainability)
- Available on demand (unlike other energy sources)
- High calorific value, ideal source of thermal energy (for cooking, frying, grilling, baking, drying, heating, and other productive uses)

Fuel is a form of *energy storage*



Source Carrier Use

Slide by Dan Sweeney



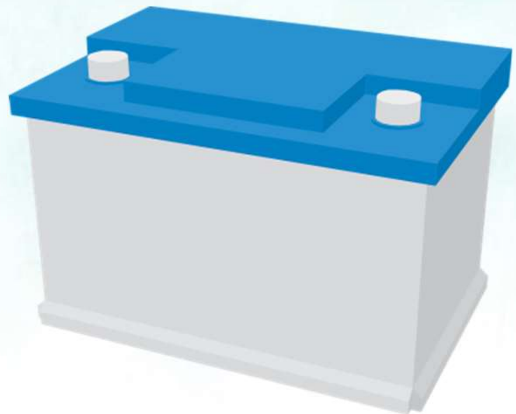
Source

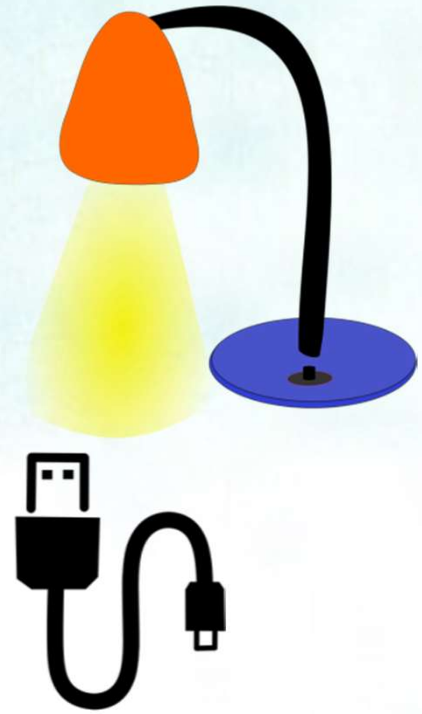
Carrier

Use

Slide by Dan Sweeney

GLOBAL ALLIANCE FOR CLEAN COOKSTOVES





Source

Carrier

Use

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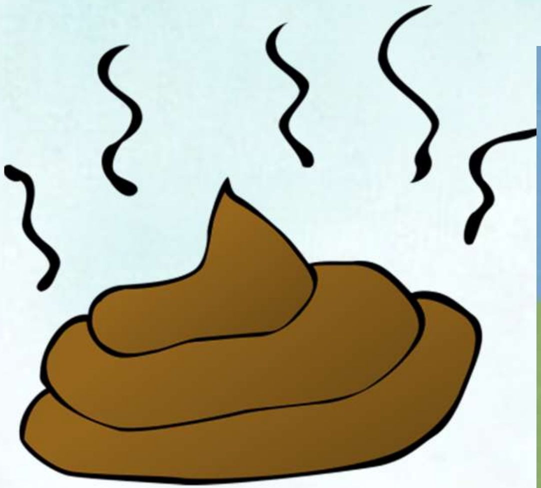
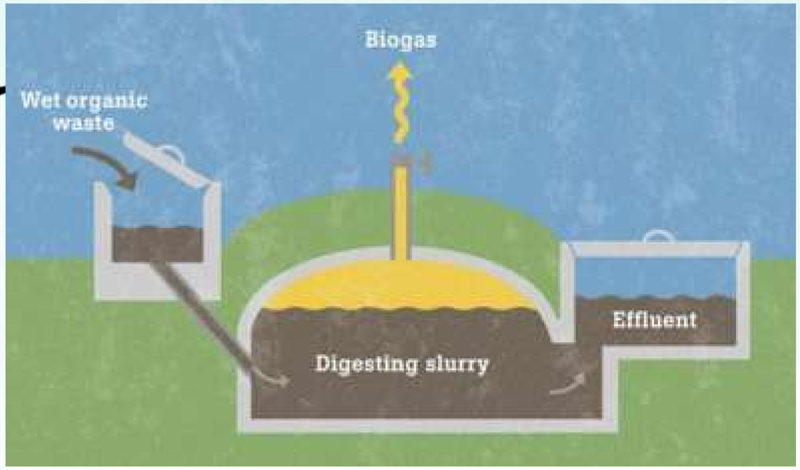




Source

Carrier

Use

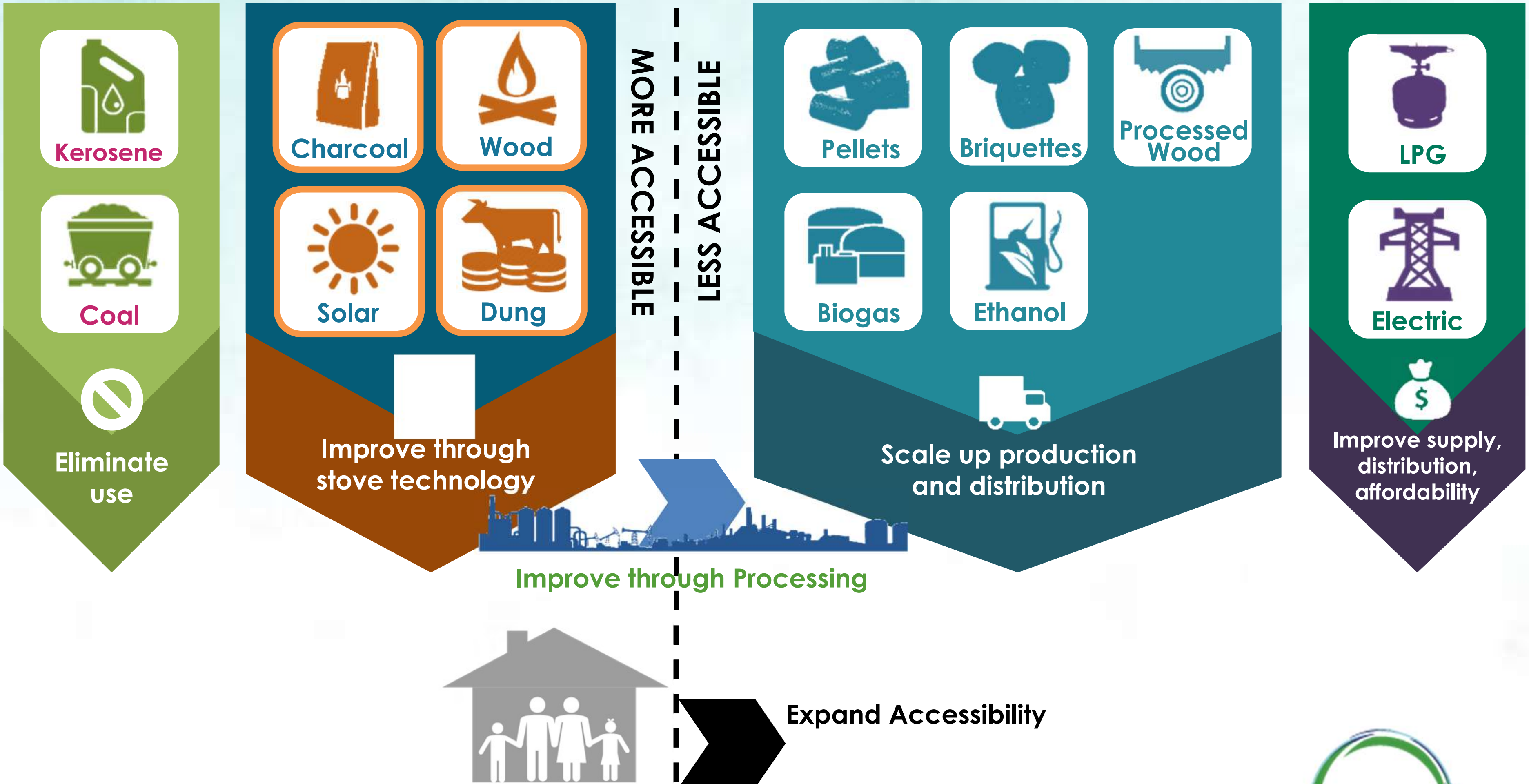
Slide by Dan Sweeney

GLOBAL ALLIANCE FOR CLEAN COOKSTOVES

Slide by Dan Sweeney

GLOBAL ALLIANCE FOR CLEAN COOKSTOVES

Technology and Fuels Landscape: Improve use of available fuels and increase access to cleaner fuels



Slide by Dan Sweeney

GLOBAL ALLIANCE FOR CLEAN COOKSTOVES

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

Slide by Dan Sweeney

Evaluation Criteria

Performance

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

Usability

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

Affordability

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

Scalability

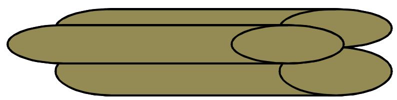
- Availability of material inputs; seasonality
- Production equipment
- Skilled labor
- Maintenance & service
- Cooperation w/ host community
- Existing supply chains

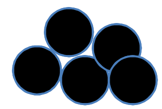
Slide by Dan Sweeney

Fuel types by categories

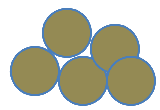
Substance:	Uncarbonised, natural	carbonised
Shape:	**Log-shape** pushed from side	**Small size Lumps / Chunks** cannot be pushed but poured in a container

Fuel: e.g. FIREWOOD





Fuel: e.g. CHARCOAL



Fuel: 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

p
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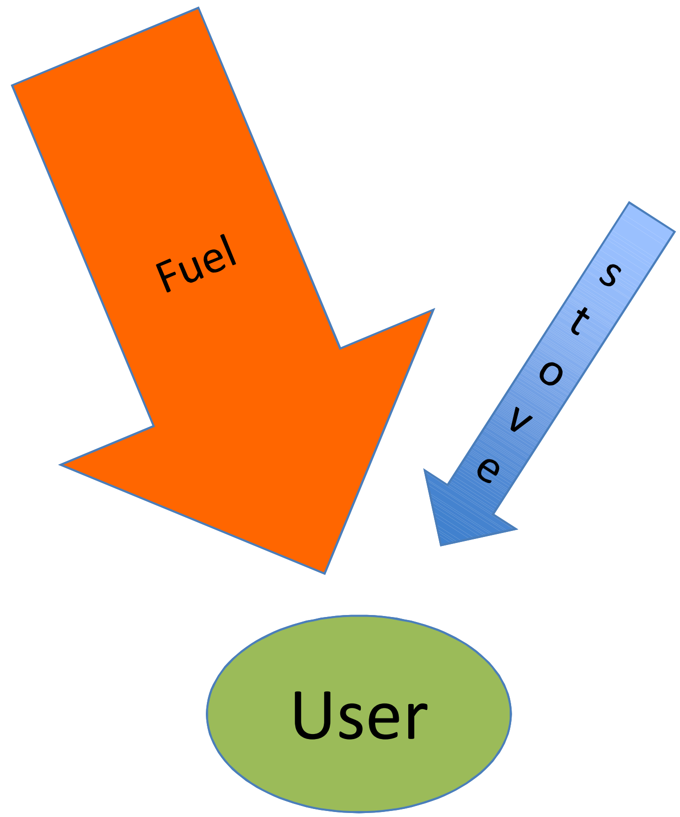
Supply chain management is crucial!

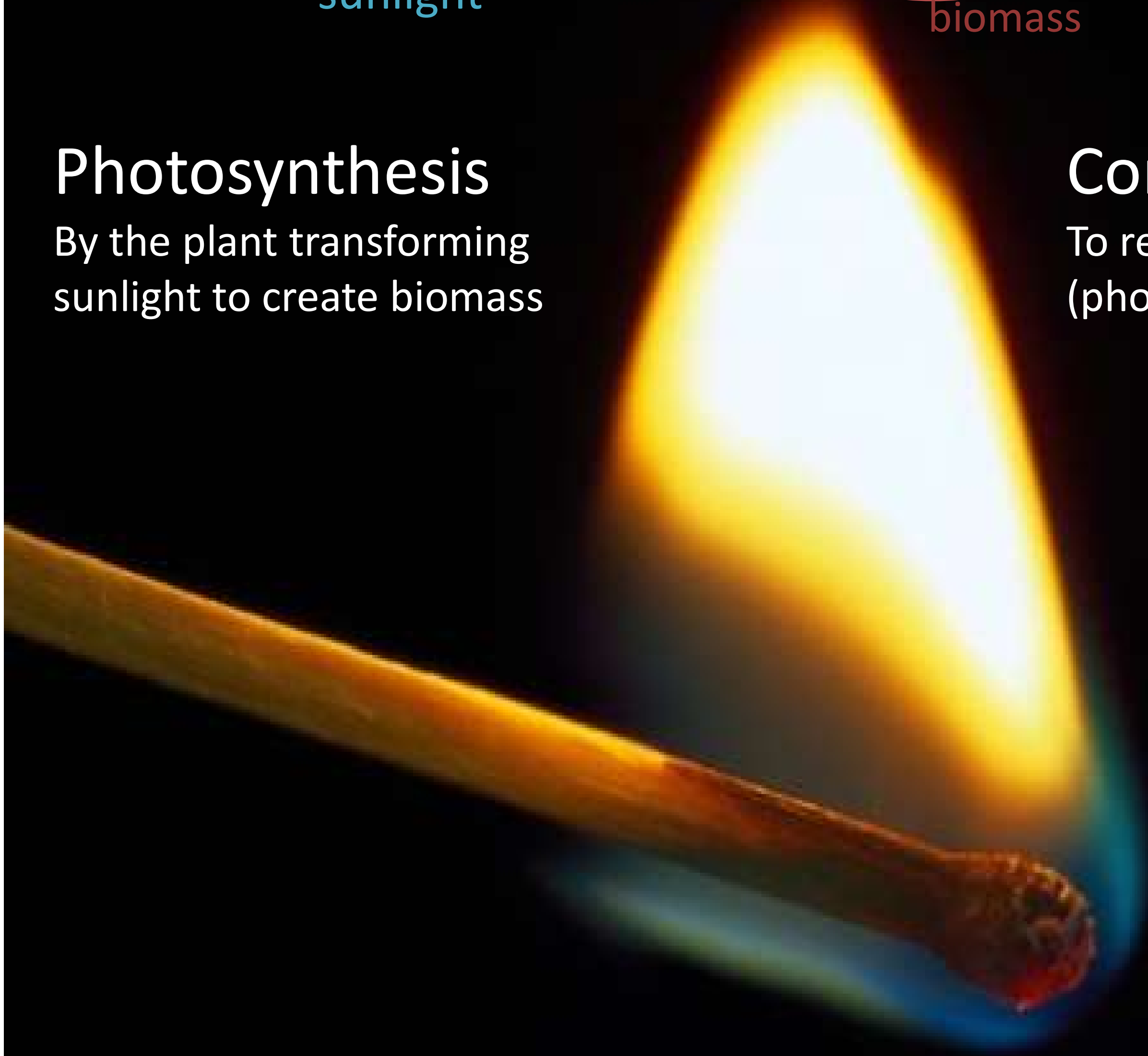
- Fuel supply is most time-sensitive and is needed in the appropiate quality and quantity on a regular / daily basis (unlike stoves)
- Logistical challenges of transport of input materials and product
- Power dependency and requirements for processed fuel production



Both need to reach the user at the same time.
There is (more) money in fuels…

$6\,CO_2 + 6\,H_2O$ + energy = $6\,O_2 + C_6H_{12}O_6$ = $6\,CO_2 + 6\,H_2O$ + énergie

sunlight — biomass — light + HEAT



Photosynthesis

By the plant transforming sunlight to create biomass

Combustion of biomass

To release the stored solar energy (photosynthesis reversed)

Products of Complete Combustion=

CO_2

H_2O

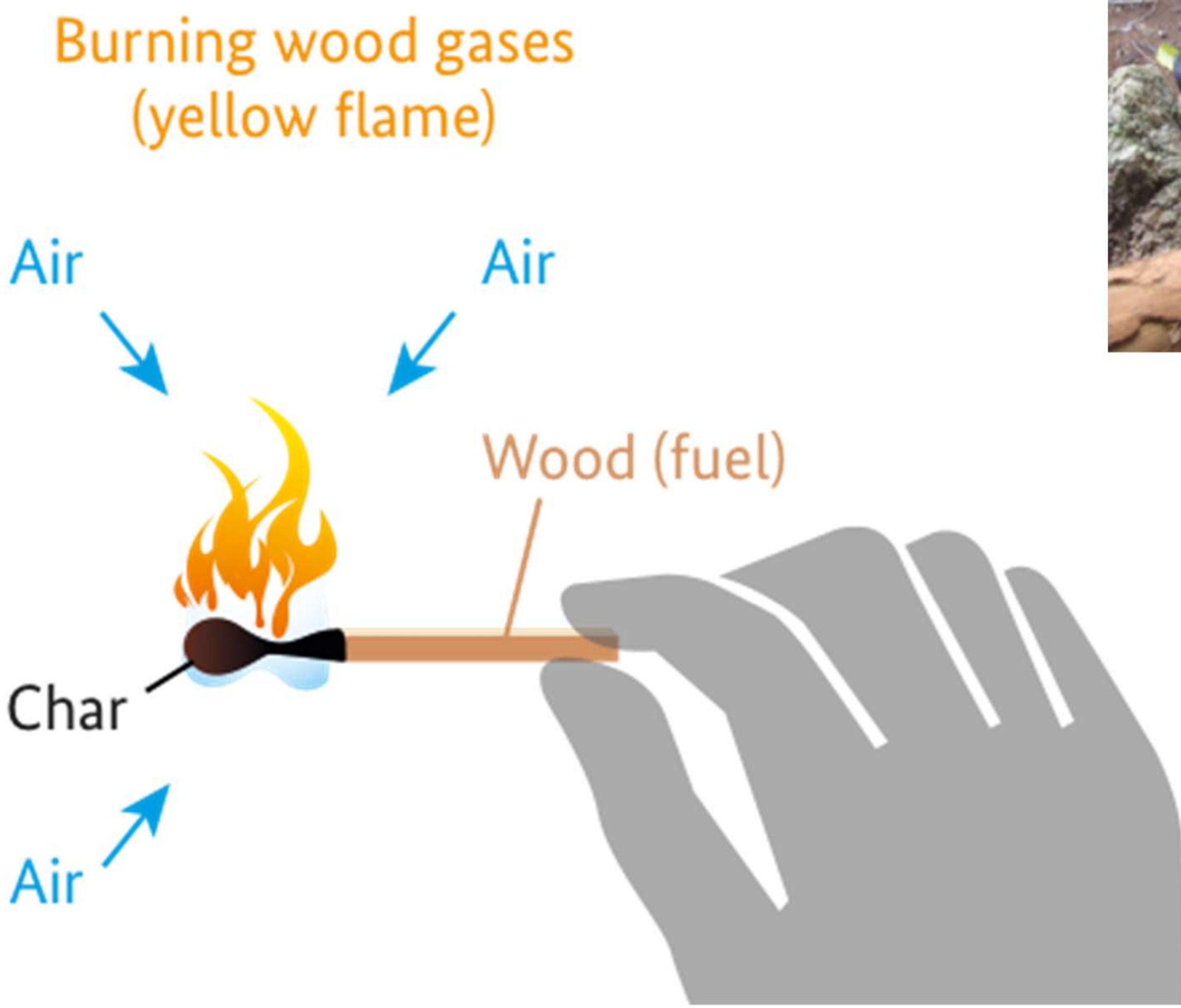
HEAT

LIGHT

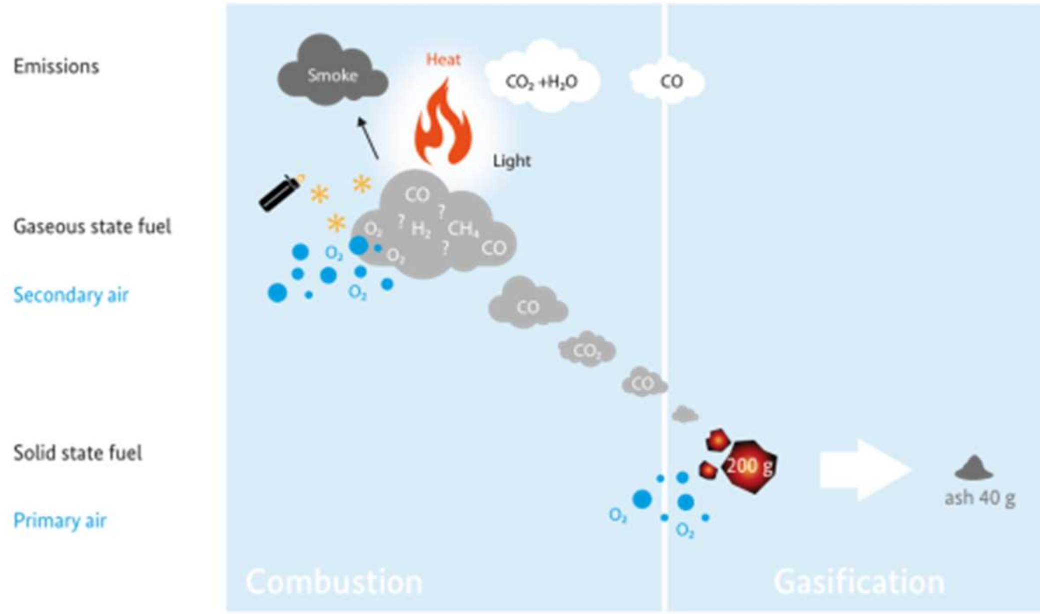
(+ash)

Note: CO_2 is a natural ingredient of ambient air, not a risk for human health, but for climate.

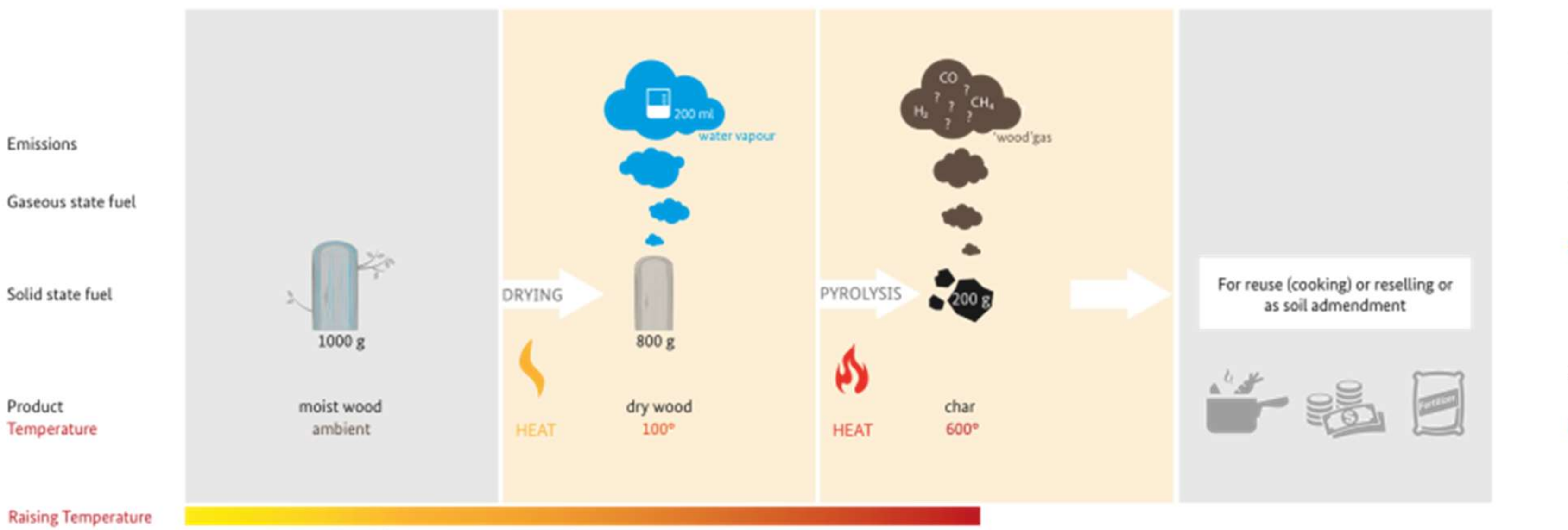
How does this translate into useful heat? Where is the best spot for a cook-pot?



How does biomass burn: Stages of biomass combustion



Oxygen Controlled (Combustion)



Heat Controlled (Gas Generation)

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"

Time, **T**emperature, **T**urbulence

Heat-Transfer-structure

= How to get most heat into the pot

Factors to optimise heat transfer: ‚TARP V'

Temperature, **A**rea, **R**adiation, **P**roximity, **V**elocity

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

- Uncarbonised
  - ‚stick'-wood, twigs
  - Briquettes
  - Woodchips, nutshells, pellets
- Charcoal lumps, carbonised briquettes

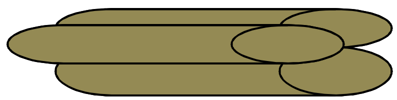
‚Form follows function':
depending on

- Fuel
- Cultural and human factors
- meal type, type of cooking
- pot-shape, material, size etc.

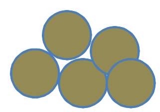
Design principles of stoves per fuel type

Substance:	Uncarbonised, natural		carbonised
Shape:	**Log-shape** pushed from side	**Small size Lumps / Chunks** cannot be pushed but poured in a container	

Fuel: e.g. FIREWOOD

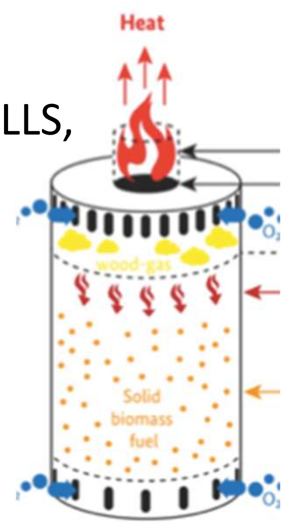


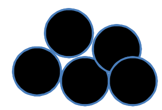
Design principle:
Continuous side feed
Rocket stove



Fuel: e.g. NUTSHELLS, WOODCHIPS, PELLETS etc.

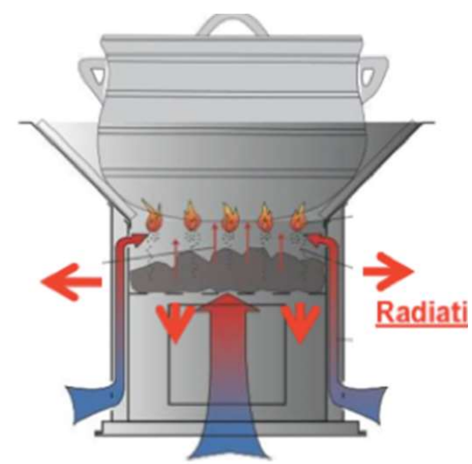
Design principle:
Batch-fed
TLUD gasifier





Fuel: e.g. CHARCOAL

Design principle:
Batch fed
Charcoal stove



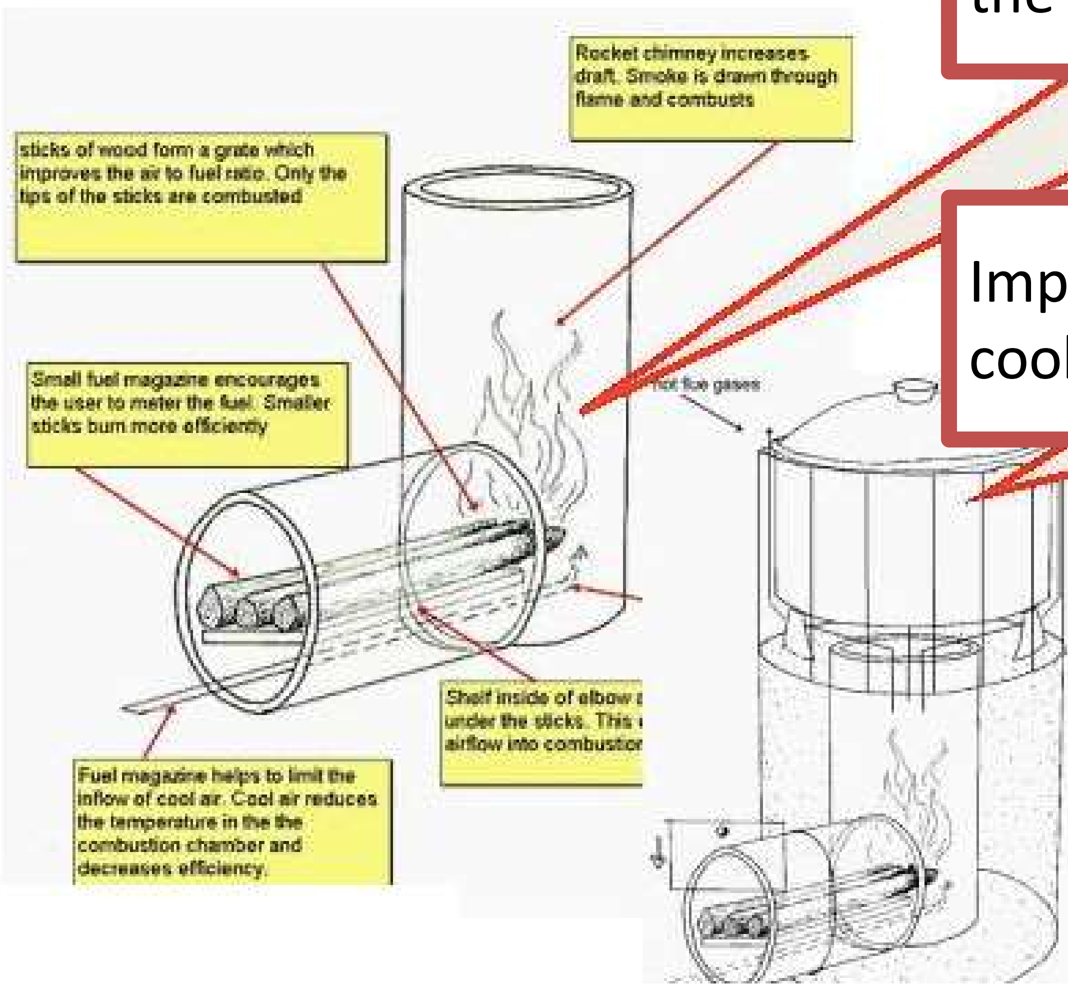
Log-shaped fuels: Design principles for firewood stoves

Rocket stove principle

Continuous feed, feed controlled

Improved combustion: burn the smoke and get more heat from the fuel

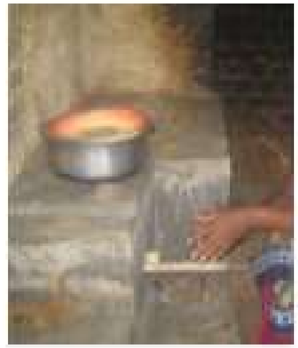
Improved heat transfer: more cooking from the heat



A range of firewood stoves to suit different needs and means (Malawi 2007)

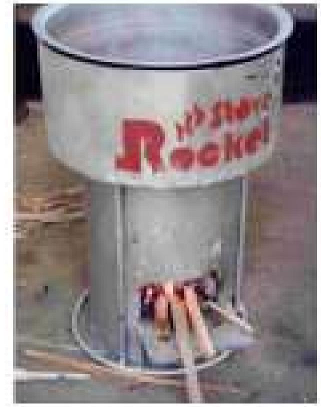
2 USD

10 USD



20 USD

20 USD



40 USD

80 USD

120 USD

100-400 USD

300 USD

400 USD

Institutional Rocket stoves

170 kg

With open fire

14 kg

With institutional Rocket Stove

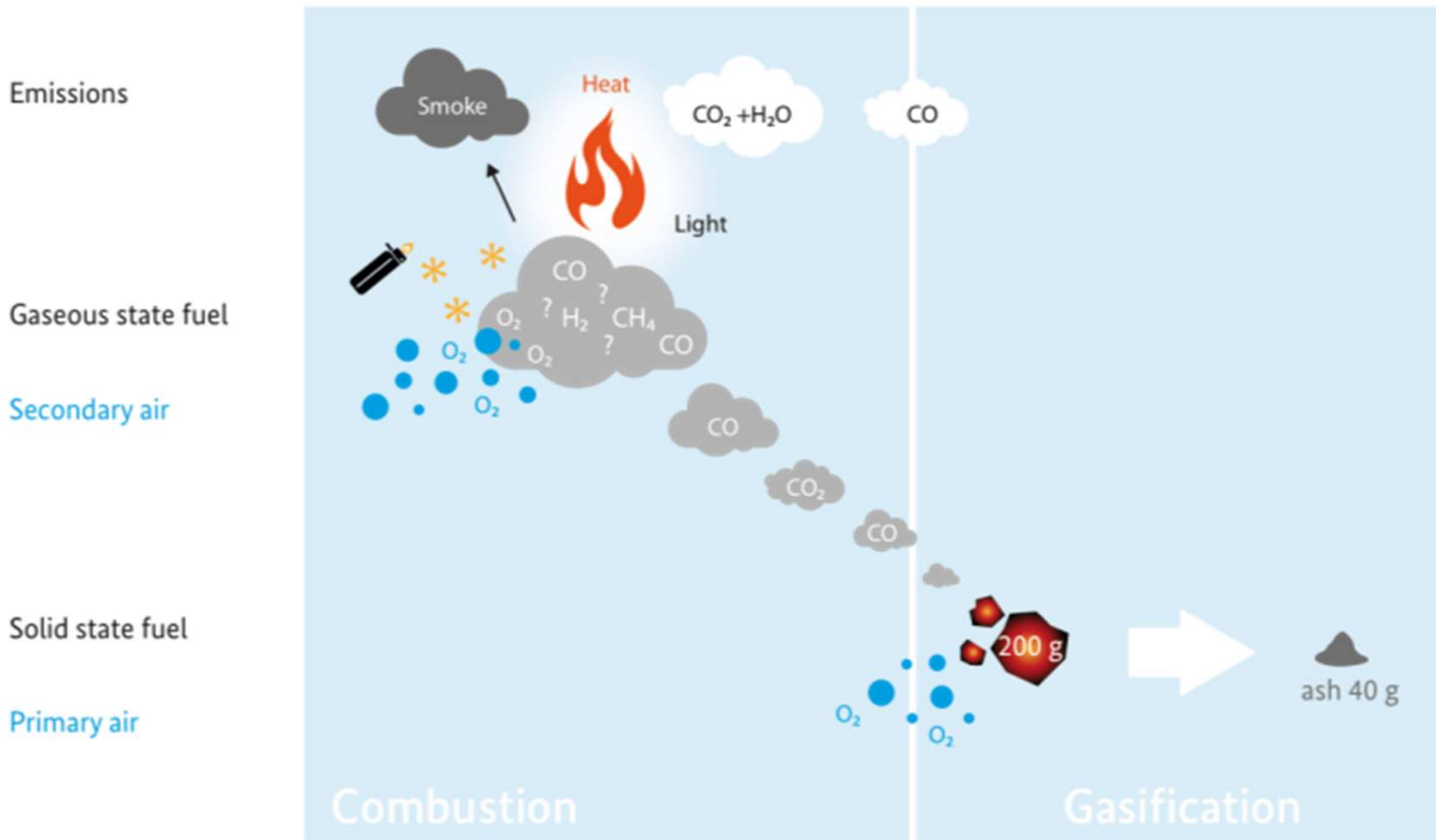
School feeding programme

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

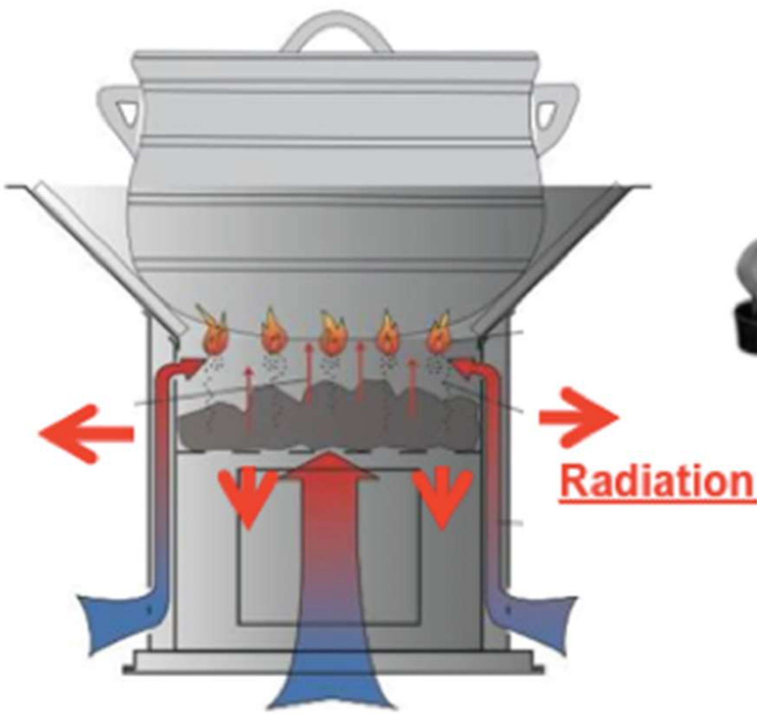
Char-burning



Oxygen Controlled (Combustion)

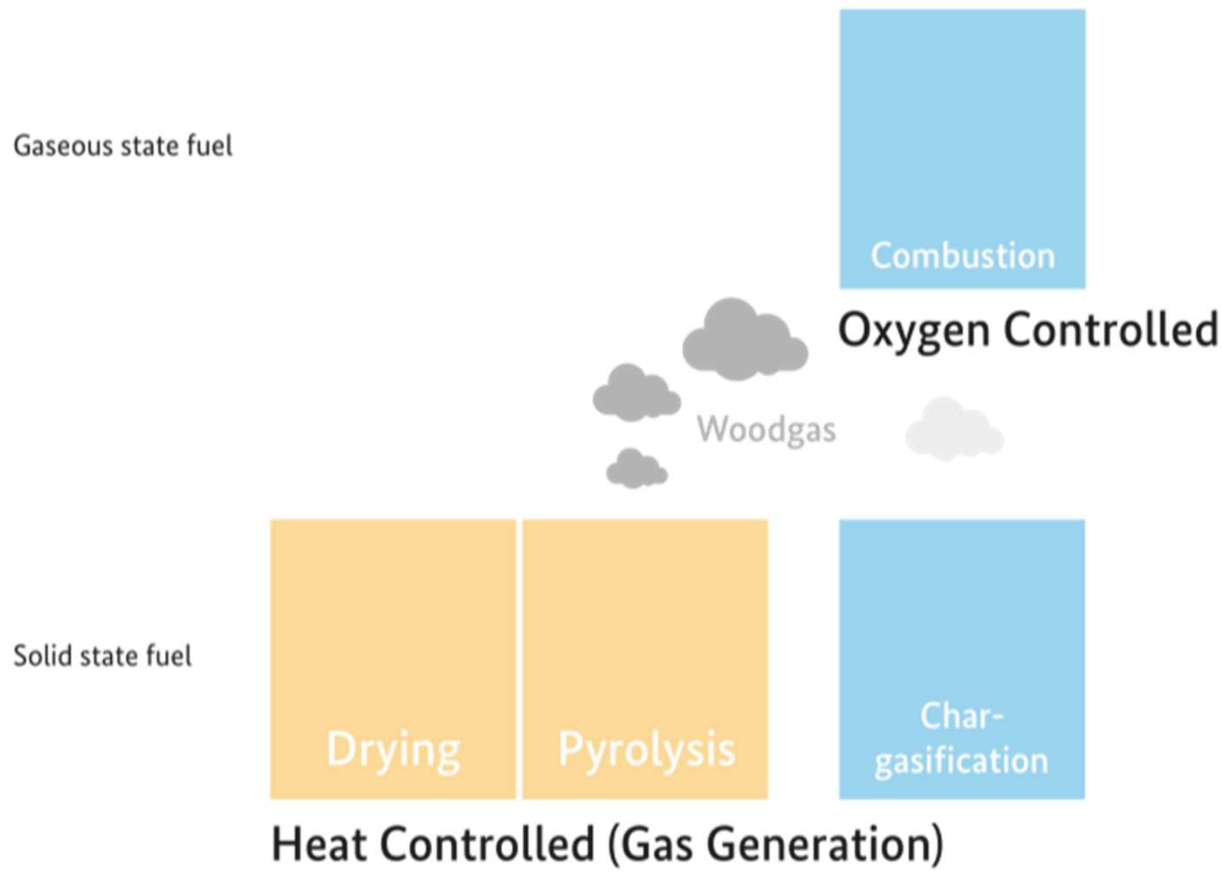
Carbonised fuel: Design principles of **charcoal stoves**

- 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

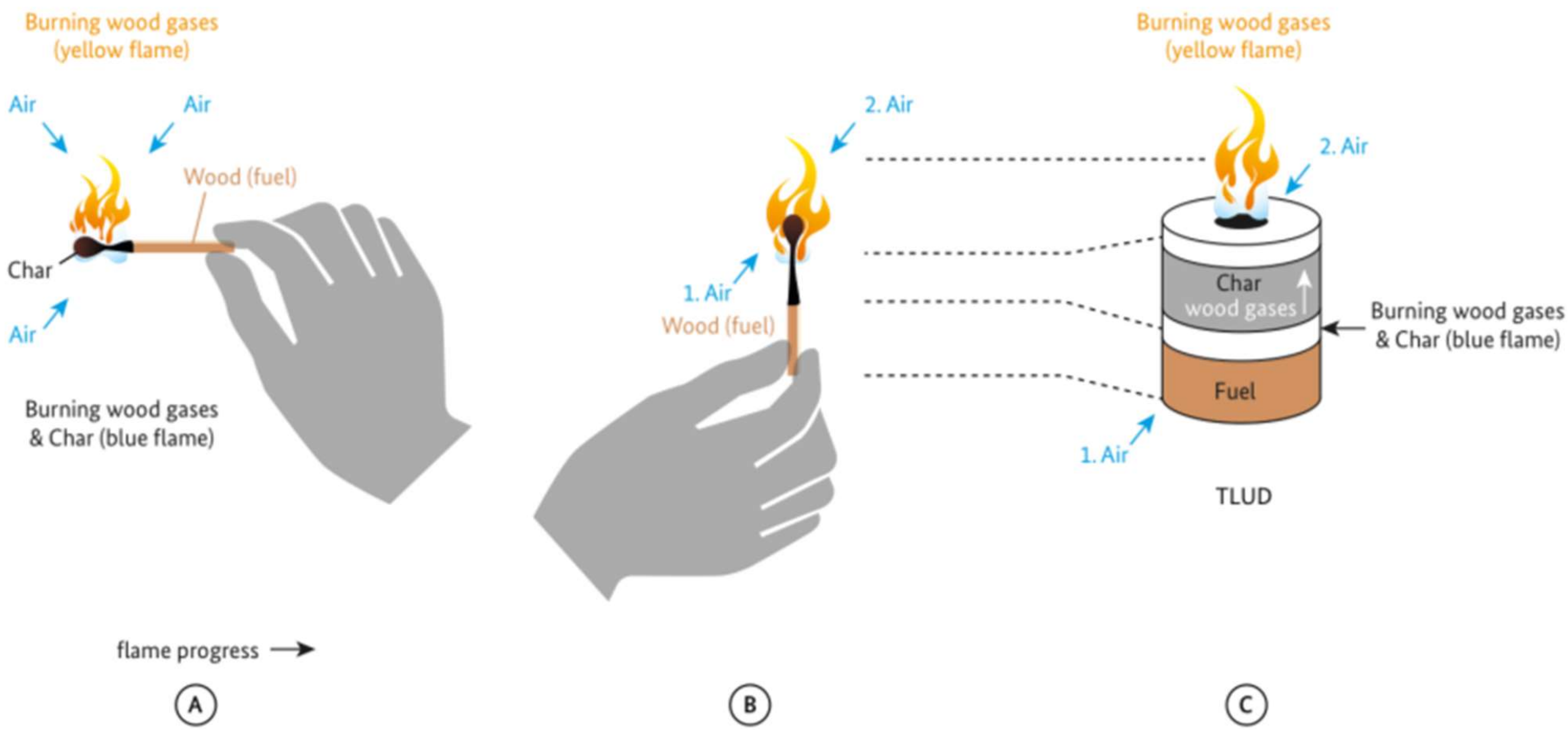


For all other small-size natural and processed fuels:

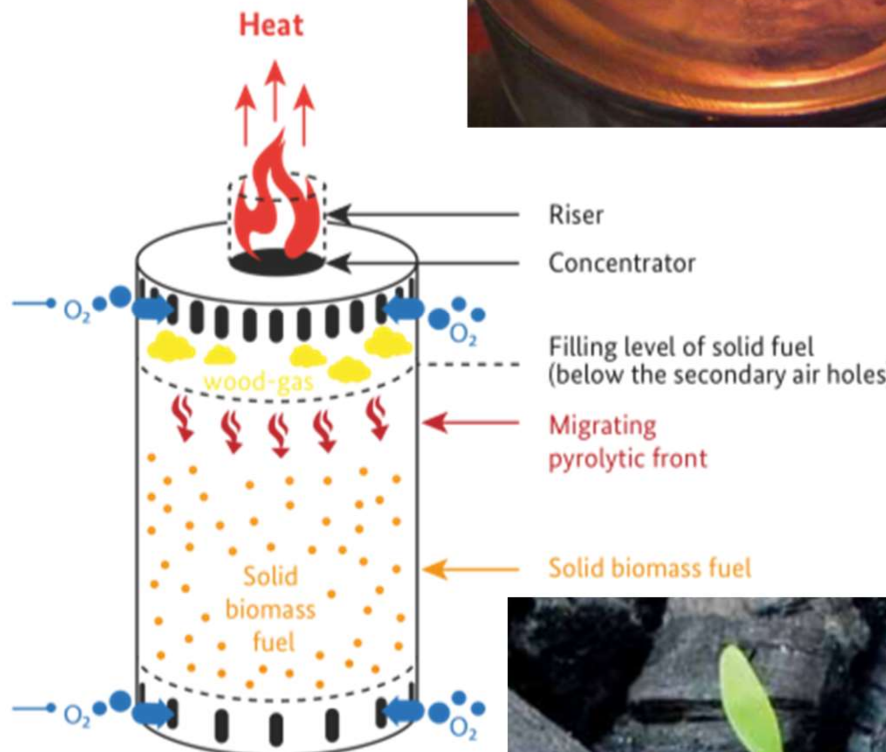
Gasifier: gas-creation seperated from gas-combustion



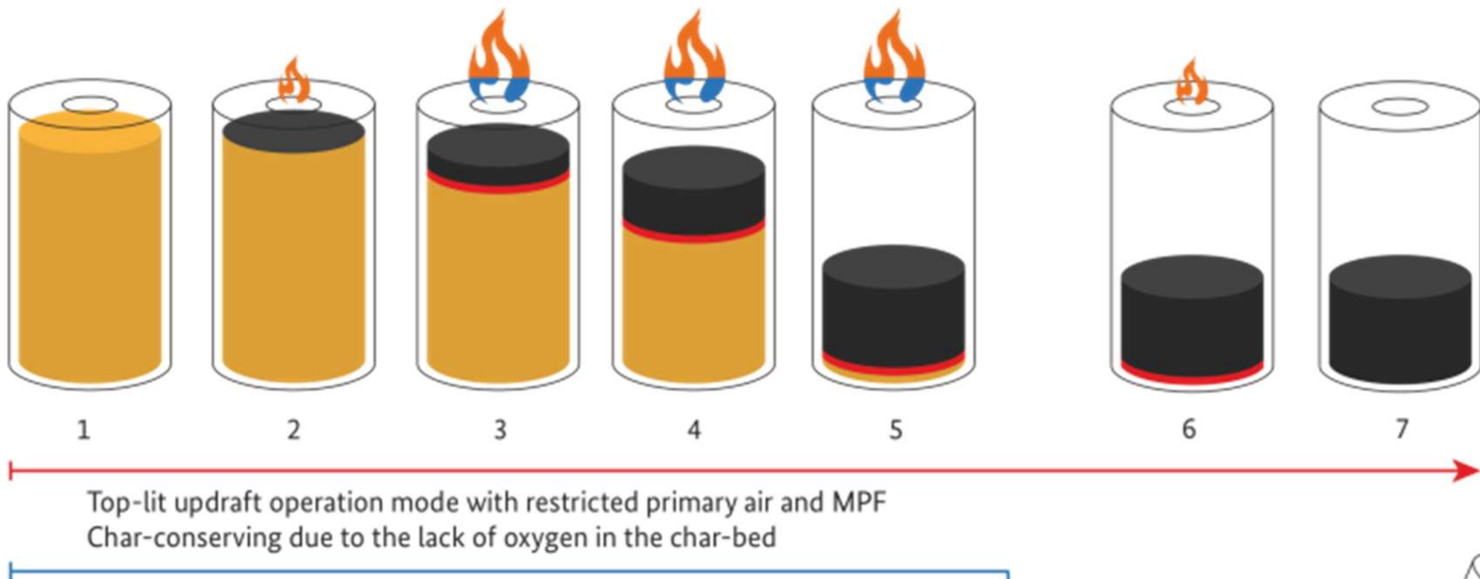
Top-lit Up-draft gasifiers: char-making gas-generator below, gas-burner on top



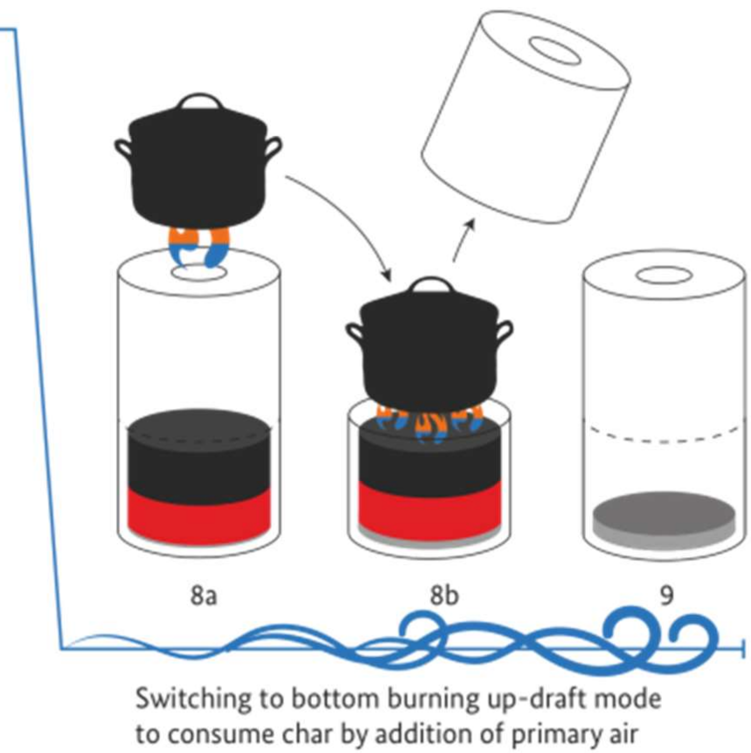
Gasifier:
mini-kiln that turns small chunky biomass into char while cooking!



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



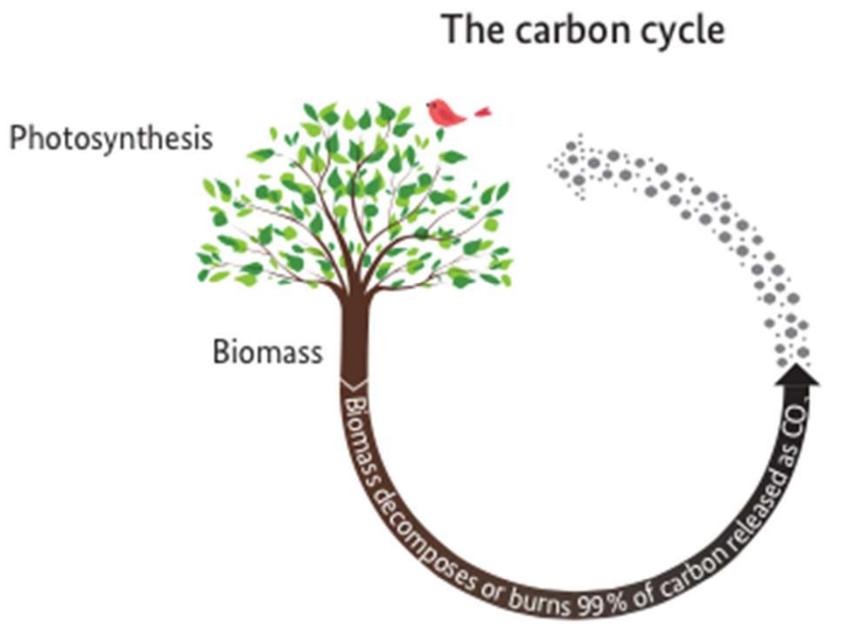
‚TChar‘: Combing multiple options

Gasifier produces own char on top of a charcoal stove,
for immediate use in charcoal stove while still hot

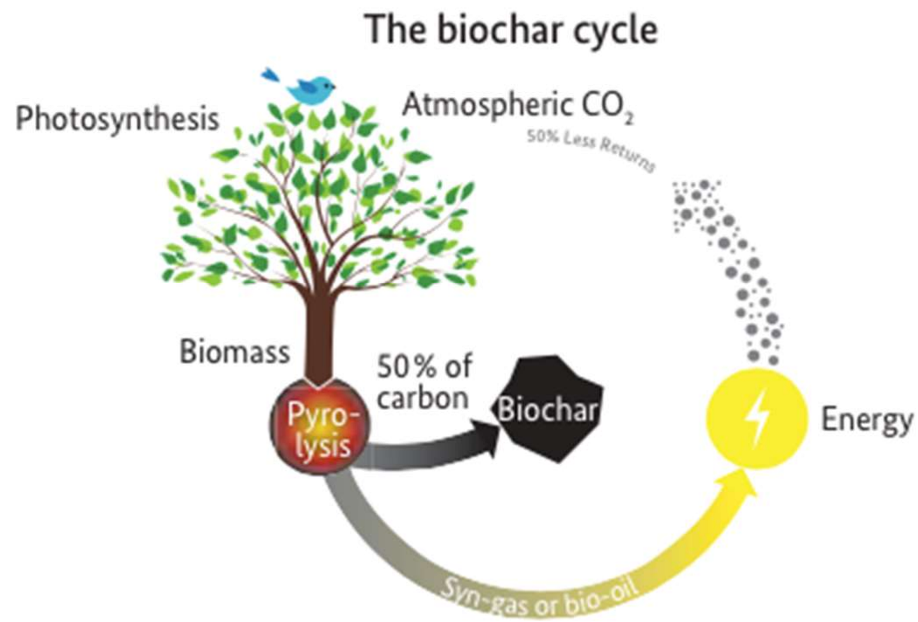
Interesting co-benefit from gasifiers:

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



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.



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.

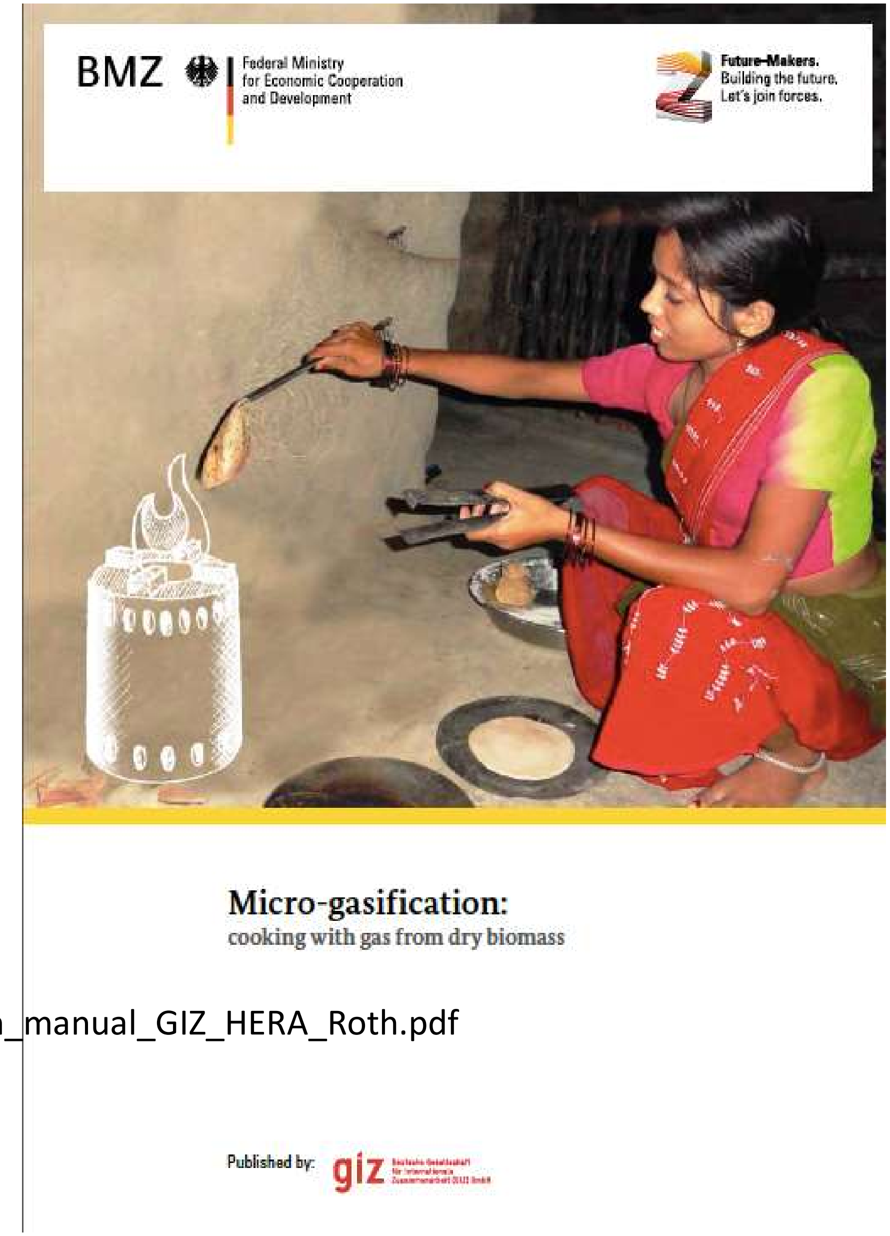
The cooks love it!

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



https://energypedia.info/wiki/File:2014-03_Micro_gasification_manual_GIZ_HERA_Roth.pdf

Cooking energy compendium

A practical guidebook for for implementers of cooking energy innovation

https://energypedia.info/index.php/GIZ_HERA_Cooking_Energy_Compendium

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, **T**emperature, **T**urbulence

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, **A**rea, **R**adiation, **P**roximity, **V**elocity

‚Form follows function': depending on

- Fuel, cultural factors, meal type, type of cooking
- pot-shape, material, size etc.

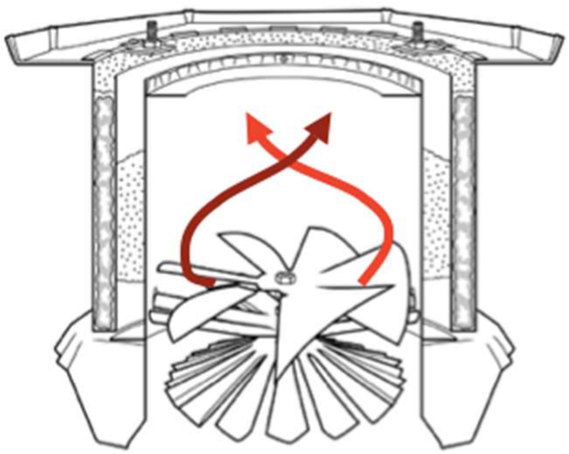
How to optimise stove design re ‘3T’ for complete combustion

- 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

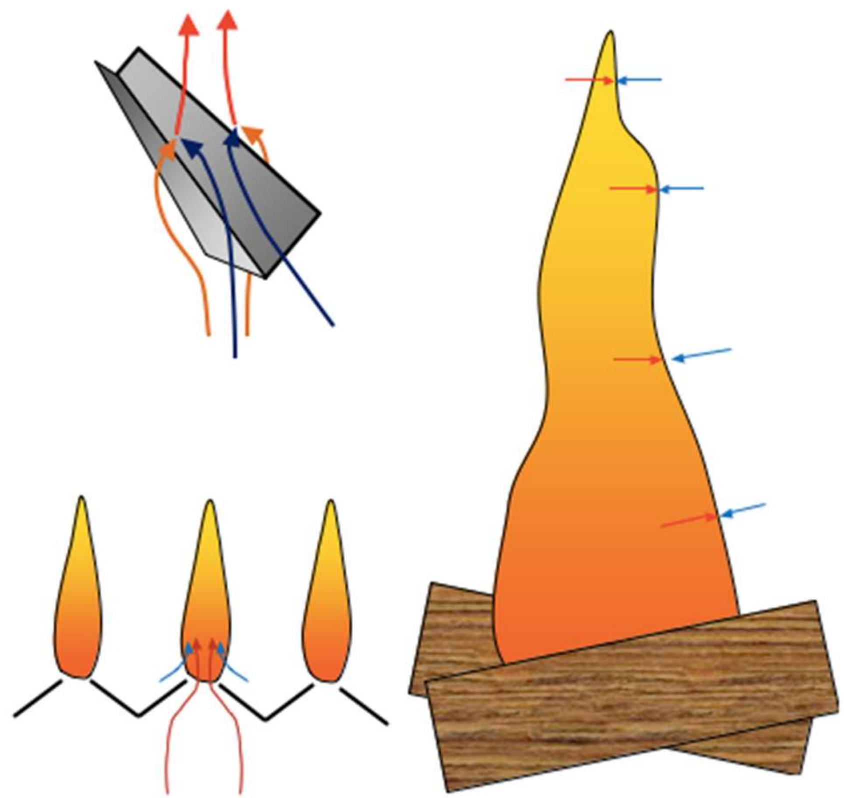
TIME

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??

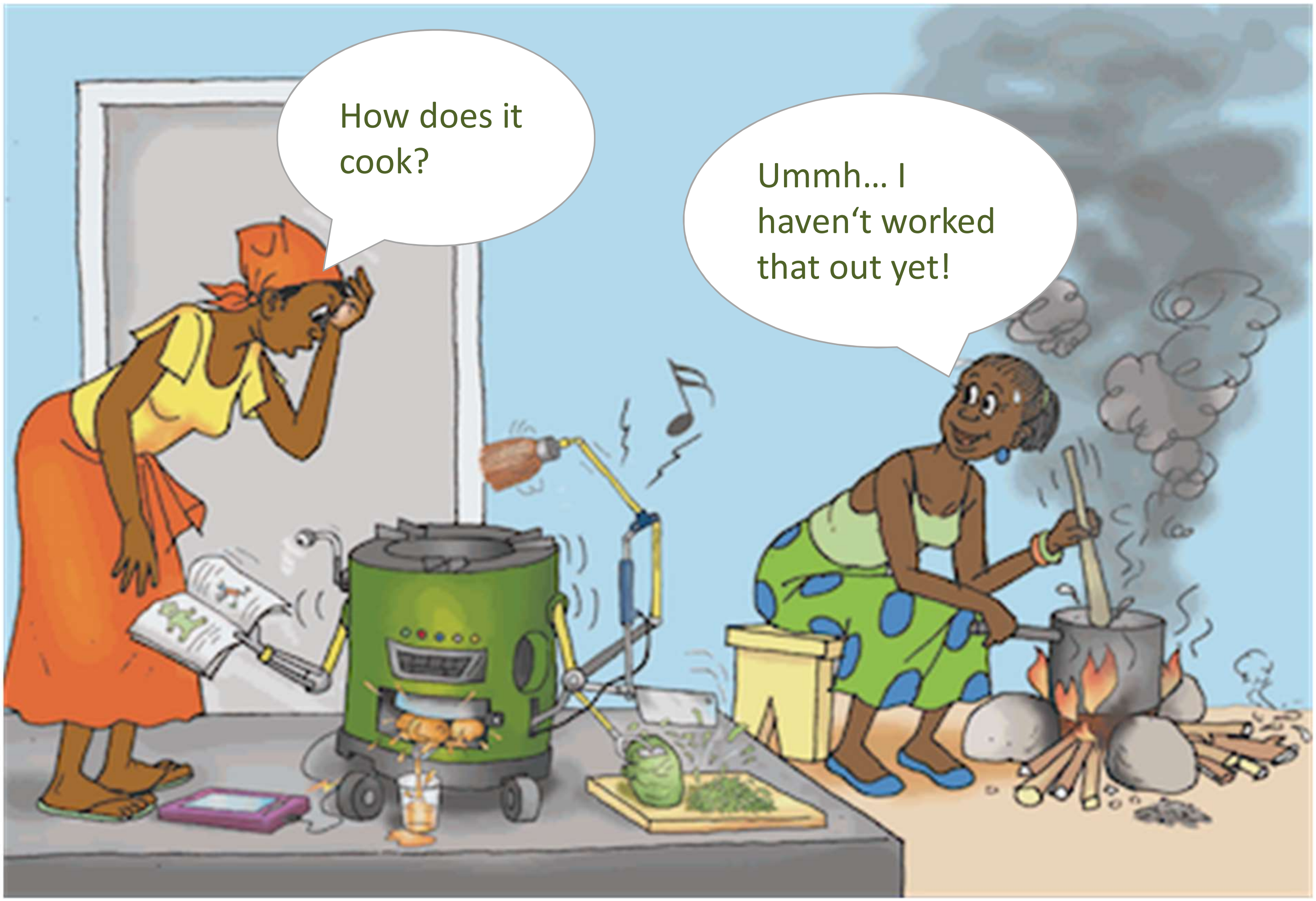
What does the engineer want from a stove?
What does the user want from a stove?

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

The over-improved stove

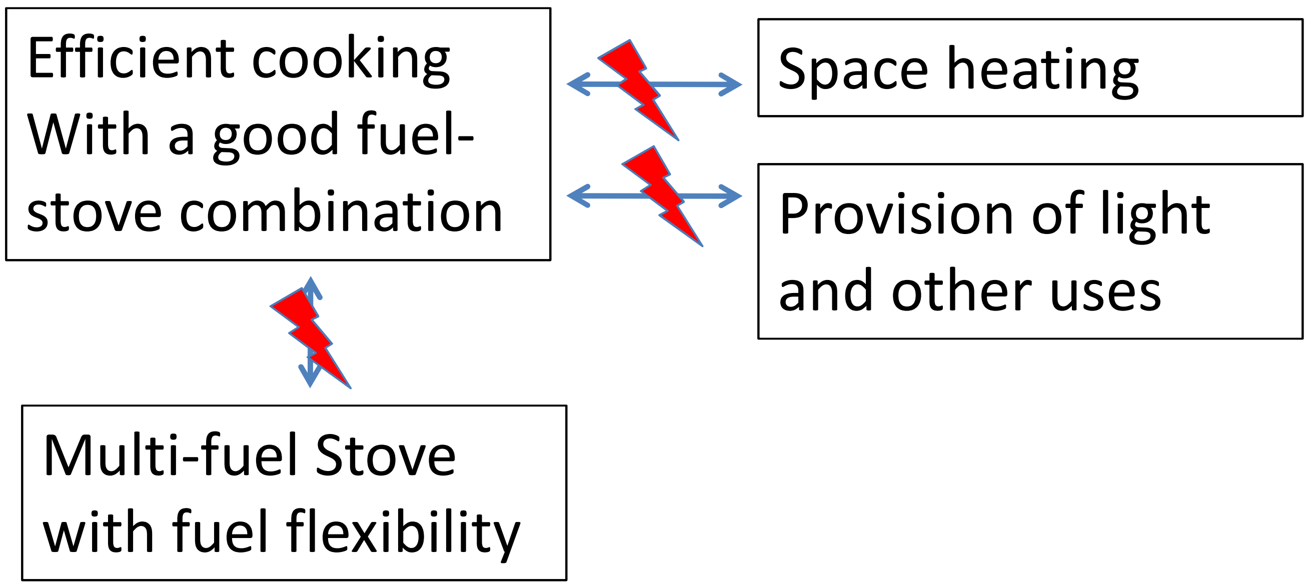
Drawing by Henderson Mawera (Malawi), idea & sponsorship by Charlotte Ray, University of Nottingham (2016)

Conclusion: a stove should first of all cook!



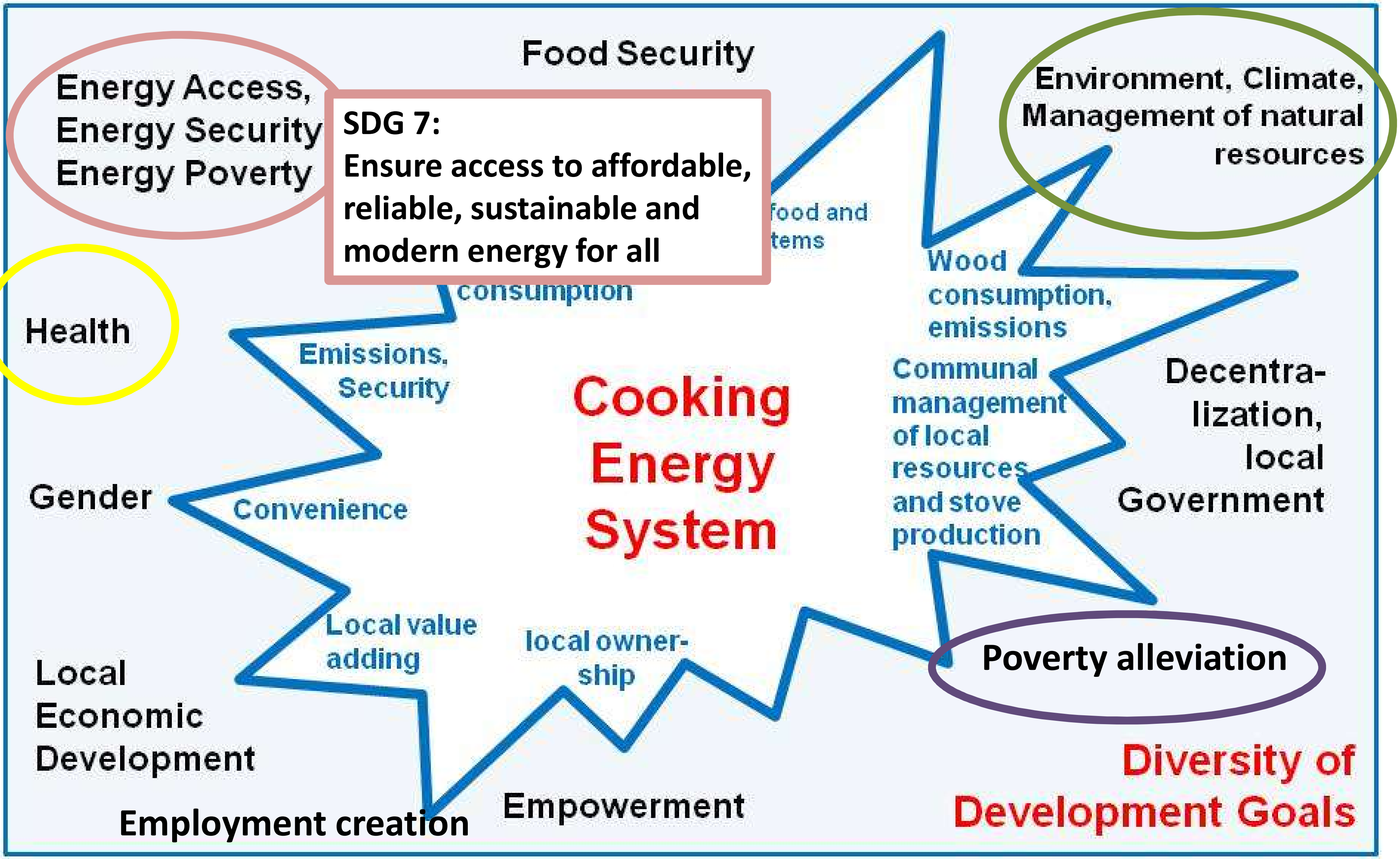
Drawing by Henderson Mawera (Malawi), idea & sponsorship by Charlotte Ray, University of Nottingham (2016)

Efficiency vs. Multipurpose

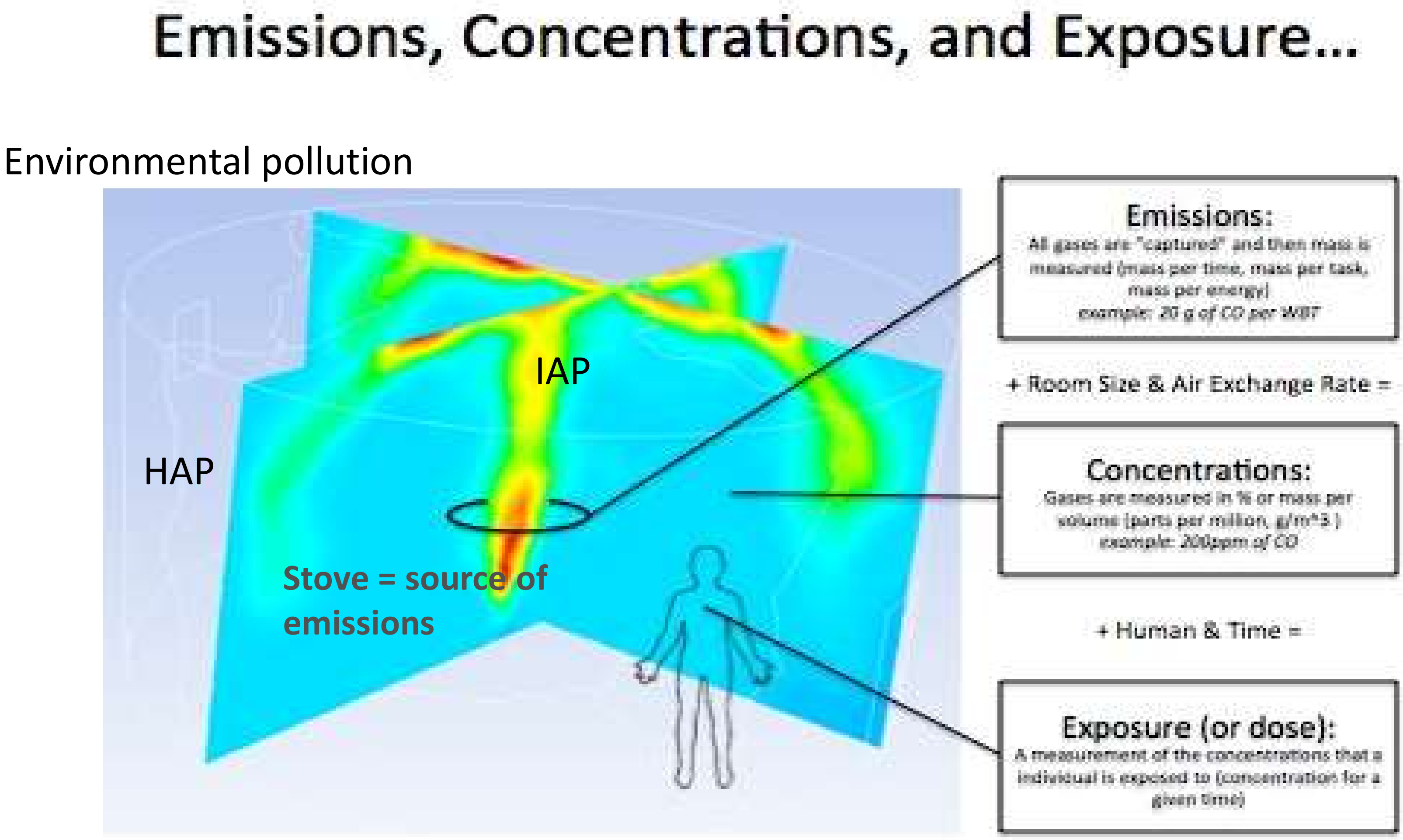


An efficient cookstove is often a bad space heater.
Compromise can be the enemy of efficiency.

How much ‚clean‘ do we need?



Health protection: How to determine what and how much people breathe in?



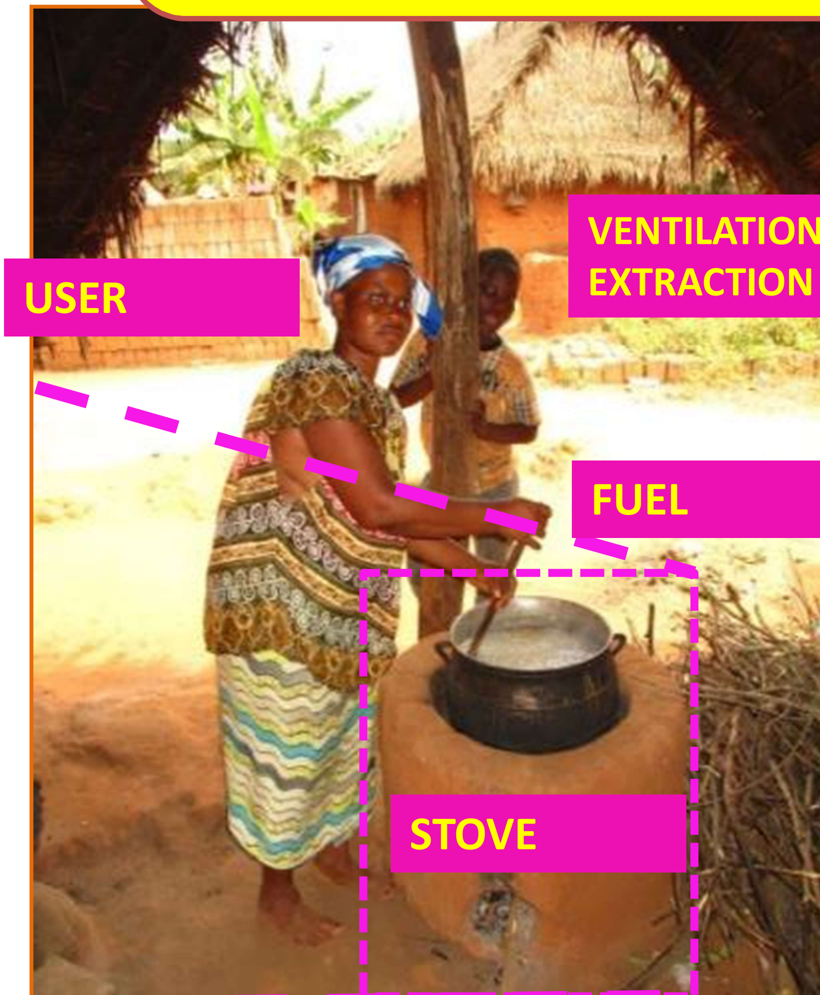
Slide based on figure provided by Morgan de Foort, Colorado State University, 2012

A ‚clean stove' is .. a myth!

Contextualising 'stoves' to define quality of CES

Quality of the service of the Cooking Energy System (CES)

Quality of the Stove



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 hassling 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

Perceived advantage by the users	High Andes	Coast area	Ama-zonas	
Fuel savings	**1**	3	9	donors emphasis
Less smoke exposure	**2**	5	3	
Increased safety, less burns	6	**2**	**2**	
Fast cooking	3	1	4	users emphasis
Less heat exposure			1	
Convenience to keep fire going		7	5	
Easy reignition, saves matches	7		6	
Ability to cook upright	4	6	7	
Cleanliness of kitchen	5	4	8	

CLEANER
Solutions for Malawi

C onvenient (fast,...)

L ess smoke

E fficient on fuel use

A ffordable and available

N ot harmful (safety)

E asy to use and aestethic (buy beautiful, cook easy)

R obust (durable, strong and long lasting)

This is what users want!

Give users options!!!!