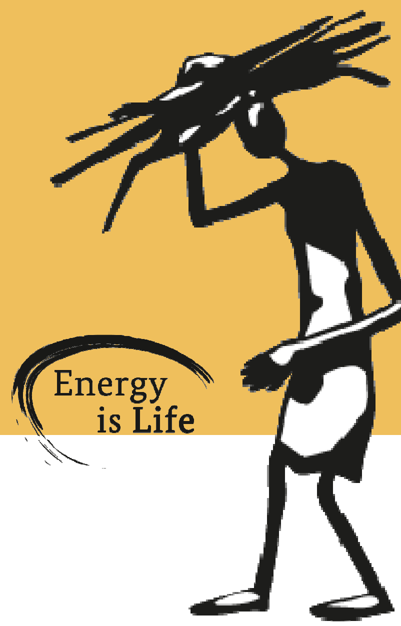
Micro-gasification:
Cooking with gas from biomass

An introduction to the concept and the applications of wood-gas burning technologies for cooking



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Micro Gasification: Cooking with gas from biomass

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Cover Photo: Christa Roth

Photo showing the typical flame pattern in a wood-gas burner, in this case a simple tin-can

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Micro-gasification: Cooking with gas from biomass

Contents

Introduction

Micro-gasifiers: much more than 'just another improved cook stove'

1) Traditional wood-fires are commonly associated with negative impacts such as

- Lack of convenience: **'not modern'** like LPG, electricity, or biogas burners
- Emissions of smoke, carbon monoxide and soot (black carbon): **'not healthy'**
- Forest degradation: **'non-sustainable'** fuel-supply from abused renewable resources

2) So-called 'improved stoves' rarely meet standards expected for clean stoves

In past decades countless efforts have been deployed to improve cooking performance over 'conventional wood-fires'. Some successes were achieved to develop wood-fuel technologies that consume less fuel, are convenient to use and also partially burn cleaner. With the recent increased focus on negative health impacts associated with emissions from solid biomass cooking fuels, better results on emissions reductions are needed if biomass is to remain a viable acceptable fuel for the billions of people relying on it to satisfy their daily cooking energy needs.

3) 'Re-inventing the fire' instead of continuing with conventional wood-fire

Micro-gasifiers or wood-gas-stoves approach the concept of generating heat from wood and biomass in a completely different way. ***Gasifiers separate the generation of combustible gases from their subsequent combustion to create cooking heat.*** The combustion step is essentially a "gas burner" that gives a 'quantum leap' in emission reductions while allowing achievement of convenience, efficiency and emission objectives! These are **"gas-burning stoves"** that make their own supply of gas when needed from dry biomass that can be safely stored and transported. Gasification advantages have been known for nearly two hundred years, but only recently could they be reliably accomplished at sufficiently small (micro) scales appropriate for household stoves.

4) Wood-gas stoves have certain advantages over other improved cook-stoves

- Cleaner burning of biomass *(much less soot, black carbon and indoor/outdoor air pollution)*
- More efficient due to more complete combustion *(less total biomass consumption)*
- Uses a wide variety of small-size biomass residues (*no need for stick-wood or charcoal)*
- Biomass fuels are often within the immediate area of the users *(affordable access at own convenience)*, easy to transport and easy to store after gathering
- Creation of gas from dry biomass can be achieved with very simple inexpensive technology directly in the burner unit *(portable, no piping or special burner-head needed)*
- Performance similar to biogas *(but not dependent on water and bio-digester)* and approaching the convenience of fossil gases
- 'Gas' available on demand *(unlike electricity or LPG that are dependent on local providers and imports, and unlike solar energy that is dependent on clear weather and daylight hours)*
- Pyrolytic micro-gasifiers can create charcoal which may be used for energy purposes or to improve soil productivity as biochar
- Easy lighting permits cooking to start within minutes *(contrasted with charcoal slowness)*

5) Micro-gasifiers can complement other wood fuel stoves where appropriate

Wherever stick-wood is plentiful and at a low cost, conventional improved cook stoves (e.g. rocket stoves) are attractive options. In the ever-increasing areas where charcoal and firewood are becoming a scarce and/or an expensive commodity, micro-gasifiers will be of growing relevance as an option to cleanly burn alternative biomass fuels.

Objectives of this handbook:

Micro-gasification for household cooking is a relatively young development. The principle was invented in 1985 and the first commercial micro-gasifier was available in 2003. Recently many more people are becoming aware of the concept and the potential of micro-gasification. New developments come up virtually every day.

This book is about biomass micro-gasifiers that are small enough for **domestic use** as heat-generating combustion units in cook-stoves and heating applications. The focus is on **'gasifier stoves',** which is the combination of a **micro-gasifier combustion unit** and a **heat-transfer unit** for effective transfer of the generated heat into a cook-pot.

This handbook is a first systematic overview on micro-gasifiers for cooking energy

a) **For project planners and conceptionists:** to give them an overview on the numerous technologies and applications of micro-gasification including the risks, benefits and potential of micro-gasifiers.

b) **For project implementers and practitioners:** to provide entry points for them to get started in testing, adapting and disseminating micro-gasifiers.

c) **For researchers:** to give feedback on open issues and questions they can take up to bring micro-gasification a step forward.

d) **For skeptics who fear the risks and doubt the benefits:** to provide them some food-for-thought

This handbook is a compilation of the current state of the art of micro-gasification, which is still very much in its infancy but growing up fast.

As 'work-in-progress' it is hoped to inspire more experience-creation on the ground that can help to spread micro-gasifiers and contribute to exciting new developments. Any reader is encouraged to provide feedback so that new developments can be incorporated in the regular updates of this handbook.

The content is structured into the following modules:

1) **'Wood-gas' from biomass and its application for cooking**
2) **Technologies and applications of micro-gasification to cookstoves**
3) **Feedstocks and fuels for micro-gasification**

In the Annex there is a 'Bonus track' on Biochar:

How cooking on pyrolytic gasifiers can mitigate climate change and enhance agricultural production (by Kelpie Wilson from the International Biochar Initiative)

A word of thanks

This manual was initiated and supported by Dr. Marlis Kees, the manager of the sector programme for poverty-oriented basic energy services HERA, implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. Without her and the entire HERA-team this resource on micro-gasifiers would not exist.

All text unless otherwise marked or quoted was written by Christa Roth, with contributions and technical review by Dr. Paul Anderson and Hugh McLaughlin, PhD, PE, who kindly allowed me to quote from their texts without marking a passage as a quote. In that sense they can be seen as co-authors of Module 1.

Kelpie Wilson (International Biochar Initiative) contributed the 'bonus-track' on Biochar, found in the Annex.

For the assistance in reviewing and giving helpful suggestions for improvements thanks go to Dr. Agnes Klingshirn, Gregor Kraft (BauerPauer), Kevin Mortimer, Nathaniel Mulcahy (WorldStove), Crispin Pemberton-Piggott (Newdawnengineering) and Paal Wendelbo.

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Unless another source is stated, all photos were taken by Christa Roth.

Christa Roth, Eschborn in January 2011

Please note:

All links were checked at the time of research for this handbook. Please note that links might change. The authors are not responsible for links becoming inactive or outdated.
This handbook does not intend to favour any company or specific product. Examples are given that prove the existence and the source of a certain technology as a reference point. Any links to commercial websites are not-for-profit of the authors and by no means exhaustive. This handbook should grow and become more complete over time.
So please send any useful references and links that you would recommend to be included in future updates to christa-roth@foodandfuel.info.

Other suggestions for improvements are also welcome. This first edition should still be considered as 'work-in-progress'. Regular updates are envisaged to incorporate the changes in this dynamic field of micro-gasification.

List of abbreviations

°C	Degrees Celsius
ARECOP	Asian Regional Cookstove Programme
BP	British Petroleum
CHAB	Combined Heat And Biochar (Applications)
CICS	Conventional Improved Cook Stoves
cm	centimeters
CO	Carbon Monoxide
CO_2	Carbon Dioxide
ETHOS	Engineers in Technical and Humanitarian Opportunities of Service
FA	Fan-assisted, also meaning Forced Air
FAO	United Nations Food and Agriculture Organisation
FOB	Free-on-board
g	Gram
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH (since 1.1.2011), previously Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, German Technical Cooperation
h	Hour
H_2O	Water
HERA	GIZ - Programme for poverty-oriented basic energy services
HHV	Higher heating value
INR	Indian Rupees
kg	kilogramm
KvA	KilovoltAmpere
kW	KiloWatts
LHV	Lower heating value
LPG	Liquefied petroleum gas
M3	cubicmeter
mg	milligram
min	Minute
MJ	Mega Joule
mm	millimeters
ND	Natural Draft
NiMH	Nickel Metal Hydrate
O_2	Oxygen
PCIA	Partnership for Clean Indoor Air
PE	Physical Engineer
PM	Particulate Matter
R&D	Research and Development
TLUD	Top-lit up-draft (gasifier)
USA	United States of America
USD	United States Dollars
WBT	Water boiling test
ZAR	South African Rand

Module 1

'Wood-gas' from biomass and its application for cooking

Table of content Module 1:

1.1 Gasifying solid biomass for cooking

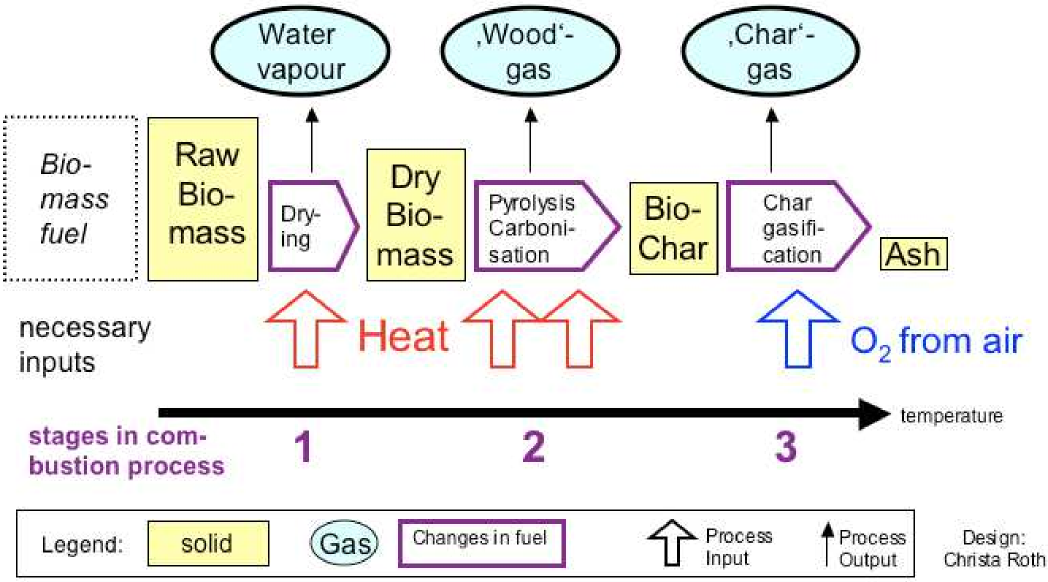
Understanding the difference between "feeding an open fire" and "controlling a combustion process in a gasifier" is one starting point for understanding the way biomass and fire are combined in cooking devices.

Let's start with a familiar example: Everybody has seen a burning candle: once lit, it proceeds to slowly melt the wax and burn with a stable flame for a prolonged time. Notably, wax burns by a multi-step process where it first melts, then travels as a liquid up the wick, then vaporizes due to additional heat received by the wick. The flame provides heat to melt additional solid wax at the top of the candle by both radiant heat and proximity. The vaporized wax mixes with oxygen in the air – and the visible flame is present at the interface where the wax vapours leaving the wick meet the oxygen in the air surrounding the flame.

Wood burns in much the same way as the wax in the candle, with a few specific differences. Most of these differences are due to the fact that candles are made from highly refined wax, and wood is a less pure fuel – but much more available and affordable than wax.
Wood and other solid biomass constitute, after all, the oldest cooking fuels. They are even today the most prevalent source of cooking energy on the planet.

As in the case of the candle, also the burning of wood and other solid biomass is a sequence of transformations – occurring in close proximity, but separated by small distances in time and space, as shown in Figure 1.

Figure 1: Changes in Solid Fuel



The solid substances undergo changes determined by the presence of **heat** and **oxygen**:

1. as biomass is heated, it evaporates excess moisture and it's surface temperature increases,
2. at elevated temperatures, biomass pyrolyses ('decomposes by fire') into combustible vapours and a solid, known as "char",
3. red hot "char" can be converted to ash if sufficient oxygen is available,
4. mixed with oxygen the vapours and gases generated can be combusted when ignited

During the whole conversion process, temperatures increase from ambient temperature to well above 800° Celsius, depending on local conditions.

In each step vapours and gases are released and the solids reduce in mass and volume.

If complete combustion is attained, emissions should be clean and only contain carbon dioxide and water vapour. If combustion is not complete, then smoke and vapours composed of unburned fuel and carbon monoxide will result.

1.1.1 Steps of biomass combustion

Once we know the conditions that influence combustion, we can use them to control and optimise the process. Therefore let's take a moment to explore each step separately:

Step 1: Drying
The first change happens during drying. The amount of water transformed into vapour depends on the moisture content of the raw fuel, which also determines the heat input needed to evaporate all the water and the loss in mass and volume to get to dry fuel.

Step 2: Pyrolysis (Carbonisation)
Increased temperatures and absorbed heat eventually cause a complete decomposition of the biomass, which separates into volatile gases and vapours, as a solid char remains behind.[1]
The vapours contain various carbon-compounds with fuel value, referred to by the term 'wood-gas'. As the solid product of this stage is char, it is also referred to as Carbonisation[2].
Pyrolysis can happen in the complete absence of oxygen**, the regulating factor is heat.**
In short: no heat input, no pyrolysis, no wood-gas generation and no fire.

Step 3: Char-gasification
Once char is formed, the next stage of the solid phase is to convert the carbon atoms to gases and the non-carbon portion to ash.
This only happens if **oxygen** is available and reaches the char while it is still hot enough to react. Then '**char-gasification'** occurs: oxygen reacts with the char solids, yielding carbon monoxide, carbon dioxide and creating additional thermal energy.
The fraction of non-burnable solid mineral content of the char remains as ash[3].

Note:
The regulating factor of char-gasification is **the amount of available oxygen** around the **hot char.**
If the char is cooled and/or the oxygen supply is restricted, the conversion from char to ash does not take place and the char will be conserved and no ash will be created.

Step 4: Gas-Combustion (see Figure 2)
The final stage of **'gas-combustion'** is where the gases are 'burnt' (combusted) and the bulk of the heat is released that can be used e.g. for cooking.

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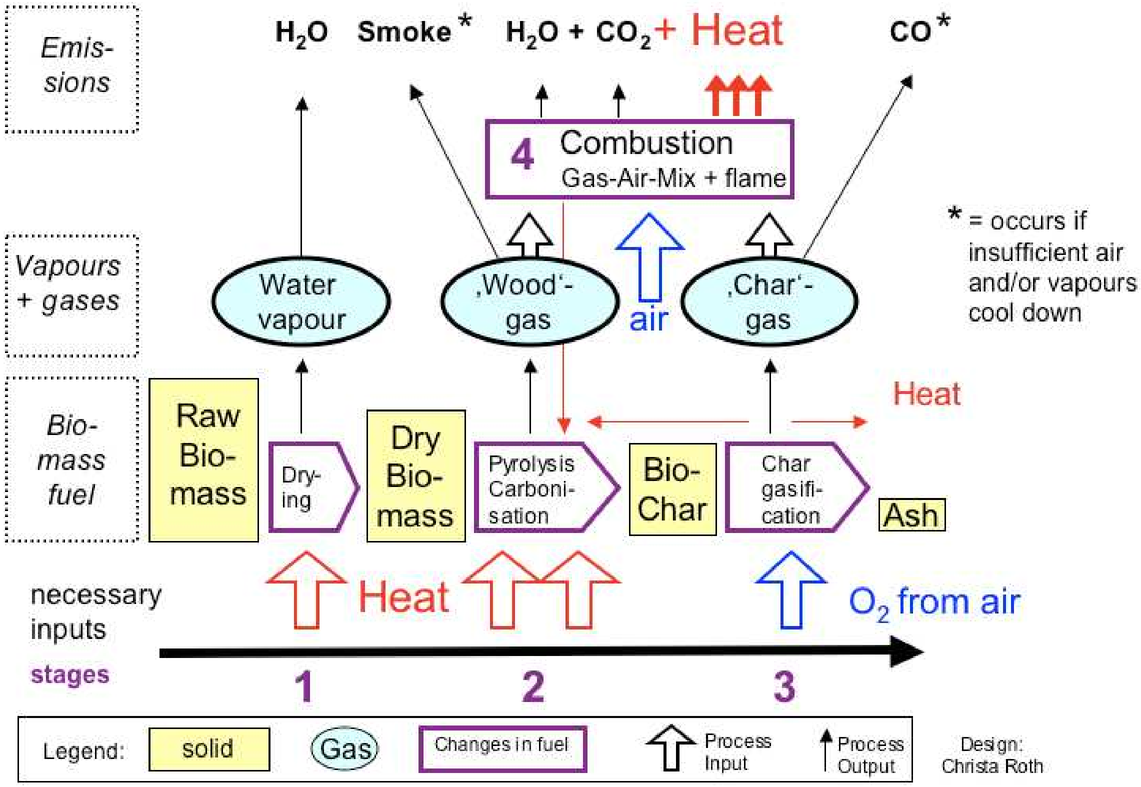
[1] Some may have own experience with pyrolytic destruction of a slice of bread in a toaster: first it starts changing colour from pale-white to golden-brown, while releasing an appetising smell. If left too long in the toaster, the emerging volatiles will soon turn to thick biting smoke ('wood-gas') while the bread will show various shades of 'black' by charring and carbonisation. In the worst case it will come out as a lump of black char unfit for human consumption.
[2] Pyrolysis (Greek: decomposition by fire) and Carbonisation are like the flip-sides of the same coin, depending if the focus is on the generation of wood-gas or the creation of char.
[3] Ash contains only minerals that the plant once absorbed from the soil. Under normal circumstances completely burnt ash should not contain any carbon or other substances with combustible value.

Combustion is a series of oxidisation reactions, which can only take place if sufficient oxygen is available. **The main regulating factor** of combustion is the **amount of oxygen mixed with the hot vapours and gases.**
If there is not sufficient available oxygen, the gases cannot be 'burnt' and combustion remains incomplete and unburnt smoke or carbon monoxide will be emitted.

Figure 2: Burning the gas (or not, if conditions are not conducive)



Thorough mixing of oxygen provided by the air with the freshly generated hot wood-gas and char-gas (if char-gasification took place), in combination with an existing flame, results in the complete combustion of the gas-components.
The flame is the visible manifestation of combustion. Ideally only fully oxidised gases, without unrealised energetic value, leave the combustion zone - meaning that all hydrocarbons from the biomass fuel have been oxidised to carbon dioxide and water vapour.

If the combustion is incomplete due to the lack of oxygen or if the vapours have cooled down below the point where they will burn, they turn into undesirable emissions: in the case of wood-gas it is in the form of noticeable, often irritating, smoke. In the case of char-gas it is in the form of carbon monoxide, an odourless, imperceptible, and highly undesirable toxic gas. Carbon monoxide is poisonous and a danger for human health.

Energy input and output
The objective of burning biomass for cooking purposes is to provide thermal energy to heat up food.
Yet, it takes energy to break the chemical bonds within the solid biomass. So the first two stages described actually consume HEAT, meaning they are endothermic. This is why we need a match or some other flame source to start a fire. Once the fire is started, the heat

released by the combustion reactions supplies the necessary thermal energy to continue the fire and make it self-sustaining.

When designing a device to control the burning of biomass and regulate the rate of heat generation, it is important to note that the drying and pyrolysis stages are controlled by regulating the amount of HEAT that reaches the solid biomass, while the later steps of char-gasification and vapour combustion depend on the availability of OXYGEN.

The two red horizontal arrows in Figure 2 symbolise that char-gasification produces some **radiating heat**. Combustion also radiates heat towards the biomass fuel. These sources of heat continue the initial endothermic steps and generate more wood-gases, sustaining the fire in the form of the yellow and blue flames above the "burning" wood.

1.1.2 The 'uncontrolled' open fire

In this photo we can detect all these stages of a 'burning' process in an open fire, happening **simultaneously in a rather uncontrolled manne**r: unburnt raw fuel (left), yellow flames (centre) indicating wood-gas combustion, red-glowing embers and charred black wood partially covered by grey-white ash (right).
A stick lying across has the left end unburnt, a black charred transition zone and the right end covered with ash.

Smoke is the result of incomplete combustion, most visible to the left, where there are no flames.

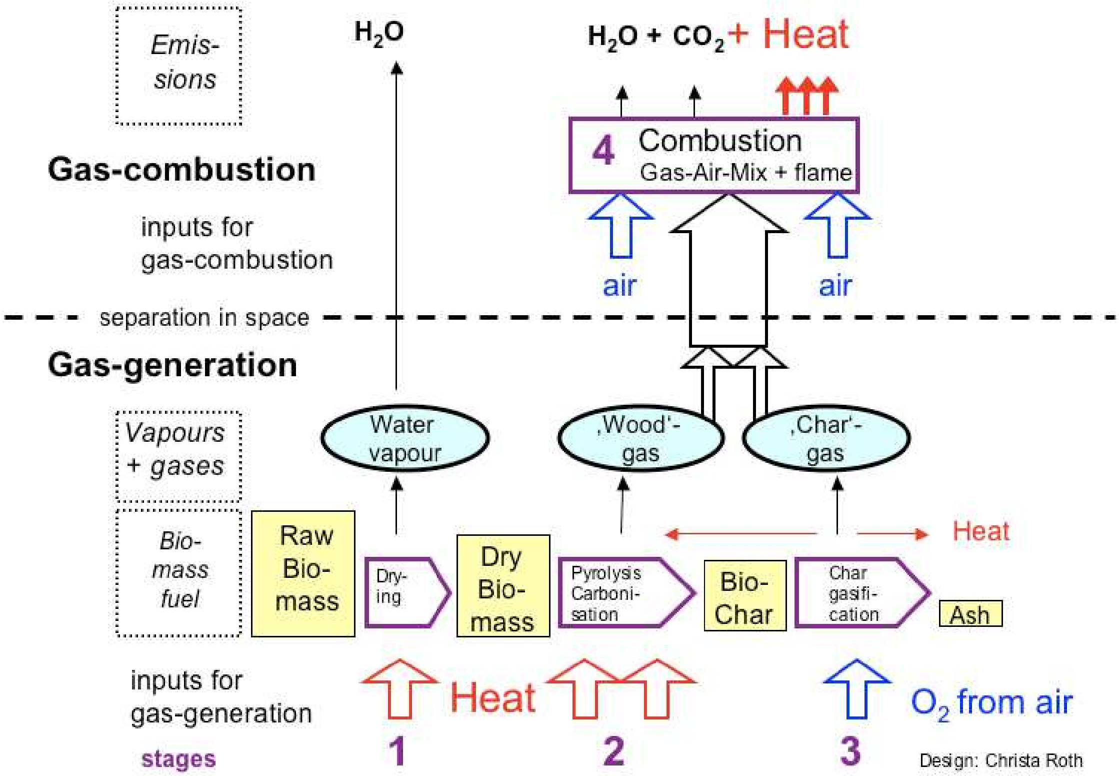
1.1.3 Improving control in a gasifier device

A **biomass gasifier** is the broad term for a device that turns solid biomass into gas that can subsequently be burnt in a controlled manner. Unlike in the open fire, the gas-generation is controllably separate in space and time from the gas-combustion, like shown in the next figure. While open fires and most conventional cook-stoves are regulated by the fuel supply, most gasifiers are **controlled by the air supply**.

Gasifiers offer the potential to deliberately optimise the frame-conditions of each conversion step. By controlling the inputs heat and air, an exceptionally clean combustion of biomass can be achieved. The major challenge is to get the right amounts of air to the right places.

The step of char-gasification can be suppressed, if the hot char does not get exposed to sufficient air. In this case the combustible gases are predominately generated by pyrolysis and a portion of the char is conserved. This type of gasifier device is often referred to as 'biochar'-making 'pyrolytic' gasifier[4].

Figure 3: Gas-generation controlled separately from **Gas-combustion = 'gasifier'**



Although the combustible gases could be piped and sent for other uses[5], for cooking purposes it makes most sense to have the combustion zone close-by and burn the gases while they are still hot.

In a nutshell: **'Gasification'** is the broad term used for the **conversion of a solid fuel into a gaseous fuel**. The process to create heat from solid biomass goes in stages: **Wood-gasification** turns wood to char and gases. It is controlled by heat input and can be slowed by cooling. **Char-gasification** turns char to ash and gases. It is controlled by oxygen and can be 'arrested' by deprivation of oxygen. **Wood-gas** is often used as summarizing term for the mixture of combustible gases and pyrolytic vapours from both gasification reactions. It combusts when mixed with oxygen and ignited. In an **'open fire'** all the stages of gasification and combustion occur simultaneously at the same place and with no or little control over the processes.

[4] The ability of pyrolytic gasifiers to produce charcoal ("biochar") as a by-product of heat generation is gaining increased interest, as the debate on climate change has sparked the search for global carbon-negative bio-energy systems. If the created char is not used for heat production and the carbon converted to carbon dioxide, but used as soil amendment, it can both enhance soil fertility and fix the carbon in the soil. More on biochar can be found in the Annex.

[5] The old 'gas-works' piped 'town-gas' generated from biomass for miles to be combusted in street lights and remote burners in households for cooking. This required cooling and cleaning of the gases.

1.2 Practical Applications of biomass gasifiers

Application	***Scale of operation***
Substitution of charcoal or firewood by other biomass residues as fuel for cooking, space heating, process heat provision and lighting	*Households, institutions, cottage industry*
Char(coal) production for further processing into cooking fuel (briquettes), filter material or biochar application	*Any from households to large industrial plants*
Power generation[6]	*Medium – industrial plant*
Production of chemicals and fertilizers	*Industrial Plants*
Production of biomass-to-liquid fuels for transportation	*Industrial Plants*
Waste management (agro-industrial, hospital waste, municipal etc.)	*Depending on toxicity and danger of waste*

1.3 Distinguishing features of biomass gasifiers

There are many basic designs of biomass gasifiers, so how to tell them apart? The main differences between the systems concern the following distinguishing points:

- The location of the combusting gas-burner (close-coupled or separated from the gas-generation)
- The flow direction (up-draft/counterflow, down-draft/co-flow, cross-draft, etc.)
- The gas pressure of operation (atmospheric, suction and pressurized)
- The gasifiying agent (natural air, oxygen, steam)
- The method of creating draft and vapour flow speed of the gasifying agent (natural draft, fan assisted, draft-inducted)
- The method of gas/fuel contact (fixed bed, fluidized bed, entrained flow etc.)
- The feedstock (reasonably dry biomass, naturally occurring or segmented or agglomerated to appropriate sizes, as in maize cobs, wood chips, and pellets from sawdust)
- The ash form (dry ash, slagging/clinkers or melting ash at higher temperatures)
- The heat for the gasification (authothermal= direct gasifiers with a flaming pyrolysis process, or allothermal= indirect gasifiers, where the fuel is only heated up but not burnt with a flame to provide the heat, as in retorts.)
- The scale of the operation and the size of the device (micro, small-medium, large industrial application systems)
- The gas cooling and cleaning process (relevant for major industrial processes, where gases are transported and/or stored before subsequent use)
- The immediate purpose (heat or electricity generation through product gas, waste management of municipal waste, etc.)

Not all of these features are relevant for the application of biomass gasification for cooking purposes. Thus the next section is about the properties and features needed to make gasifiers suitable for cooking. It is sometimes useful to think of the gasifiers as the liberator of heat energy, that comes from various original fuels, and goes to any of a wide variety of desired applications that include many types of cooking.

[6] Other publications deal with the options for off-grid decentralised electricity generation by diverting the wood-gas to the electricity generator unit (normally an internal combustion engine). Though outside the focus of this book, it is necessary to provide a warning that utmost care is needed to ensure wood-gas is properly cleaned before being supplied to the electricity generator, or the system will not run properly.

1.4 Micro-gasifiers for cooking applications

Because gasifiers require high temperatures and heat transfer into cold biomass, making them small is difficult. As such, it has been a challenge to make biomass gasification suitable for domestic cooking! Commercially viable gasifiers have long been understood and used in large industry and even in transportation: over one million vehicles were fueled by biomass (mainly charcoal) gasification during WWII, when liquid fuel was hard to come by. But there was nothing similar for small applications such as a household stove. The most common and best known industrial applications are downdraft gasifiers, where the gases are generated and removed from the reactor (gas-generator), then combusted in a remote burner, e.g. in an internal combustion engine or in a street-lamp supplied by town gas.

Fundamentally, the challenge in cooking is a question of scale; how to gain control over the pyrolysis, gasification and combustion in a small enough (vertical) space to be used by individual households.

Micro-gasification refers to gasifiers small enough in size to fit under a cooking pot at a convenient height. It was conceptualised as a top-lit up-draft (abbreviated TLUD) process in 1985 and developed to laboratory prototype stages by Dr. Thomas B. Reed in the USA. Independently in the 1990s the Norwegian Paal Wendelbo developed stoves based on the same TLUD principle in refugee camps in Uganda. TLUD devices have always been intended as biomass-burning cook-stoves and there were some early Do-It-Yourself backpacker efforts, but it was only in 2003 that the first micro-gasifier was commercially made available by Dr. Thomas B. Reed when he presented the Woodgas Campstove to the outdoor camping niche market in the USA.[7]

Commercially available models are still scarce, though there is growing interest. Module 2 of this book attempts to give an overview on the current ‘state of the art’ of gasifiers appropriate for domestic use.

1.4.1 Comparative advantages of micro-gasfiers for cooking

Small-scale **micro-gasifiers** offer good opportunities for the use in cook-stove applications and/or for domestic heating, because they can

- Cleanly burn the woodgas in mainly smoke-free combustion (unlike conventional burning of solid fuel)
- Provide a steady hot flame shortly after ignition (no waiting, as with charcoal)
- Have high fuel-efficiency due to complete combustion of the fuel (little smoke)
- Be operated batch-fed over extended periods without attention (no tending of fire)
- Utilise a wide variety of solid biomass fuels, even inexpensive often discarded small biomass residues, that other stoves cannot easily handle (no stick-wood)
- Give the user the freedom to decide individually when to use the device, as biomass fuel is often locally available, within reach of most people. It can be collected or bought directly by the stove user. Hence it makes biomass-gasifiers ‘ready-to-use’ options, independent from external factors beyond the control of the user that determine the availability of other energy sources like electricity, fossil fuel supply, or sunlight for solar cooking.

[7] More details in Module 2 and on http://www.woodgas.com/, where the stove can also be ordered.

1.4.2 Design features making micro-gasifiers suitable for cooking

To make micro-gasifiers widely usable for **practical and cost reasons** they need to

- Operate at atmospheric pressure (no pressurized storage of fuel or air needed, but could include very small, economical fans or blowers in some situations.)
- Use ambient air as the gasifying agent (available at no cost)
- Use solid, dry biomass as a fuel, if possible inexpensive biomass residues
- Use a fixed fuel bed (the fuel basically does not need to be moved during operation)
- Produce a 'dry' residue, either char or ash, to facilitate removal (not slagging and clogging the stove)

Common properties of micro-gasifiers suitable to **heat a cooking pot placed on top**:

- **Close-coupled combustion** of the produced gases: they are combusted directly above the gas generating zone and the fuel-bed while still hot. The heat can directly reach a cooking pot. No cooling, scrubbing and piping of the gases needed.
- **Top-lit**: Most micro-gasifiers for cooking use are lit at the top of the fuel-bed. This is an easy way to keep the heat close under the cooking pot. Many micro-gasifiers work with a batch-load of fuel, meaning the fuel container is filled once and then lit at the top.
- **Up-draft:** One main differentiating feature of micro-gasifiers is the flow of the gases in relation to the progression of the pyrolysis front. The air and the combustible gases flow upwards, while the flaming pyrolysis front moves down-ward. Up-draft design is one easy option for cooking purposes, because hot gases naturally rise if they are lighter than cold ambient air. This creates a natural draft through the fuel-bed, facilitating the oxygen supply to the pyrolysis zone. Depending on the fuel type and the density of the fuel bed, fans can be added to force air through the fuel-bed for an appropriate flow of oxygen. The use of fans or small blowers augments the natural draft, and is often called "forced convection".
- Most micro-gasifiers are **autothermal**, meaning the fuel is directly pyrolysed with a flaming pyrolysis. Yet there are hybrid forms specifically designed for biochar-production with two separated fuel chambers: the fuel in the inner combustion chamber features flaming pyrolysis or conventional open fire, and the heat generated in this process heats up the fuel in the surrounding outer container until it starts the allothermal pyrolysis without having been in touch with a flame. [8]

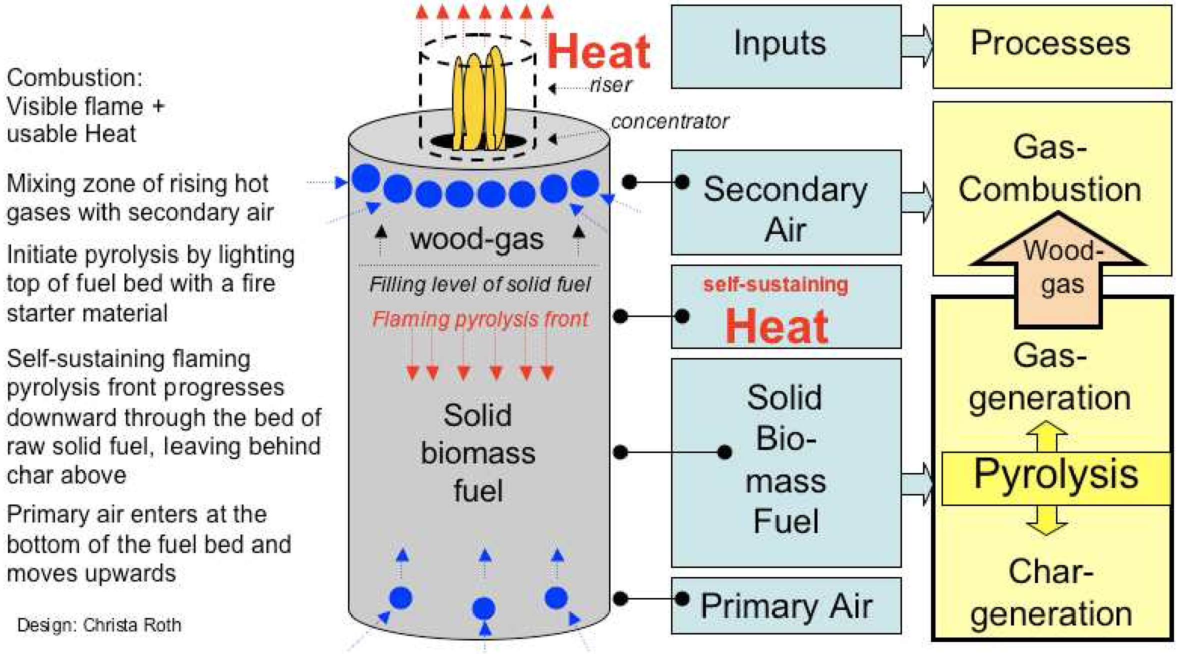
1.5 Example: the Top-lit Up-draft TLUD gasifiers

The first known micro-gasifiers from Tom Reed and Paal Wendelbo respectively are pyrolytic TLUDs that can create char with a flaming pyrolysis and a restricted supply of primary air. The TLUD design principle is 'open source', in the public domain and not protected by copyrights or patents. TLUD construction plans are publicly available on the Internet or from some designers. Thus, TLUDs are easy to adapt and replicate in individual projects without patent infringement or copyright issues. Therefore the TLUD-principle will be explained here in detail:

Figure 4 depicts the basic design features of a pyrolytic Top-Lit Up-Draft micro-gasifier, derived from the principles of biomass gasification explained earlier.

[8] The Anila Stove is an example presented in detail in Module 2.

Figure 4: Basic design features of a pyrolytic Top-Lit Up-draft microgasifier



The simplest TLUD can be a single tin-can with separate entry holes for primary and secondary air as combustion unit, like shown on the cover photo[9]. Thorough mixing of the gaseous fuel with the oxygen provided by the secondary air to ensure optimal combustion can be enhanced with a concentrator disk or forced air. A riser above the combustion zone can increase draft and further enhance thorough mixing of gas and oxygen.

In TLUD gasifiers, the fuel does not move except by shrinkage in volume when pyrolyzed. Two things move:
1) a hot “flaming pyrolysis front” moves downward through the mass of solid raw fuel, converting the biomass to char.
2) The created gases travel upward towards the combustion zone, while the char remains behind above the pyrolysis front.

The name “Top-Lit UpDraft” denotes two key characteristics of these types of micro-gasifiers: The fire is ignited at the top of the column of biomass fuel and the primary combustion air is coming upward from the bottom through the column of fuel. The limited amount of primary combustion air allows only a partial combustion of the created wood-gas, just enough to provide the heat required to keep the pyrolysis reactions going. Since the rate of heat generation is determined by the amount of available oxygen, the progression of the pyrolysis front is controllable by regulating the primary airflow. Additionally, increased air-flow (with a fan or sufficient riser/chimney) will result not only in faster progression of the flaming pyrolysis front down the column of biomass, but also in higher temperatures in the pyrolysis zone. This will impact the characteristics of the created char, which is important if it is intended to be used as biochar.

In a typical TLUD, the pyrolysis front moves downward 5 to 20 mm per minute, depending on the nature of the fuel and the amount of primary air.

[9] The ‘iCan’ described in Module 2 represents one such example

Above the pyrolysis front, the created char accumulates, prevented from combustion because of the lack of oxygen. The remaining hot inert gases (mainly nitrogen) sweep the created pyrolytic gases and water vapor to the secondary combustion zone. There, additional air is provided and the pyrolytic gases are burnt in a separate and very clean flame. The pyrolytic gases are tarry, long-chain hydrocarbons that, if not burned, form a thick smoke.

Unique among the gasifiers, TLUDs operate in an oxic batch mode and do virtually all of the biomass pyrolysis or wood-gasification before doing appreciable char-gasification. The transition between the two phases is quite distinct, changing from a characteristic yellow-orange flame (from burning tarry gases) to a smaller bluish flame that denotes the burning of carbon monoxide.

A multitude of videos visualising TLUD microgasifers in action are found on Youtube. The following link http://www.youtube.com/watch?v=SaeanoWZE7E provides a good overview of a TLUD and its operation by Paul Anderson.

1.6 Performance of micro-gasifiers for cooking

The following paragraphs look into the factors that influence the performance of micro-gasifiers for cooking. Later some results concerning fuel use and emissions are presented.

1.6.1 Performance factors influenced by design or user

If we want to fine tune the performance of a top-lit micro-gasifier and adapt it to local conditions, we need to know the factors and parameters that dictate successful operation in a given application. Some of them need to be addressed by the stove-designer at the time of designing the stove, and others are determined by the user when operating the stove.

Gasifier power and heat-output

The power output of a gasifier unit is mostly determined by the amount of gaseous fuel or pyrolytic vapors produced at any one time from the solid fuel.
The burn rate, at which solid fuel is pyrolysed to create the combustible vapors, largely depends on

- the peak **temperature** in the fuel container: higher temperatures in the gas-generator will create more gases per time unit because of a slightly greater percentage of the volatile matter is converted into gases. Also, the pyrolysis zone travels more rapidly down the fuel column.
- the available **primary air** strongly influences heat in the reactor and, therefore, the speed and intensity of the pyrolysis processes: Less primary air = less wood-gas created = less conversion of biomass into char.
- the **diameter of the fuel container**, which determines directly the size of the surface of the pyrolysis front that travels through the fuel: a smaller diameter will have less surface area, so that the pyrolysis front can ‘convert’ less solid fuel per time unit into gas than occurs in a wider container
- the **type and the density of the fuel** and how much primary air can go through the fuel for the pyrolysis to take place: chunky, fluffy fuel will burn faster than compact densified fuel with less air gaps, e.g. pellets.

Regulating firepower by design features

Elevating the temperature at the combustion zone

The combustion reactions can be enhanced at higher temperatures. This can be achieved by protecting the gasifier from cooling especially by wind, **by insulating the combustion chamber** and/or by **preheating the secondary air** before entering the combustion zone. Many gasifier models therefore combine the preheating with the insulation by adding another 'sleeve' around the fuel container: the secondary air enters at the bottom of the gap created between the sleeve and the original fuel container. The entering secondary air captures the heat radiating from the hot fuel container while rising all along the sides until entering as heated secondary air at the top into the fuel container. This has various benefits: it acts as insulation (it prevents the heat from radiating directly off the surface of the gasifier) and recycles part of the radiated heat, boosting combustion efficiency and overall system efficiency.

Draft speed and airflow

Natural draft (ND) vs. forced convection (FA = Forced Air or Fan Assisted)

All options for providing adequate primary air depend on fuel size. With chunky fuels, natural draft can work, whereas with small particle size fuels, air needs to be forced through the fuel bed, which is easiest to provide with a small fan or blower. Sources of electrical power can be the grid, small generators without storage (like solar PV-panels or thermo-electric generators) or storage devices (like discardable batteries or hand cranked rechargeable accumulators).

Some gasifiers with the provision of forced air can regulate the fan speed and thus the air supply. Tom Reed's Woodgas stove provides two sockets for the battery pack for a choice between low or high fan speeds. Other applications have a turning knob that can regulate the power input from the electricity source. Most systems cannot regulate primary and secondary air separately.

The separate control of primary and secondary air offers further options to adjust the performance of the microgasifier during operation.

With more primary air available, the rate of the pyrolitic reactions can be increased. This will lead to an increased 'burn rate' and the generation of larger amounts of wood-gas. If the secondary air supply is not sufficient , a portion of the created wood-gas will not be combusted and unburned gases will leave the gasifier. This situation not only wastes fuel, but also is likely to create excessive smoke.

If the secondary air is increased at the same time as the primary air, the increased amount of wood-gas can be entirely combusted, which will increase the power output of the stove. An abrupt increase of secondary air may blow out the flame in the combustion zone, which will cause all the wood-gas to leave the combustion zone unignited and unburned. This would generate a lot of smoke until the secondary combustion is reignited.

Diameter of the fuel container

If constant high power is needed, a fuel container with a greater surface area is advisable. For simmering where less power is needed, a smaller diameter has advantages. One way to 'regulate' power output is to have different sizes of fuel containers for different tasks. This requires certain skill by the users and practice to match the cooking requirements with the heat production pattern of the variable fuel canisters.

With constant fuel and air supply, the AREA of the fuel container determines the **heat-output** of the gasifier. More experience and data needs to be gathered on how to regulate fire-power or achieve a good turn-down ratio between high-power and low-power operation of a micro-gasifier.

Regulating the firepower by the user during operation

Primary air control

Primary air is probably the easiest parameter for the user to control to 'regulate' the power output during operation, especially if its movement through the fuel is facilitated by a fan. Even with natural draft systems, the primary air supply can be regulated by opening or restricting primary air entry holes.

Care must be taken that secondary air supply is increased at a similar rate to the primary air, as more primary air means more combustible woodgas, which only translates into more power if enough oxygen is available to ensure the combustion of all the created woodgas. Otherwise too much primary air will cause some woodgas to leave the combustion zone unburned, wasting the fuel and resulting in smoke.

Duration of cooking time

In a batch-operated pyrolytic TLUD gasifier, fuel is usually not added during operation. The duration of the cooking time depends on the mass of fuel that can be placed in the fuel container. Mass is a function of density and volume of a substance. This means a low-density fuel in the same volume of the fuel container will have less mass to burn and will provide less total heat during the burning of the fuel stack.

Regulation by design features

With constant fuel and air supply, the **HEIGHT** of the fuel container determines the **duration of burn-time** of a batch-fed TLUD micro-gasifier.

The cooking time can be extended, when a sequence of fuel containers is used, with minor disruption of the cooking cycle as the container with the 'spent' fuel gets exchanged and replaced by a container with fresh fuel, already lit at the top before inserting it in the stove.

Regulation through the user

Fuel properties

High-density fuels have a higher energy value than low-density fuels. For the same rate of primary air, the high-mass fuel will burn longer and give more energy, as more solid fuel can be converted to woodgas. One can fit either 80 g low-density rice husks or 250 g of dry wood chips or over 500 g densified wood pellets in a fuel container with a volume of 1 litre.

Other consequences linked to fuel properties:

- Fuel species and their energy content: In general, fuels with higher energy values result in better stove operation and cleaner combustion.
- Moisture content: any moisture content exceeding 20 % will reduce efficiency of combustion. Fuel should therefore be dry, even if separate drying before use is necessary.
- Quality of fuel preparation:
    - Size and form: chunky fuels that allow for some natural draft airflow through the fuel bed give better results. Particle sizes below 1 mm (like fine sawdust or rice husks) are likely to need forced air to ensure sufficient draft.
    - Size distribution: fairly uniform particle size will result in more predictable behaviour of the pyrolysis front. This is why pellets or small briquettes give better results than do fuels with significant variations in dimensions.

1.6.2 Environmentally influenced performance factors

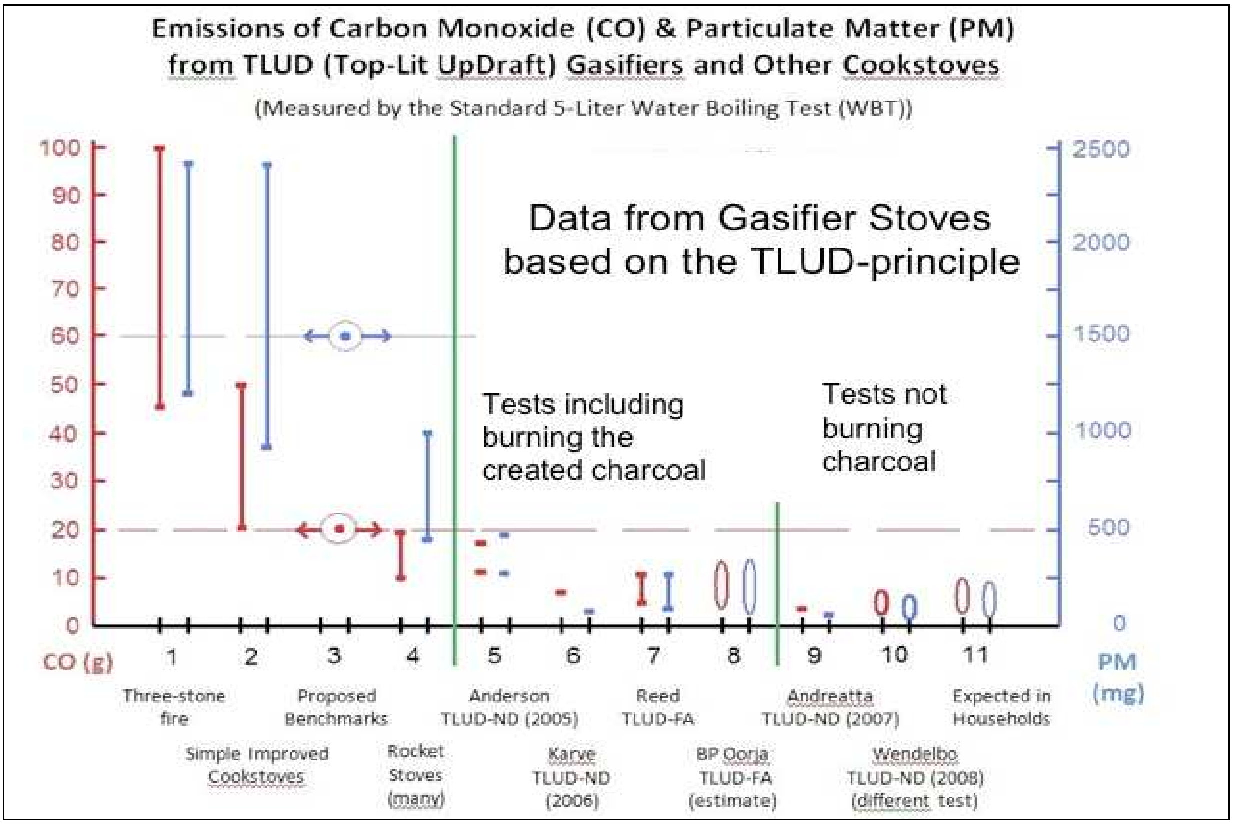
The major **external** factors influencing the performance of gasifiers are related to the environment and mostly out of reach for the user to influence.

- Location: wind is never favourable because it increases cooling effects. If wind enters into the combustion zone from above, there is a risk that it extinguishes the gas-burning flame and the woodgas can no longer be combusted until the flame is relit. The best is to use a gasifier in a well-ventilated location sheltered from the wind.
- Altitude: with lower atmospheric pressure at high altitudes (such as above 1500 meters), draft enhancing measures like an additional riser for increased natural draft or forced convection with a fan might be needed.
- Ambient Temperature: low temperatures have a negative influence on the speed of chemical reactions and the overall energy yield. Higher temperatures favour the completeness of combustion.
- Humidity: very high air humidity may negatively influence the performance.

For any gasifier to operate without problems within all these variables, the design must be able to handle them all in the very worst situation. Design adaptations might be necessary to compensate for adverse influences on performance.
More data and user experience needs to be gathered and documented on this topic to better understand the various effects. This calls for more field trials to generate more user feedback, so that applications can be better adapted to the multitude of needs of the various users.

1.6.3 Performance results

Micro-gasifier cook-stoves are currently the cleanest-burning stove option for solid biomass fuels. They feature the lowest emissions, as shown in the graph below which was compiled by Paul Anderson in 2009, based on then available results. A clearer printing, additional comments, and updates are available on the Internet at:
www.bioenergylists.org/andersontludcopm



Graph Compiled by P. Anderson (2009), Legend: FA= fan assisted, ND=natural draft

CO emissions are shown in red, PM in blue: vertical lines indicate ranges of measured data.

Source data from Aprovecho Research Centre (Comparing Cook Stoves), other tests by the indicated persons and own estimates. All gasifiers listed are top-lit-up-draft versions.

CO emissions were, unsurprisingly, lower in the tests when the charcoal was saved and not burned. They are the devices that stay well below the proposed benchmarks of 20 g CO and 1500 mg PM for the 5-l-WBT.

Comparable data on fuel consumption are still scarce, because few gasifier stoves have been tested according to comparable protocols. A challenge is that the currently recognised water-boiling-test is not well suited for batch-fed stoves. So the test results are not yet easy to compare with continuously fed stoves where cooking times can be easily extended to attain the boiling plus the subsequent simmering time of 45 minutes to complete the test. Anecdotal test results from Stove Camp 2009 showed, that the PekoPe, as an example for a TLUD, was the cleanest burning of all stoves while still having a low fuel consumption: with 768 g of wood pellets for the 5 liter water-boiling test it stayed well below the currently proposed benchmark of 850 g.

For details see http://www.bioenergylists.org/stove-camp-2009 and the report on http://www.bioenergylists.org/files/Stove%20Camp%20Final%20Report_8.11.09.pdf

Please note that the results for the other TLUD figuring in the report are not representative: experiments on air control were done during the 'test', as this was the first time this stove was ever tested under an emissions hood. Furthermore the tests were not repeated 3 times to be statistically sound. More data will hopefully soon be generated and shared, as many more TLUD-tests will be done.

1.7 Summary: biomass gasification in a nutshell

Solid biomass does not combust directly. **'Biomass Gasification'** is the broad term used for the **conversion of a solid biomass into wood-gas**. The process of combustion of solid biomass goes in stages: Wood turns to char, and subsequently, char turns to ash. Wood-gas, the mixture of combustible gases and pyrolytic vapours, is easily combusted when mixed with oxygen and ignited.

In an **'open fire'** all the stages of gasification and combustion occur simultaneously and with no or little control over the individual combustion processes.
The deliberate separation of the processes is the principle in biomass gasifiers.

A gasifier is a device where the gas-creation is controllably separate in location and time from the gas-burner where the combustion takes place. Micro-gasifiers are small devices suitable for cooking purposes, generally small enough to fit directly under a cookpot. The following table summarises some strengths, weaknesses, risks and opportunities of using micro-gasifier burner-units in cook-stoves:

Strengths: • Clean and complete burning of a broad variety of solid biomass • Currently lowest emissions of natural draft cook-stoves • High fuel efficiency due to complete combustion • Can use a wide range of local biomass including residues that can otherwise not be burned cleanly in other stoves • Less tending of fire with batch-loading • Ready for use immediately after lighting	Weaknesses: • Regulation of firepower can be difficult. • Difficulties to extinguish gas-generation at the end of the cooking process before all fuel is consumed • Inflexibility of cooking times with batch-feeding device that cannot be refueled during operation • Require fire-starting material to initiate pyrolysis in the gas-generator
Opportunities: • Gasifier units can be attached to existing stove structures to broaden the range of usable fuels, giving users the choice to use what is available at the moment • Can create charcoal as by-product of cooking • Enable carbon-negative cooking if char is saved and used as biochar	Risks: • If the flame of the combustion unit extinguishes and the gas-generator keeps on producing woodgas, thick smoke leaves the unit unburned. How people learn to avoid this risk needs to be assessed, and to see how different this is from the same phenomenon in a regular smoky smoldering open fire without flame...

Module 2

Applications of biomass micro-gasifiers in cook-stoves

A display of various micro-gasifiers usable for cooking

Table of content Module 2:

This module gives an insight on existing and potential applications of micro-gasifier burner units in cook-stoves. Please remember, that a burner unit is not yet a 'cook-stove'. It is only the heat-generating core element of an appliance that can be used for cooking.
There are some basic principles for stove designs that can be adapted to a variety of different user needs and fuel situations all over the world.
Many leading personalities in the 'stove development world' agree that as a consequence, these applications have to look different too:

There is not one cook-stove-solution, there are many, depending on their use[10]
A single cook-stove design would be bad genetics[11]
One size fits some (not all). It is important to first identify groupings of users with similar cooking preferences, fuel, availability of electricity, etc., and to ...define a "cook stove user space". [12]

Micro-gasifier burner units are fuel-flexible heat generators and offer a wide variety of clean-burning fuel efficient applications to complement or substitute existing cook-stove-solutions for 'conventional' wood fuels (such as 'stick' firewood) or charcoal.

In the following section existing and potential micro-gasifier applications are presented by categories according to their relevance for a project:

2.1. Factory-finished gasifier stoves commercially available from a known address
  2.1.1. Cook-stoves suitable for daily domestic cooking
    a) For chunky dry biomass fuels
    b) For rice husk fuel
  2.1.2 Campstoves to start experimenting with biomass gasification

2.2. Prototypes with certain field testing and potential for local adaptation and production

2.3. 'Tincanium' and low-cost prototypes to demonstrate the principle and create awareness

2.4. Other inspiring concepts with potential to develop further for specific applications

[10] Dean Still in http://www.charcoalproject.org/2010/06/to-achieve-cook-stove-scale-we-need-standards/
[11] Nathaniel Mulcahy from WorldStove at the ETHOS conference 2009 in Kirkland, Washington State
[12] Steven Garrett in the report to the US State Department on Next Generation Cook-stoves in November 2009, document under http://www.pciaonline.org/files/Cook-stoveResearchRoadMap.pdf

Preliminary notes to keep in mind

- 'Hardware' alone is not enough to start disseminating a new technology. The 'software' for the hardware to work is needed as well: the operation of a micro-gasifier requires skills, like any other new technology. And skills have to be acquired through training, they don't come naturally.
  In that regard, a micro-gasifier is like a bicycle: the buying of the hardware doesn't make somebody a good bicycle-rider. It takes some time until the technology is mastered by the user. During the learning curve, people will fall off their bicycles, get a bit bruised, but continue to learn, until they feel comfortable and eventually wonder how they got along before they knew how to ride a bike.
  With micro-gasifiers, the learning and adaptation curve is similar. The challenge is to learn how to master even difficult situations. People have done that and will do that in future. With expert guidance and exchanges of experience, learning a new technology is even easier and faster. But this needs to be considered as a 'make-or-break' factor for the acceptance of a technology.

- User training is of utmost importance for any sizeable introduction of micro-gasifiers. It is best done by skilled knowledge-bearers who can provide the initial training of trainers in a new area. Thereafter, the local people who have learned the skills themselves are the best resource to disseminate the necessary skills.

- Many micro-gasifiers are only a 'burner unit'. They become part of a 'cook stove application' when combined with additional features that allow the burner unit to be effectively used for cooking. This usually involves adding any structure that is able to hold the pot above the flames, like a pot stand, or building the micro-gasifier into the current local cooking devices of appliances

- To make the application become more energy efficient, there are some additional features to route the hot combustion products around the pot and enhance the effective transfer of the heat into the pot (like a pot skirt or wind shield). As with any cook-stove application, the fuel, stove, pot and the human factor (user, designer, manufacturer) should be regarded as related elements in one single system.[13]

- If char should be saved from pyrolytic gasifiers (char-makers), the stove assembly must allow easy dumping of the char from the hot container in a convenient and safe way. Four key features enhance this:

  - The fuel container should have a **handle** to turn it over and dump out the char or instead a mechanism to cut off primary and secondary air supply to quench the char while still inside the container. Wooden handles stay cooler than metal ones.
  - **Light-weight robust** structures assist safe and easy dumping of the char.
  - A **fuel container detached** from the stove assembly by an independent pot support (a tripod or a supported grate) helps char-removal without moving the pot.
  - If it is a model with forced air, the **ventilator/fan should be detached** from the fuel container, so that no cables obstruct the handling of the hot char container.

- The stove structure can be adapted to the local cooking preferences concerning height, pot or pan size and shape, stability requirements etc. and/or the ease of saving char, while the burner unit can be similar in different parts of the world.

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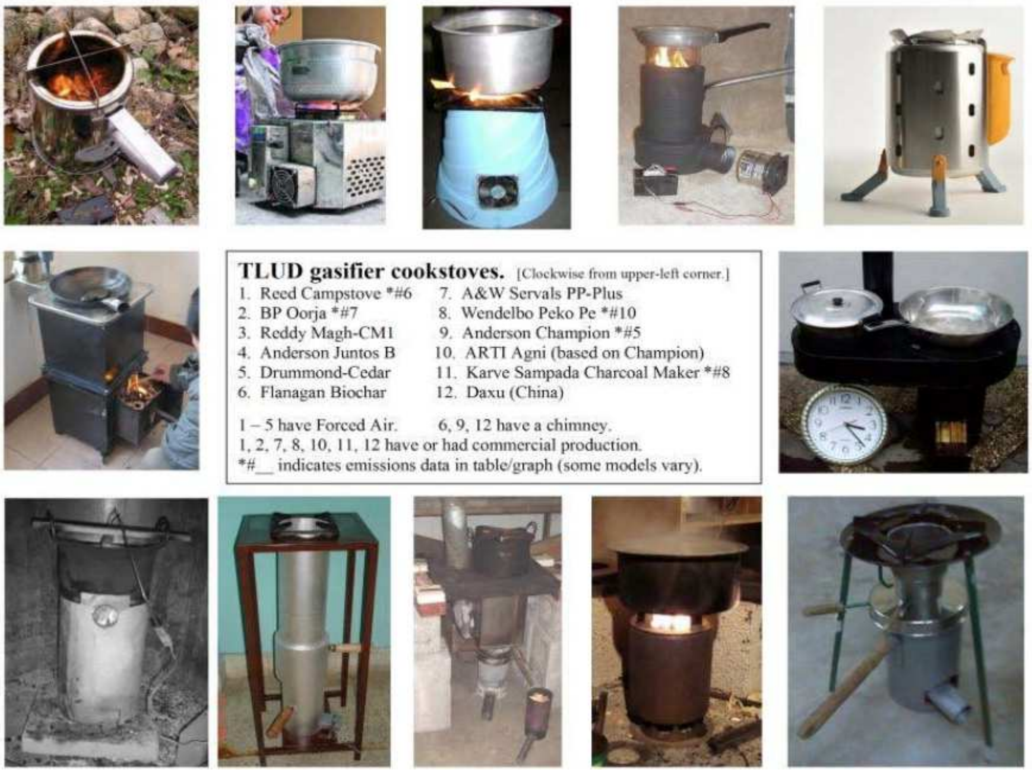
[13] According to http://www.pciaonline.org/files/Cook-stoveResearchRoadMap.pdf the improvement in cook stove energy efficiency (i.e. both combustion efficiency and heat transfer efficiency)

- Some burner units can be fitted into existing stove structures, broadening the options of fuel and enable the choice of fuel type according to what is available at the moment.
- Some gasifier stoves can easily be fitted with a heat resistant glass of a paraffin lamp so that they can provide light during operation. This is a good argument when users resist to change from the open fire to an enclosed fire chamber because of the loss of light to brighten the cooking space.
- Not enough data are yet available to quantify emissions and fuel consumption of different micro-gasifier models. Some tests like the 5-litre Water-boiling tests to determine fuel consumption are not applicable to certain batch-feed micro-gasifiers. New testing protocols are being developed to suit micro-gasifiers.
- There is no single answer to the numerous needs of the world. Some stoves can do one task really well but are not suitable for other tasks. The solution is in a variety of custom-made or purpose-designed applications. This variety of designs is imperative and there is no ‘superior’ or ‘best’ design. There is no ‘one-size-fits-all’ design, but always a ‘one-size-fits-some’. Some designs are more appropriate in certain scenarios than others. Therefore we need to know the uses of the different designs and how to make choices in each set of conditions.
- Some features are valued differently by different users: batch-feeding of a stove is seen by some as a big advantage, as they don’t need to tend to the fire every 2-5 minutes. Others consider this a disadvantage, as the entire container needs to be exchanged and reloaded at the end of the burn.
- Some micro-gasifiers have been optimized for specific fuels, making them excellent in some situations but inappropriate in other places.
- Micro-gasifiers are not always an appropriate solution for a household stove, depending on fuel access. It does not make much sense to chop up big chunks of wood with a machete or an axe, so that the fuel becomes small enough for the use in a micro-gasifier. Where access to stick-shaped wood is still reasonable, appropriate stoves for this fuel-type should be encouraged. Micro-gasifiers should never been seen as a threat to existing systems, but always as a complementing element, as they offer the opportunity to use available and often discarded biomass as a fuel, that other stoves cannot burn cleanly. There is more information on fuel and fuel preparation in Chapter 3.
- Some developers (Belonio, Reddy, Karve, Anderson, Donnelly, and others) offer many more designs and models than shown here. Those designs might be important in niche situations. Links are provided for further reading.

There are also different concepts of producing stoves, ranging from entirely local production based on scrap or new materials, to partially pre-manufactured and locally assembled production or entirely ‘foreign’ manufactured imported technologies. Each concept has its own advantages and disadvantages. On a case-by-case basis, the situation needs to be evaluated for the most feasible option. Sometimes a sequential approach is more effective, starting with one type to lead to another in the long run.

Entirely locally manufactured out of		Pre-manufactured parts, local assembly	Entirely 'foreign' manufactured
scrap or tincans	new materials		
			
Lucia stove made in Haiti February 2010 (Design: Nathaniel Mulcahy, WorldStove) http://tweetphoto.com/13062972	Champion Stove manufactured by Servals Group in Chennai, India (Design: Paul Anderson, photo during testing at Aprovecho Institute)	Lucia stove from Italy, assembled from flat-packs in Haiti (Design: Worldstove) http://tweetphoto.com/13064374	Woodgas Camp-stove (Design: Tom Reed) as a publicly available example from http://www.woodgas.com/bookSTOVE.htm

While there are many designs for micro-gasifiers, the basic TLUD technology is "open source" (not protected by patents or copyrights) and there are literally hundreds of variations and improvements yet to be discovered. All people are welcome (and are encouraged) to participate. There is quite a variety of cook-stoves around the world that are based on this open-source, public domain Top-Lit UpDraft micro-gasifier principles, others will be presented in the manual. Paul Anderson has compiled a list of TLUDs as per March 2009 for the PCIA meeting in Kampala:



Conclusion: any cook-stove solution must

- satisfy the cook (convenience of use, provide appropriate heat suitable for local dishes, culturally acceptable, time need to tend the fire, etc)
- use the locally available fuels (without tedious effort for fuel preparation)
- be affordable (local manufacture based on locally available materials, or imported at a reasonable cost)
- satisfy other needs of the user (like the production of biochar, provision of light, etc.)

Stoves must adapt to people and traditional cooking habits, not the other way round![14]

A PekoPe-design by Paal Wendelbo, locally manufactured in Malawi

[14] Quote from a WorldStove-presentation in 2010

2.1 Factory-finished gasifier stoves commercially available

This section lists micro-gasifier cook-stoves that are factory-finished from a known address, have reached dissemination beyond the prototyping stage and that are currently in production. It provides information on their current dissemination, user feedback etc. as far as information could be obtained. Most of the currently known commercial production of micro-gasifiers is in South-East Asia, more specifically in India and China, with Indonesia and Vietnam starting up.
Please note that the following listing is by no means exhaustive and comprises only those micro-gasifiers known to the authors at the time of compilation of this manual. If there are any other devices that should be included, please forward the information to the authors for future inclusion. This is 'work-in-progress' and the list of commercially available devices will hopefully grow fast in the near future.

<table>
<tr><td colspan="3">Factory-finished gasifier stoves currently commercially available
(in brackets country of current production, sorted by alphabetical order of country of production)</td></tr>
<tr><td colspan="2">2.1.1 Suitable for daily domestic cooking</td><td>2.1.2 Campstoves</td></tr>
<tr><td>With considerable known dissemination (> 5,000 units) in communities</td><td>Without considerable known community use or dissemination just starting</td><td>Targeted at affluent niche market for occasional use, not designed for daily use</td></tr>
<tr><td colspan="2">a) For chunky biomass</td><td rowspan="4">Tom Reed Woodgas Campstove (USA)
Beaner Backpacker Stove (Italy)</td></tr>
<tr><td>Over 450,000 units:
Oorja (India)

Over 25,000 units:
Daxu (China)</td><td>JXQ-10 (China)
Champion (India)
Navagni (India)
Philips (India)
Sampada (India)
Lucia (Italy)
VeSTO (Swaziland)</td></tr>
<tr><td colspan="2">b) Mainly for rice husks</td></tr>
<tr><td>Belonio (Philippines)
Mayon (Philippines)</td><td>Minang Jordanindo (Indonesia)
Paul Olivier (Vietnam)</td></tr>
</table>

2.1.1 Gasifier stoves suitable for daily domestic cooking

This section comprises gasifier stoves suitable for the day-to-day use as cooking device. It is subdivided by the type of biomass fuel that can be used, as it different fuel properties required different design features: 'chunky dry biomass' (whereby 'chunky' is broadly defined by 'an average particle size bigger than 5 mm') does perform well with natural draft, while 'rice husks' (the worldwide most widely available 'fine particle fuel') can best be gasified with forced convection.

a) Devices for chunky dry biomass fuels

The only gasifier stove that has been sold in really big numbers exceeding 450,000 units is the Oorja stove in India. It was developed by First Energy and the Indian Institute of Science in Bangalore with long-term experience on biomass gasification (http://www.iisc.ernet.in/).

Oorja (India)

Target area:	Maharashtra, Madhya Pradesh, Karnataka, Tamil Nadu. Only sold in India.	
Fuel type:	Pellets from agricult. residues	
Designed by:	Indian Institute of Science and First Energy	
Retail price: 3 models: (15 – 35 USD, June2010)	Oorja Eco 999 INR Oorja Plus 1,350 INR Oorja Super Plus 1,650 INR	
Numbers sold:	Over 450,000 by May 2010	
Start production:	2006	
Manufactured by:	First Energy Pvt. Ltd.	
Contact:	CEO Mr Mahesh Yagnaraman, maheshyagna@firstenergy.in	
Address:	Office No. B-101 to B-105, First Floor, B-Wing, Signet Corner, S.No-134, Baner, Pune - 411 045, India. Tel : 91-20-67210500	
Product. capacity:	Up to 300,000 stoves per annum, 30,000 tons of fuel p.a.	
Short Description:	Power level 2-3 kW, depending on fan speed. Burn rate 9-12 g/min. 450 g pellets give max. burning time of 75 minutes at low fan speed. Normal load of 600 g pellets (ca. 600 kg/m3) can last 55-65 min.	
Features:	Fan-assisted, rechargeable NiMH battery pack, fan speed controlled by regulator. Fan attached on bottom-side. Ceramic combustion chamber (100mm diameter, 130 mm high), bottom cast-iron grate	
Handling:	Batch-fed from top, top-lit. during operation only small quantities of fuel (< 20%) can be topped-up for extra 15 minutes of cooking time.	
Char-making:	No. Ash ca. 10%, char combustion gives useful 10 min heat at end.	
User feedback:	Fast, clean, no soot on utensils, no smoke. Oorja-Super new variant with flame control as well as Oorja-Plus can also bake chappatis, rotis, dosas and cakris (a popular type of maharashtra rotis).	
Accidents reported:	No stove-caused safety incidents reported recently. However, wrong usage in initial years had led to electric shocks and people being careless with high flames.	
Performance data:	Boiled 5 liters in 24 minutes with 190 g fuel, emitting 2,2 g of CO and 166 mg of PM[15] or 45 g pellets per liter of water to boil, no data on simmering phase. Emissions: CO 0,7-1 g/MJ, PM 0,75 g/MJ[16],	
Further information: http://www.youtube.com/watch?v=X2XOjT7V_qo http://www.bioenergylists.org/content/oorja-stove-bp-first-energy (source of photo above) http://www.pciaonline.org/first-energy-private-limited		
Comments: The stove was designed to use pellets from agricultural residues that are distributed by First Energy through their fuel distribution network. First Energy has taken over the business from BP in late 2009. Before that, not many data on sales, user feedback etc. were available. This will hopefully change now, as First Energy apparently makes serious attempts to focus on the user and adapt the stove according to users' preferences.		

[15] Source http://cgpl.iisc.ernet.in/site/Portals/0/Publications/Report2004-2008.pdf
[16] Source: CURRENT SCIENCE VOL. 98, NO. 5, p. 636 http://www.ias.ac.in/currsci/10mar2010/627.pdf

Daxu (China)

In China quite a variety of modern gasification systems using straw and other crop stalks seem to be developed. Most are more comprehensive downdraft systems that can be operated for 24 hours a day for water heating in combination with a radiator for space heating and remote table-top burners for cooking. Some even have sophisticated features like remote controls for gas ignition and knobs for power control, just like an LPG burner. It is not always apparent for a non-Chinese-speaker, who is a producer and who is a trader represented on the internet. Various websites refer to the same product. It is very interesting for areas with adequate purchasing power and cold climates with need for space heating.
The one Chinese TLUD is the Daxu Stove Series which apparently reached sales exceeding 25,000 units since 2006. It won the Ashden Awards for Sustainable Energy in 2007.

Target area:	Yangqing County, NW of Beijing	
Fuel type:	(Briquetted) crop residues like straw etc., any solid biomass	
Designed by:	Mr Pan Shijao	
Retail price:	In 2007 it was Y 1,000 (ca. 90 €), in some areas subsidized by government to Y 50-200	
Numbers sold:	Over 25,000 (by April 2007), current figures not known	
Start of production:	April 2005	
Manufactured by:	Beijing ShenZhou Daxu Bio-mass Energy Technology Company Ltd.	
Contact:	Zhu Yan, Assistant to GM zhuzhulinda@126.com,	http://www.szdxbj.cn/
Address:	Beijing Shenzhou Daxu Bio-energy Technology Company Ltd No. 6, 5th Floor, Beijing Technology Centre A48, Suzhou Street ,Haidan District, Beijing, China Phone +86-10-51051697, Mobile Ms Yan +86-1391091245	
Product. capacity:	Not known	
Short Description:	Width 340 mm, Length 340 mm, Height 780 mm, Weight not known, but heavy, not portable. Stove to be installed, with chimney. Can have added water and space heater features, assembly for one or two cooking pots.	
Features:	Burn rate 2 kg/hour	
Char-making:	Not fully known, probably burns to ash.	
User feedback:	Faster than coal, clean, less smoke, can make hot water, cheap to run on biomass briquettes	
Accidents reported:	None known.	
Performance data:	According to data found from comparative tests done by the Centre for Entrepreneurship in International Health and Development (CEIHD) it had the highest efficiencies of all stoves tested (41% with loose straw, 42% with straw briquettes).	
Further info: Product catalogue (Chinese): http://www.dxkj888.com/ArticleShow.asp?ArticleID=109. Case study and general info on http://www.ashdenawards.org/winners/daxu and http://www.bioenergylists.org/files/TLUD_Gasifier_in_Ashden_Award_for_Enterprise_2007-09-19.pdf, Video on http://www.youtube.com/watch?v=x65M9zX4gAo		
Other comments: According to a report on http://childrenofshambala.org/pdf/FR%2077%20-%20Fuel%20Efficient%20Stoves%20-%20Pilot%20Project.pdf, a group that wanted to do comparative testing of various stoves in China in 2009 had difficulties to obtain a stove from the factory. Once they explained that they were no competitors, stoves could be purchased. More details in the report.		

TN ORIENT JXQ-10 (China)

A downdraft stationary model with chimney is a system that is designed to burn straw and other biomass residues in a combination of a downdraft reactor and a remote table-top burner which seems to have similar properties like other gas-burners. Over 1,000 units have been sold in China so far. No field data or any user feedback is known, but it seems to be a technology worthy of a closer look for scenarios where it could fit. Probably only makes economic sense, if it is not used for cooking only, but where water heating and radiators for space heating are required regularly.

downdraft straw gasifier		 
Target area:	Export worldwide	
Fuel type:	Big variety of crop and forestry residues (straw, stalks, rice husks, nut shells, sawdust, woodchips)	
Designed by:	Company development of product range over past 7 years	
Retail price:	700 USD (FOB) for 1 unit, cheaper per container-load	
Numbers sold:	Over 1,000	
Start production:	In 2001	
Manufactured by:	Xuzhou Orient Industry Co. Ltd	
Contact:	renewable-energy01@orient-biofuel.com renewable-energy001@hotmail.com Skype: renewable-energy001	
Address:	Suite I, 17/F, Success Bld., Zhongshan South Rd. Xuzhou, Jiangsu, PLC Tel: 86-516-82029972, Fax: 86-516-82029977	
Short Description:	Downdraft gasifier system, gas piped to burner unit on a table-top through a gas-cleaning system to remove tars. Should be clean burning. For continuous use for 24 h/day for water and spcae heating. Gas output: 5-10m^3/h, Gas caloric value:4600-5200KJ/m^3 Gas stove power: 4.7—5.1KW Packing Dimension: 1150*650*1230mm, Weight: Net 190/Gross 240kg Quantity in one 20'-container: 34 Units, Delivery Time: 20-40 Days	
Features:	Fan grid-powered. Some models with electronic ignition, remote control	
Handling:	Claim that gas generation starts 2 minutes after lighting combustion unit. Gas needs to be lit separatedly, e.g. with a piece of newspaper or through electronic ignition. Ash removal (ca. half kilogram) every 5-7 days.	
Char-making:	Does not make char, burns to ash.	
Performance data:	Claim to boil 4,5 kg water in 8-12 minutes. No independent data found.	
Further info: http://www.orient-biofuel.com (source of photos above) http://orient-biofuel.en.alibaba.com/product/271032281-0/Small_Biomass_Gasifier.html		
Other comments: claims to have received 3 national chinese patents, not suitable for local production. Company invests into R&D for new next-generation products. In 2008 started production of bigger versions in the same range: JX 50, with gas output 50 m3/h at fuel use of 25-40kg/h: ca. 8,500 USD FOB, JX 100, with gas output 100 m3/h at fuel use of 50-60kg/h: ca. 10,500 USD FOB		

Champion TLUD (India)

The Champion –TLUD-ND (Natural Draft) by Servals is based on Paul Anderson's TLUD design that won the Award for cleanest burning stove at Aprovecho Stove Camp in 2005. Artisanal versions of this design are already in use in several countries, because they are easy and cheap to manufacture locally. This very reasonably priced assembly with two exchangeable fuel canisters and pot-stand from Chennai is ideal to test the suitability of the TLUD gasifier technology in a new area. Paul Anderson is ready to assist in any technology transfer to a new area. More information is given in the section on transferable and adaptable gasifier concepts.

Target area:	India, export upon request
Fuel type:	Any chunky dry solid biomass
Designed by:	Paul Anderson
Retail price:	1,700 Rupees (37 USD, 9/2010)
Numbers sold:	No current update available
Start of production:	2009
Manufactured by:	Servals Automation Pvt. Ltd
Contact:	Mr Parthasarathy Mukundan mukundanpa@gmail.com
Address:	Servals Automation Pvt. Ltd, Chennai - 600 032, Land line: + 91 44 64577181 / 82, Fax: + 91 44 45540339
Production capacity:	Can be scaled up upon demand
Short Description:	Batch-loading top-lit updraft stove. Package comprises set of two fuel canister/reactor units, one concentrator lid and a tri-pod pot-stand with pot-rests and a riser that can slide down and be coupled onto the concentrator lid. Containers, lid and coupler stainless steel.Width 200 mm, Height 280 mm, Weight of fuel container 1,6 kg Power output depending on primary air control 3-5 KW
Features:	Natural draft (manual regulator for primary air). External fan can be fitted. Fuel container with handles for easy dumping of char.
Handling:	Canister is filled with fuel, then one layer of fire-starter material on top. Lit at the top, then canister placed in the 'stove structure' under the pot (can be the tripod or any other structure, like the mud-stove depicted above). Burn time for one batch of fuel depending on type of fuel: over 75 minutes on 1000 g wood pellets or 45 minutes on 600 g wood chips. For extended cooking time the second unit can be filled and lit and the containers easily exchanged.
Char-making ability:	Yes. Easy to dump char because fuel container has a handle and is detached from the stove structure holding the pot. Char yields typically 20% in weight and 50% in volume of original fuel.
User feedback:	Easy exchange of fuel containers to extend cooking time.
Accidents reported:	None so far.
Performance data:	Emissions comparable to other tests of Champion stoves published. In a test at Aprovecho Research Institute Feb 2010, it boiled 5 l of water without a pot-lid from 11°C in 19 minutes with 384 g wood pellets or in 20 min with 368 g wood chips.
Further info: http://servalsgroup.blogspot.com/2009/05/tlud-gasifier-stoves-wood-stove-with.html Contains link to a video, where the details and operation of the stove are shown (source of 2nd photo)	
Other comments: in May 2010 the company won the SANKALP CLEAN ENERGY AWARD in India for the TLUD production http://www.sankalpforum.com/Sankalp/awards.php	

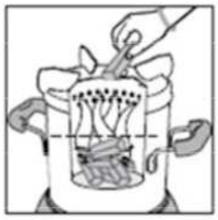
Navagni (India)

The Navagni stove is a model recently found via internet. No detailed information from people who had used the stove could be obtained so far. Company is difficult to contact via email or internet. Most interesting feature is the fire-stopper inserted as a cap in the combustion chamber to extinguish the fire. In the video it seems to work without causing smoke. It would be interesting to get independent performance data from the stove.

Target area:	Not known
Fuel type:	Any solid chunky dry biomass
Designed by:	No information obtained
Retail price:	No information obtained
Numbers sold:	No information obtained
Start of production:	Probably 2009
Manufactured by:	Qpre
Contact:	No information obtained
Address:	Qpre energy (india) private limited 129/5 6TH MAIN ROAD, 6TH PHASE, 1ST STAGE, WEST OF CHORD ROAD, MAHAGANAPATHI NAGAR, BANGALORE 560 044, INDIA PHONE +91 80 3200 2130, FAX +91 80 2660 5654 In USA: 17153 90th place north, Maple Grove, MN 55311 phone 612 554 1589, fax 763 494 3903
Production capacity:	No information obtained
Short Description:	Sturdy TLUD Gasifier with regulated natural draft, Estimated dimensions (from video): Width 400 mm, Length 600 mm, Height 400 mm, Weight 7 kg
Features:	Controllable natural-draft air system with rotary knob for power control. Fuel chamber can hold up to 1kg of various types of biomass. Stopper-cap to stop fire. Drying chamber to pre-dry fuel.
Handling:	Lit from the top. Can be operated in continuous feed mode, meaning fuel can be added from the top during cooking. 1 kg of biomass provides 45 minutes cooking time. Ash removal by tilting the stove and dump ash through a sliding door at the bottom of the stove.
Char-making ability:	Stove is too heavy and bulky to dump charcoal while still hot. So coals burn to ash.
User feedback:	No information obtained
Accidents reported:	No information obtained
Performance data:	No information obtained
Further info: http://www.navagni.com/tech/tbs.htm for the stove (source of photo above), http://www.qpre.com/energy/eproducts.html for the manufacturing company. Video: http://www.youtube.com/watch?v=YujomisovTQ&NR=1 Training video in english: http://www.youtube.com/watch?v=u2rlcJ8f4JI&feature=related	
Other comments:	

Philips Natural Draft Woodstove (India)

In 2005 Philipps started developing a woodstove with a thermo-electric generator recharging the batteries to power the fan. To avoid technical challenges with the power-supply, a natural draft model was developed. Apparently it has entered a phase of extensive field-testing in India, but not much information or user feedback was made available by Philips. The stove was also included in a comparative study in a refugee camp in Dadaab (Kenya) in 2009.

Target area:	India, no details known.	 
Fuel type:	Designed for small wood pieces 2x3x10 cm, but could probably use any chunky small dry biomass	
Designed by:	Philips	
Retail price:	No information	
Numbers sold:	No information	
Start of production:	First prototype 2006	
Manufactured by:	Philips Electronics India Limited	
Contact:	Vitika Banerjee, Marketing Manager Pawandeep Singh, Pawandeep.Singh@philips.com	
Address:	9th Floor; DLF 9-B; DLF Cyber City; DLF Phase 3; GURGAON - 122002; India, Tel: +91 124 4606000, Fax: +91 1244606666	
Production capacity:	No information	
Short Description:	Stainless steel. Power output adjustable from 1,5-3KW	
Features:	Regulating knob for air control. 5-year life span expected.	
Handling:	The stove is top-loading, needs small pieces of wood or other chunky biomass. Can be operated as bottom-lit continuous feed or top-lit batch fed stove. If used as top-lit batch fed stove, it should not be filled more than half. Can be refuelled during use.	
Char-making ability:	No, usually burns to ash, due to excess air supply	
User feedback:	Convenient in terms of speed, clean cooking, portable to allow cooking outside, saves cost by increased fuel efficiency and wood has lower cost than LPG and kerosene, Appealing design and attractive alternative to LPG and kerosene, Robust, promises a long life-time. Users in the test in Dadaab (link below) did not like the fuel preparation as they did not have sufficient suitable small biomass available and found it understandably tiresome to chop big woodsticks to small pieces and then feed them bit by bit to the fire.	
Accidents reported:	None known.	
Performance data:	Up to 55% reduction of fuel use, up to 90% reduction of emissions	
Further info: http://www.vrac.iastate.edu/ethos/files/ethos2007/Sat_PM/Session_4/Alders%20ETOS%20presentation%20Philips%20Woodstove%20v3.ppt http://siteresources.worldbank.org/INTENERGY/Resources/335544-1232567547944/5755469-1239633250635/Jan_Alders.pdf technical features on page 10 of http://www.pciaonline.org/files/Cook-stoveResearchRoadMap.pdf, report on comparative use of 5 wood-burning stoves in refugee camps in Dadaab (Kenya) in 2009: http://www.hedon.info/docs/USAID_Evaluation-wood-burning-stoves_Dadaab_final.pdf (source of photo above)		
Other comments: It is not very clear which model is manufactured and promoted where.		

Sampada (India)

Target area:	India countrywide, export on request	
Fuel type:	Wood chips, pellets, biomass briquettes, small twigs, wood chunks, etc.	
Designed by:	AD Karve, ARTI	
Retail price:	INR 1,200 (Euro 24, USD 30)	
Numbers sold:	Over 500	
Start of production:	2006	
Manufactured by:	Samuchit Enviro Tech Pvt. Ltd	
Address:	Flat No. 6, Ekta park Co-op Hsg. Soc., Behind Nirmitee Showroom, Law College Road, Erandwana, Pune-411004 Phone 91 20 2546013, Fax 91 20 25460138	
Production capacity:	Not known	
Short Description:	Portable natural draft TLUD with stainless steel body Diameter ca. 150 mm, Height 280 mm, Weight 1,5 kg Low power stove for light cooking tasks such as making tea, snacks etc.	
Features:	The special feature of this stove is that charcoal is left behind in the fuel holder after the stove operation.	
Handling:	The fuel is put into the fuel chamber and lighted from the top. One full charge of fuel keeps the stove in operation for about 1 hour. Additionally, it also has a provision for adding additional fuel through a side opening for longer duration of continuous cooking.	
Char-making ability:	Makes very good charcoal that can easily be saved as stove is lightweight and has handles. 1 kg of wood leaves 250-300 gm of charcoal.	
User feedback:	Clean cooking while making charcoal, fuel efficient and cheap to operate. It is a source of additional income, as produces charcoal has a higher value than original woodfuel.	
Accidents reported:	None known	
Performance data:	Emissions to cook 2,5 litres of food: 8,1 mg CO, 69 mg PM	
Further info: http://www.samuchit.com/index.php?option=com_content&view=article&id=1&Itemid=3#sampada%20stove http://www.arti-india.org/index.php?option=com_content&view=article&id=76:improved-cook-stoves-for-the-rural-housewife&catid=15:rural-energy-technologies&Itemid=52 (source of photo above)		
Other comments: State of current production not known		

Vesto (Swaziland) (Variable Energy Stove)

Target area:	Can export worldwide
Fuel type:	Designed for all biomass including split hardwood, sawdust briquettes, charcoal, branches and chunky biomass less than 180mm long; in TLUD mode can burn wood. Dung, pellets (wood, switchgrass)
Designed by:	Crispin Pemberton-Pigott
Retail price:	440 ZAR (ca. 45 Euro), incl. accessories Barbecue plate+support stand, available separate
Numbers sold:	Over 3,000
Start of production:	2004
Manufactured by:	New Dawn Engineering
Contact:	Thabsile Shongwe, thabsile.s@newdawnengineering.com sales@newdawnengineering.com, support@newdawnengineering.com
Address:	P.O. Box 3223 Manzini, MZ200, Swaziland +268 518-5016 or 518-4194
Production:	Can produce 100 stoves per day (upon order)
Short Description:	Natural draft Stove with incorporated pot-skirt based on a 25-l paint can. Controllable preheated primary air of three types as well as preheated secondary air. It can accommodate fuel from twigs up to 110mm diameter wood, preferably less than 200 mm long or less (over-filling a wood stove blocks proper air flow and creates a smoky burn). Diameter 300 mm, Height 440 mm, Weight 4,5 kg without accessories, 7kg with accessories, boxed. Power output 4 kW depending on air regulation. Best suited for pots <270 mm diameter, so that the pot can be sunken in the skirt though larger pots, woks and frying pans can be used.
Features:	Designed for rapid fire development (start cooking 1 minute after ignition); replaceable consumable parts (modular design); stove body has a wire handle; removable, perforated fire chamber with a replaceable grate at the bottom; stainless steel pot-supports.
Handling:	It can be used as bottom-lit continuous feed stove or batch-fed TLUD. Cooking time typically 20-40 minute without attention, correctly loaded with dense hardwood up to1 hour. Light biomass requires more frequent refueling.
Char-making:	Only in pyrolytic TLUD mode with restricted primary air supply.
User feedback:	Fast, little smoke, economic and fuel efficient especially with pot that can be sunken in the skirt. Inconvenience of having to remove pot entirely for refuelling as the pot skirt prevents refuelling with pot inside.
Accidents reported:	None known.
Performance data:	Sunken pots: Wood fuelled: 25-35% efficient, charcoal fuelled 35-55%; heat can be partly controlled by a combination of fuel or air metering; fuel saving 70% compared with open fire (typical).
Further info: http://www.newdawnengineering.com/website/stove/singlestove/vesto/ (photo above)	
Other comments: The Vesto was developed as a mass produced product though components can be incorporated into artisanal products in villages. It can burn extremely hard wood. It won the DISA Chairman's Award and Housewares division, (South African Design Excellence Awards 2004); received a Merit Award from the Stainless Steel Manufacturer's Association (2004) for innovative use of stainless steel.	

In the comparative study done in Dadaab, the stove was not used to realise the full potential because a griddle was placed between the fire and the pot which negatively influenced heat transfer. The detailed report can be found on http://www.hedon.info/docs/USAID_Evaluation-wood-burning-stoves_Dadaab_final.pdf.

MJ Biomass Gas Stove (Indonesia)

A new promising stove range is just starting up in Indonesia. According to the producer they develop models that can burn wood-charcoal or coal fines. The one presented here is designed for pelletised biomass and small wood chunks, but it can also burn small lumps of wood charcoal, that are too fine to be used in regular natural draft charcoal stoves.

Target area:	Urban poor in cities of Indonesia where charcoal fuel can be used
Fuel type:	Pellets or wood chunks can be used or small wood charcoal lumps (ca. 1 to 2 cm in diameter)
Designed by:	Alexis Belonio
Retail price:	20 USD
Numbers sold:	200 units
Start of production:	2009
Manufactured by:	PT Minang Jordanindo Approtech
Contact:	Mr. Bima Tahar
Address:	Adhi Graha Building 15th floor, Suite 1502 A, Ji. Gotot Subroto Kav 56, Jakarta 12950, Indonesia Phone 021-5262525, Fax 021-526 24 16
Production capacity:	40 units per month
Short Description:	Stainless steel batch-feed TLUD, fan-assisted Width 250 mm, Length 250 mm, Height 380 mm, Weight 2.3 kg Power heat output 1 KW
Features:	Fan powered by 12 volt, 0.12 Amp DC Fan; 9 volt battery can be used in case of power failure
Handling:	Fuel filled from the top, Lit with some fire starter from the top, start-up time 2 minutes. Char removed at the bottom by tapping the grate.
Char-making ability:	Very good.
User feedback:	Affordable, convenient to use, easy to ignite, no smoke during operation, flame intensity can be controlled, uses very small amount of electricity to power fan, safe to operate
Accidents reported:	None
Performance data:	13 minutes to boil 1 liter of water; Fuel load 300 g; Additional fuel can be loaded gradually to sustain firing.
Further info and order form: http://www.minangjordanindo.com/biomasgastove.htm (source of photo above)	
Other comments: Although based on the proven Belonio-designs, the product is right now in a development and testing stage in Indonesia. Currently only small numbers are manufactured, scale-up still envisaged for late 2010 or early 2011.	

LuciaStoves (Italy)

Nathaniel Mulcahy from WorldStove has designed various top-lit pyrolytic gasifier cook-stoves that are all based on a draft principle that is referred to as the 'LuciaStove'-principle. Therefore different models all get summarised under the term 'LuciaStoves'. All provide the option for 'carbon-negative' cooking if the inert char created is taken out of the carbon-cycle by adding it to the soil. More details on http://worldstove.com/about-2/why-pyrolytic-stoves/ . The stoves are designed for industrial mass production and local assembly. WorldStove offers concepts and training programs for stoves based on the Lucia principle, with the focus to set up micro industries in communities. WorldStove constructs the base components and then works with local liaison partners to set up small manufacturing plants. These plants do not require welding, riveting or drilling. They serve as a skill-based income generating activity for the community. WorldStove provides instructions and guides for assembly of additional stove parts and will work with local groups to set up the plant, and to adapt the LuciaStove to local cooking needs. As a single-item, the Beaner backpacker stove is available (see next section 2.2 on Campstoves). The factory-finished example for developing nations is intended for lots of 500 or more. For bigger numbers, the price drops significantly. Other models are shown on the website.

Name of stove:	LUCIA stoves for developing nations	
Country:	Italy	
Target area:	Export worldwide	
Fuel type:	Most dry small-chunky biomass	
Designed by:	Nathaniel Mulcahy, WorldStove	
Retail price:	Set by local dealers or producers	
Numbers sold:	Over 10,000 in 2010 alone	
Start of production:	2003	
Manufactured by:	WorldStove	
Contact:	Electronic contact form: http://worldstove.com/contact-us/	
Address:	290 North Pleasant ST Amherst MA 01002 USA	
Production capacity:	Geared at mass production: 32 aluminium stove tops per minute or 8,000 'origami' versions of the LuciaStove in 40 work hours	
Short Description:	Width 270 mm, Length 270 mm, Height 333 mm, Weight depends on mode. Power output can be regulated through fan speed. Biomass feed rate: On low setting 300 g fuel can give 1,25 h cooking time, on high setting it can burn 1,5kg per hour.	
Features:	Injection-molded high precision basic components to ensure optimal combustion. Different components shown in http://www.youtube.com/watch?v=8Zefrhc8kgM&feature=related Fan powered AC and DC versions available.	
Handling:	Fuel filled from the top, lit with some fire starter from the top. Fuel can be added while cooking. Char removed by tipping the stove.	
Char-making:	Very good in pyrolytic mode. Produces pH-neutral char and can be tuned for density, pore size and nitrogen content of the char.	
User feedback:	Can use little fuel, optimal with windshield and strong pot-support	
Accidents reported:	None known.	
Further info: http://worldstove.com/products/luciastove-for-developing-nations/ (source of photo)		

An example how versatile the burner unit can be used as heat source in existing stove designs: Fitting of a Lucia burner unit into a fixed brick stove with two plates shown on http://www.youtube.com/profile?user=WorldStove#p/u/19/qK99va4NwkY
WorldStove has come up with a unique 5-step program to build up local ‘stove hubs’ in co-operation with local partners. The aim is to create local jobs through production and distribution of locally adapted LuciaStoves. It adds two more lines to the value chain: the processing of local biomass residues into adequate alternative fuels to reduce dependency on conventional fuels like charcoal, and the further use of the char created in the stoves as a byproduct of cooking. For details see http://worldstove.com/album/download-area/ file name http://worldstove.com/wp-content/uploads/download/five_step.pdf or an interview with Nathaniel Mulcahy on http://www.charcoalproject.org/2010/05/a-man-a-stove-a-mission/

An example of adaptation of a natural draft version of the LuciaStove in post-earth-quake Haiti also including efforts to diversify the fuel access options can be found e.g. on
http://haitirewired.wired.com/profiles/blogs/cook-stoves-that-produce-more
http://www.bioenergylists.org/taxonomy/term/1475
http://www.huffingtonpost.com/kelpie-wilson/worldstove-transforming-h_b_556250.html

The flat-packed pre-cut parts were imported at reduced transport costs in the post-quake emergency, and then assembled by trained local artisans. Once the imported examples were shown to be working, the local adaptation started, which resulted in the copies made by the same artisans out of available scrap material.

 http://tweetphoto.com/9897841 ‘how to pack 1000 stoves into a small pickup truck’: flat pre-cut sheets ready for assembly	 http://haitirewired.wired.com/profiles/blogs/cook-stoves-that-produce-more	 http://mobile.tweetphoto.com/13064374 original stove and local copy from local scrap material.

Last but not least, this video on ‘Why we do what we do’ from WorldStove is worth watching: http://www.youtube.com/watch?v=3mgUg6GWLJg

Outlook on gasifiers for chunky biomass fuels

There is a KYOTO TURBO stove advertised for sale at 10 Euros on the website http://kyoto-energy.com/kyoto-turbo.html. It seems to be a model based on the PekoPe design by Paal Wendelbo, which is described in more detail in chapter 2.2. of this module.
Neither a sample nor more detailed information could be sourced yet but will hopefully soon be available.
Reports from Indonesia indicate two new types of gasifier stoves being promoted. More information is being sought from Mr Nurhuda from the Physics Department of the Brawijaya University in Malang. To be included in the next update.

b) Rice husk burning devices

Rice-husks are an important source of fuel, with the annual world supply estimated to exceed 115 million metric tons. Due to small particle sizes, low bulk density and high ash content, this fuel needs special burner-designs.
The LoTrau stove in Vietnam was directly burning rice husks in a sophisticated way. It was the basis for the development of the Mayon Turbo Stove and other so called ‘quasi-gasifiers’.

It was regarded impossible to gasify rice husks in small TLUDs until Prof Alexis Belonio from the Philippines proved that it is feasible. The first model conceptualised by Alexis Belonio has been overhauled and is now manufactured in its 2nd generation in the Philippines. Over 2,000 units have been sold since 2006. Prof Belonio was awarded the prestigious Rolex Award in 2008 for his efforts on making rice husk fuels usable as a clean energy source.
Several commercial rice-husk gas burners are now based on his concept. In 2010 SIAMEX Biomass Energy LLC was created as a new business entity with the aim to commercialize the latest improved model of the rice husk gas stove under a new brand throughout Asia, starting from Philippines, Indonesia and Vietnam. So within 2011 considerable progress on the dissemination of rice husk gas stoves is expected.
Design features of rice husk gasifiers developed by Prof Belonio: They all have a fan that requires an external power source. Various versions of the same stove with fans of different sizes and power sources are on offer. The stove top is removable to allow filling in the fuel and emptying the ash. It can act as a pot-support, or the pot can be placed on an outside structure, e.g. an enclosure for the reactor. The bottom of the reactor is sealed except for the entry for primary air, which is pushed in by a fan attached outside. The reactor has a double-wall with a gap open at the bottom.

Photos Christa Roth

The pyrolysis front is ignited on the top of the fuel in the reactor, the stove-top placed on top and the formed gas exits the reactor through the holes in the stove top with the help of the forced convection. Ambient air rises through the gap between the double walls as it picks up heat from the reactor and exits through the upper side-holes. Due to the clever design the preheated air clings to the metal and is drawn naturally towards the combustible gas, which The gas can only ignite and combust outside when oxygen is available.

BMC Rice Husk Gas Stove (Philippines)

Model RHGS 15D		 Source: A Belonio
Target area:	Rural villages worldwide where rice husks is available and with access to electricity	
Fuel type:	Rice husks	
Designed by:	Prof. Alexis Belonio / Center for Rice Husk Energy Technology-CPU, Iloilo City, Philippines	
Retail price:	USD 30-40	
Numbers sold:	More than 2,000 units sold in the Phil-ippines and abroad since 2006	
Start of production:	First started to develop the model in 2007, now it is in its 2nd generation	
Manufactured by:	Belonio Metal Craft	
Contact:	Mr. Dennis Belonio, Manager/Owner	
Address:	Purok II, Pavia, Iloilo, Philippines bmc.phil@yahoo.com	
Production capacity:	25 per week	
Short Description:	Width 3f50 mm, Length 350 mm, Height 800 mm, Weight 7.5 kg Power heat output 1.2 kW	
Features:	Air supply: 16-watt, 220 volt computer fan; airflow can be varied by sliding the shutter plate or with the use of rheostat switch; gas burner is a plate-type for better quality flame and for ease of char disposal	
Handling:	Lighting at the top with a piece of paper or sprinkling 1 ml kero-sene, Start-up time 1 minute, Char removal by tipping over the stove.	
Char-making ability:	Very good, charred rice husk can be used for Bokashi-type soil fertility amendments	
User feedback:	Affordable, cheap to run, uses waste rice husk as fuel, convenient to use, easy to ignite, no smoke during operation, flame intensity can be controlled, easy to load fuel and discharge char	
Accidents reported:	None	
Performance data:	8 min to boil 1.5 liters of water; Fuel load 0.95 kg; Batch system of about 40 to 60 min per load of rice husks fuel.	
Further info: From 2007: http://www.bioenergylists.org/beloniolowcostrhstove http://rolexawards.com/en/the-laureates/alexisbelonio-the-project.jsp		
Other comments: Plans on future development of '3rd generation' with a thermoacoustic power-source: http://rolexawards.com/en/the-laureates/alexisbelonio-fighting-theblackbeast.jsp		

A similar design is manufactured in Indonesia since 2009. Towards the end of 2010 the production is expected to scale-up considerably to a capacity of 10,000 stoves per month.

MJ Rice Husk Gas Stove (Indonesia)

Model RHGS 140-62D	 Source: A Belonio
Target area:	Indonesian rural villages near rice husks with access to electricity
Fuel type:	Rice husks
Designed by:	Prof. Alexis Belonio
Retail price:	USD 25-30
Numbers sold:	500 units
Start of production:	First started to develop the model in 2007, now it is in its 2nd generation
Manufactured by:	PT Minang Jordanindo Approtech
Contact:	Mr. Bima Tahar
Address:	Adhi Graha Building 15th floor, Suite 1502 A, Ji. Gotot Subroto Kav 56, Jakarta 12950, Indonesia Phone 021-5262525, Fax 021-526 24 16
Production capacity:	40 units per month
Short Description:	Width 300 mm, Length 300 mm, Height 780 mm, Weight 6.0 kg Power heat output 1 kWt
Features:	Air supply: 16-watt, 220 volt computer fan; airflow can be varied by rotating the air shutter ring; gas burner is an open-type for ease of char disposal
Handling:	Lighting at the top with a piece of paper or sprinkling 1 ml kerosene, Start-up time 1 minute, Char removal by tipping over the stove.
Char-making ability:	Very good, charred rice husk can be used for Bokashi-type soil fertility amendments
User feedback:	Affordable, cheap to run, uses waste rice husk as fuel, convenient to use, easy to ignite, no smoke during operation, flame intensity can be controlled, easy to load fuel and discharge char
Accidents reported:	None
Performance data:	8 min to boil 1.5 litres of water; Fuel load 0.9 kg; Batch system of about 40 to 60 min per load of rice husks fuel.
Further info: http://www.minangjordanindo.com/ricehuskgastove.htm From 2007: http://www.bioenergylists.org/beloniolowcostrhstove http://rolexawards.com/en/the-laureates/alexisbelonio-the-project.jsp Plans on future development of '3rd generation' with a thermoacoustic power-source: http://rolexawards.com/en/the-laureates/alexisbelonio-fighting-theblackbeast.jsp	
Other comments: same manufacturer has a steam-injected version of a rice husk stove which is considerable lower. http://www.minangjordanindo.com/steaminjectedgastove.htm	

A new production of rice-husk gasifiers based on the Belonio-design has just started in September 2010 by Mr. Paul Olivier in a Vietnamese-owned workshop in Dalat (Vietnam). All three gasifiers (reactor diameters of 150, 250 and 500 mm) have the same height (775mm) and share the basic design. All are manufactured from stainless steel and equipped with the same fan, covered by a plate for protection from spills.
The speed regulator is mounted on the fan housing. Two heat sink fins on the fan housing block the transfer of heat to the fan and the fan speed regulator. Power supply can be from the grid or for the household-size units via a motorbike battery inexpensively pre-wired for this purpose. The supplied adapter handles all electrical inputs (Vietnam, Laos, Cambodia, USA, Colombia and Europe).
The following prices include gasifier (all in stainless steel), fan, speed regulator and adapter. Prices as per December 2010 do not include a battery or battery charger:
150 gasifier (burn rate 2-4 kg biomass/h) = 52 USD
250 gasifier (burn rate 5-10 kg biomass/h) = 92 USD
500 gasifier (burn rate 20-40 kg biomass/h) = 232 USD (for institutions, greenhouses)

Models 150 and 250 (Vietnam)

Fuel type:	Rice and coffee bean husk	
Designed by:	Alexis Belonio	
Retail price:	52 / 92 USD. Table-high stove top for 1 or 2 pots, enclosures available	
Numbers sold:	Just starting, < 100	
Start of production:	September 2010	
Contact:	Paul A. Olivier PhD paul.olivier@esrint.com http://www.esrla.com/	
Address:	27C Pham Hong Thai Street, Dalat, Vietnam, Skype: Xpolivier	Source: Paul Olivier
	Louisiana phone: 1-337-447-4124 (rings Vietnam)	
Short Description:	Top-lit updraft combustion unit (reactor), either with incorporated burner unit or a stove top at table height with a main burner for cooking and one pot hole for warming. Stainless steel. Reactor with 150 or 250 mm diameter, 775 mm high.	
Features:	With powerful fan, fan speed controllable by rheostat, powered by a wet-cell motorbike battery (not included).	
Handling:	In operating the stove, one removes the burner and fills the reactor with hulls. The hulls are lit and the burner is put back in place. It takes about 15 seconds for the stove to be fully operational, and over 45 minutes to gasify all of the hulls in the reactor. Generally this is enough time to cook a meal at the cost of about 1.1 cents of a USD.	
Char-making:	Makes good biochar, which can be removed at the bottom of the reactor /combustion unit.	
Further info: http://www.esrla.com/pdf/gasifier.pdf also featuring drawings and photos of various types of enclosures for safety and stability. A video showing the 150 model is found on http://www.esrla.com/pdf/gasifier.mpg More info on the Model 250 http://www.bioenergylists.org/content/250-gasifier, or see section on gasification in http://www.esrla.com/pdf/composting.pdf		
Other comments: Contact Paul Olivier for a custom-made offer.paul.olivier@esrint.com The 500 mm diameter model is very suitable to heat greenhouses and to produce larger amounts of biochar, 800 mm unit for 50-100 kg of rice hulls per hour is under development.		

There is a type of natural draft stove with a conical fuel hopper. It is not a batch-loaded fan-assisted TLUD, but a continuous feed also referred to as a ‘quasi’ or ‘semi’-gasifier. It is therefore much shorter than the rather tall and top-heavy TLUD rice husk gasifiers. REAP (Resource Efficient Agricultural Production) has also introduced the model in West Africa. It is a promising option for areas, where stove-height might be an obstacle for cultural acceptance, electricity access is challenging and purchasing power rather demands low-cost options.

Mayon Turbo Stove

(Philippines / Gambia / Senegal)		
Target area:	Currently promoted by REAP in Philippines,	
Fuel type:	Rice husk, also peanut shell and other shells and husks	
Designed by:	Developed by REAP Canada, based on LoTrau from Vietnam	
Retail price:	15-20 USD	
Numbers sold:	Over 5,000 in Philippines, 500 in Gambia and Senegal	
Start of production:	In 2003	
Made by:	Local artisans	Source:
Contact:	Roger Samson info@reap-canada.com	http://www.hedon.info/View+Stove?itemId=8957
Production promotion:	In order to encourage more stove production around the world, REAP Canada has prepared an International Marketing and Manufacturing Package which includes information on what is needed to manufacture and disseminate the stove at the local level. It includes general information on the stove, design drawings for manufacture, an instruction manual, brochures, and former case studies and can be obtained for 200 Canadian Dollars from REAP.	
Short Description:	Bottom-lit continuous feed natural draft gasifier, dimensions depending on model 165 or 178 mm diameter, Weight 4-5 kg Made from sheet metal and steel by local artisans.	
Features:	conical fuel hopper open on top, combustion chamber in the centre of hopper, secondary air holes enhance the complete combustion.	
Handling:	Can be fed continuously from the open top of the conical hopper. Tapping to introduce new fuel to the combustion chamber in the centre of the hopper is required every 7-10 minutes.	
Char-making ability:	No, burns to ash, which can be used as a fertilizer.	
User feedback:	Fast, convenient, smokeless, economical to operate, enables considerable savings, good pot stability, uses a wide range of cheap fuels	
Accidents:	None known.	
Performance data:	1 liter of water can boil in 6-7 minutes. More in Report from 2005 done by Aprovecho downloadable on http://www.reap-canada.com/library.htm#mts	
Further info: http://www.reap-canada.com/bio_and_climate_3_3_1.htm http://www.reap-canada.com/online_library/IntDev/id_mts/30-Sustainable%20Household.pdf http://www.hedon.info/View+Stove?itemId=8957		
Other comments: The stove was started to be developed together with local artisans in the Philippines in 2001. It was introduced in the Gambia in 2003.		

Outlook rice husk burning gas stoves

For institutions and restaurants, a 2-3 pot remote-burner stove can be found at http://www.minangjordanindo.com/multipleburneerricehuskstove.htm

More rice husk-burning stove designs once prototyped and presented at a wood gasifier workshop organized by ARECOP in 2003 can be found in the handbook compiled by Alexis Belonio
http://www.bioenergylists.org/stovesdoc/Belonio/Belonio_gasifier.pdf.

A very comprehensive training manual on Rice husk gas stoves updated by Alexis Belonio and others in April 2010 can be obtained upon request by email from crhet_cpu@yahoo.com. Further information is available on www.crhet.org. It includes learning modules about the underlying principles and the development of the technology. It features construction and marketing options, testing reports and detailed plans of the rice husk gas stove.

Minang Jordanindo in Indonesia also has started to manufacture a model that can burn rice husks without an external power source, but with steam injection into the flame to enhance the complete combustion. It has the advantage that it can be continuously operated (no batch-feed), and it is considerably lower, which might be important for acceptance in certain cultures with preferences for lower stoves. The stove is still in the socialisation phase, but samples should be obtainable.

RHSIS -20 D (Indonesia)

Steam injected Rice husk gas stove		
Fuel type:	Rice husks	
Designed by:	Prof. Alexis Belonio	
Retail price:	USD 25-30, to be determined	
Numbers sold:	Not known	
Start of production:	2008	
Manufactured by:	Minang Jordanindo Approtech	
Contact:	Via Prof Belonio or address below	
Address:	Adhi Graha Building 15th floor, Suite 1502 A, Ji. Gotot Subroto Kav 56, Jakarta 12950, Indonesia Phone 021-5262525, Fax 021-526 24 16	Source: A. Belonio
Production capacity:	Not known	
Short Description:	Natural draft continuous-feed rice husk burner with steam injection to enhance flame. Two models differing by the method of steam injection either from the side or from the center. Width 350 mm, Length 350 mm, Height 400 mm, Weight not known Power output (according to the website): 1 KW for side-injection of steam at fuel burn rate of 2,4 kg/hour, 1.3 KW for center injection of steam at burn rate of 3,2 kg/hour	
Features:	Conical fuel hopper surrounding the combustion chamber. Fuel is inserted into the combustion chamber on the bottom. Water tank: Steam is generated around the combustion chamber, then injected to the flame either from the side or from the center.	
Handling:	Unlimited operating time: the fuel hopper is filled with rice husks, which enter by gravity (supported by tapping to make the fuel move) on the bottom of the combustion chamber. Hopper can be refilled during operation. Lighting at the top with a piece of paper, Start-up time 1 minute for side-injection model, 3 min for center-injection, ash removal by tipping the stove.	
Char-making ability:	Final product is mostly ash	
User feedback:	Operates continuously, high power output, no external power needed, uses waste rice husk as fuel, convenient to use, easy to ignite, no smoke during operation, flame intensity can be controlled, easy fuel-loading and ash-removal	
Accidents reported:	None known	
Performance data:	6 min to boil 2 litres of water with the center-injection of steam at a water consumption of 1,32 liters/hour	
Further info: http://www.minangjordanindo.com/steaminjectedgastove.htm http://www.bioenergylists.org/belonioggas		
Other comments: The bigger 5,5 KW-model RHSIS -30 D is suitable for restaurants and institutions. It has a center-injection of and burns 10 kg of rice husks in 1 hour.		

2.1.2 Campstoves

These stoves are mainly targeted at an affluent niche market for occasional use and not very suitable for daily domestic use. They are only suited for reasonably small-size flat-bottom pots and don't allow for the often very big pot size used by normal households in developing countries. They also don't provide the stability needed for regular cooking. They are rather suited for warming food on a camping trip than preparing meals that require vigorous stirring.

Yet they are important to be included here, as they are '*a low-cost introduction to micro-gasification which allows you to begin experimenting with turning biomass into clean, blue-burning gas' (source WorldStove)*.

The value of these campstoves is that they can be ordered via mail, paid for electronically, and shipped into even remote corners of the world at reasonable costs, because they are designed to be very light, compact and sturdy enough to endure being carried around in a backpack. They can use nearly any type of dry biomass fuel that is found outdoors and picked up without the need for chopping (leaves, twigs, pine cones, straw etc.).

Currently there are two campstoves readily available on the market: a fan-assisted model with heat control and a natural-draft model without heat control. Another model where the fan is powered by a thermo-electric generator unit is envisaged to come on the market in 2011.

The'Tom Reed Woodgas Campstove'

Top-lit updraft campstove with a fan that allows heat control by choosing between high and low speed of the fan. The fan serves primary and secondary air supply at the same time. It is powered by a separate battery pack for 2 AA-batteries. Two sockets on the stainless steel stove body allow heat control. It is calibrated to reproduce the heat of a normal kitchen stove.

It can be used as a batch-fed pyrolytic TLUD when fuelled up to capacity, or as a continuous-feed when ideally only filled in the bottom third.

Two different models can be ordered from the Biomass Energy Foundation:
http://www.woodgas.com/bookSTOVE.htm (source of photo above)

WoodGas LE: Weight: 23 oz, Height: 6.25", Diameter: 5", mail order price: US Dollar 55
Woodgas XL version: US Dollar 75.

The 'Beaner' Backpacker Stove from WorldStove

The Beaner is a bi-fuel fan-free stove without temperature control. Created for backpackers as a carbon-negative camping stove, it is also currently being used in developing countries as a small cook-stove. It can be used with dry biomass (pine needles, wood, etc.) or with any alcohol (ethanol, alcohol, vodka, etc.). It is also possible to add waste plant oil, such as sunflower seed oil, jatropha or olive oil, to dry biomass for a 21% increase in energy. Campers need only add on an 8oz soda can as a consumable item. Using the Beaner with solid biomass fuels creates biochar, which enriches the soil and sequesters carbon. This means by burying your biochar in the soil where you have cooked a meal on an outdoor trip, the site is left richer than you found it.
Compatible with stainless steel pot stand and aluminum flat folding windscreen. For an alternative to the stainless steel pot stand, there are instructions to build a micro pot stand out of hardware cloth. Photo source: WorldStove website

Technical Information
Adding fuel: Top fill. Not batch driven, can add fuel while cooking.
Biomass feed rate: 100g = 42 minutes of cook time, Alcohol: 29 ml = 22 minutes
Weight: 244 g / 8.6 oz
Measurements: 134 mm (height) 51 mm (diameter)
Accessories: Stainless steel pot stand, Aluminum flat folding wind screen
Weight of stainless steel pot stand: 5.7 oz, Weight of windscreen: 0.1 oz

Can be ordered via http://worldstove-germany.com, price was quoted around 50 Euro as per September 2010. It needs to be assembled using a standard can. Instructions for assembly available from the download area at:
http://worldstove.com/album/download-area/
http://worldstove.com/wp-content/uploads/download/beaner_instructions.pdf
More info from http://worldstove.com/products/the-beaner-backpacking-stove/.

Outlook Campstoves: BioLite CampStove

Photo: Christa Roth, 2010

This campstove is being developed by Biolite. founded by Jonathan Cedar and Alec Drummond.
(http://www.biolitestove.com/CampStove.html).
The most interesting feature of that CampStove is a unique thermo-electric generator (TEG) that creates electricity from heat. Otherwise the stove is mainly based on Tom Reed's fan-assisted Woodgas Campstove, but the fan is powered by TEG instead of batteries. Biolite hopes to start a commercial production of the CampStove in 2011. The current priority is to get their TEG to power a fan attached to a side-fed wood-burning rocket-stove for developing countries, with the aim to reduce emissions by 90% as compared to an open fire. This is currently only possible with proper gasifier technologies. More details on that joint venture with Aprovecho Research Centre to develop a next-generation wood-burning stove on:
http://www.charcoalproject.org/2010/06/a-great-stove-with-a-killer-app/ and
http://www.biolitestove.com/NextGen_Cook_Stove.html

2.2 Prototypes with certain field testing and potential for local adaptation and production

This category comprises conceptualised micro-gasifiers that
- achieved a certain level of field-outreach through artisanal production
- have prototypes ready for industrial or artisanal production in a new area
- do not depend on external power sources but function with natural draft
- are based on easily replicable, publicly available plans and instructions

The following list is only a non-inclusive selection; there are more designs out there:

<table>
<tr><th>Type</th><th>Designed by</th><th>Name of stove</th><th>Current known field-outreach</th></tr>
<tr><td rowspan="5">Portable metal</td><td>Paal Wendelbo</td><td>PekoPe and MUS</td><td>Uganda, Zambia, (Haiti?)</td></tr>
<tr><td>Paul Anderson</td><td>Champion</td><td>India, Cambodia, Uganda, Mozambique, Malawi</td></tr>
<tr><td>Art Donnelly</td><td>FINCA</td><td>Costa Rica</td></tr>
<tr><td>Ravi Kumar</td><td>ANILA</td><td>India</td></tr>
<tr><td>Sai Bhaskar Reddy</td><td>MAGH series</td><td>India</td></tr>
<tr><td>Fixed brick</td><td>Sai Bhaskar Reddy</td><td>AVAN series</td><td>India</td></tr>
</table>

The selected designs are open source with downloadable plans or otherwise expertise available through the designer to assist in establishing a local production. Training of trainers can be facilitated, so that artisans get properly trained how to produce good quality gasifiers, and the end-users can get trained how to handle the devices properly.

A word of caution at this place: to assist in the introduction of micro-gasifiers in a new context, it is advisable to get early practical advice from a skilled knowledge-bearer, who is very familiar with all the tricks of the technology:
In a new context all the variables and influencing parameters that are to important stove performance will be different: altitude, fuel, dishes to be cooked, untrained users etc. With factory-finished products, the quality of the product should not constitute a ‘variable’. Though, with a start of a new production, many additional variables are added to the equation like materials used for stove construction, dimensions of the burner, quality of craftsmanship etc. Small variations can sometimes make a big difference. In a new context, it is advisable to start with a small pilot and adapt the technology in a participatory process together with the communities and the assistance of a knowledge-bearer.

'PekoPe' and 'MUS' designs by Paal Wendelbo (Norway)

The PekoPe ('no problem' in vernacular Acholi from Uganda):

- probably the simplest TLUD design with field-experience
- very clean-burning, pyrolytic TLUD gasifier 'energy unit'
- char-making optional, the user can chose whether to use the energy for cooking or save the char for other use
- very simple to make from any type of metal, ideal for replication
- can be scaled from household sizes to institutional and commercial sizes.

http://www.bioenergylists.org

Local PekoPe production in Uganda in 1996.

Photo Paal Wendelbo

Technical features: The 'energy unit' consists of an inner cylinder as fuel chamber (or reactor), outer cylinder to guide and preheat secondary air, a concentrator disk on top. Two vertical handles on the outer cylinder ease handling and dumping of char. Inner container fixed to outer container with spacers that also function as legs to keep the fuel chamber above ground and let the secondary air enter between the cylinders.

Handling: top-lit, batch-fed, cooking time depending on volume and mass of fuel, up to 75 minutes is well possible. To extend cooking time, the entire energy unit needs to be exchanged. Combining more units under one pot support increases firepower, e.g. for use in restaurants, industries or institutions.

Paal Wendelbo is one of the two 'fathers of TLUDs'. Paal worked on burner units for stoves, based on observations making smokeless fire when he was with resistance fighters in the forest in Norway during the 2nd World War. He started conceptualizing the first natural draft TLUD in the late 1980s, about the same time but independent from the work of Tom Reed in the US. After a lot of trying and failing he made a simple cook stove which was found very clean burning when tested at Copenhagen Technical high school in 1988. It was introduced in various countries where Paal worked: Malawi (1988, fuelled with grass), Mozambique (1990, fuelled with cashew nut husks), Ghana (1989, fuelled with residues and chopped wood) and Tanzania (1990). In 1994, the stove was adjusted in refugee camps in Uganda to burn straw, bundled and packed vertically into the unit, 'without problem', which gave it the vernacular Acholi name 'PekoPe'.

In all the countries the stoves were locally made by local tinsmiths with their existing tools from the materials they could get, either new sheets or scrap metal. The artisans needed only some guidelines, a template and customers for this simple technology.

At a Trade Fair exhibition in Kampala 1997 they were selling 500 stoves in two days at market price, at that time 5 US$. Over 5,000 units were in use by 1999, when Paal left Uganda for medical reasons. Because he developed the technical aspects but not the business side in the refugee situation, the 'stove business' did not carry on, though the design has great business potential. The stove was introduced in Zambia in 2008 fuelled with chopped wood.

At Aprovecho Stove Camp 2009 Paal made a PekoPe from a 3 litre tin and some leftover sheets: The combustion chamber had a diameter of 150 mm and was 180 mm high. Other features (according to an email posted on the stoves-listserv in December 2010):

- 55 mm free space from concentration lid up to the pot
- 105 mm hole in concentration lid

- 6 mm gap between the concentration lid and top of the combustion chamber - 4x15mm for the stand for secondary air
- five 5 mm holes 75 mm up from the bottom on the side of the combustion chamber
- five 5 mm holes 25 mm up from the bottom on the side of the combustion chamber
- five 13 mm holes at the bottom plate for primary air
- 15 mm space between combustion chamber and cover for preheating secondary air

This unit was tested and given the Kirk Smith Award for its clean-burning. It boiled 5 l of water in 28 minutes, using 768 g of wood pellets. The emissions were among the lowest ever measured in the Aprovecho laboratory up to then: only 23 g of CO was emitted in the task, nearly meeting the ambitious benchmark of 20 g. The PM was 223 microgram, staying well below the current benchmark value of 1,500 for a stove without chimney.

Paal always emphasises that you ‘have to start with the fuel’, as ‘fuel, stove and user is one system which can not be separated, If you don’t have the fuel at an appropriate price you will not manage to promote the stoves.’

The following videos show Paals work in Northern Uganda:
http://www.youtube.com/watch?v=amaUDK6VyRg
http://www.youtube.com/watch?v=gi3Xx7NtTGw&feature=related
http://www.youtube.com/watch?v=dsfuVGBi4fc&feature=related

Construction plans and information on Paal and the PekoPe can be downloaded from:
http://www.bioenergylists.org/wendelbopekope (Wendelbo TLUD Pioneer Experiences)
Further reading on: http://www.bioenergylists.org/content/tlud-nd-peko-pe
http://www.pekope.net/stove.html with the concept of combining energy units
http://www.bioenergylists.org/pekopetests
Or contact Paal Wendelbo on paaw@online.no

The MUS (multi-use-stove): a new very promising concept under development

The lowest micro-gasifier so far found (< 15 cm height), while still offering enough power to cook. Thus it is very interesting for communities, where the acceptable height of the stove is a limiting factor for adoption like in many parts of East Africa.

- includes pot stand that can accommodate more than one pot at the time
- adaptable volume of fuel container allows to meter the fuel and the cooking time
- allows refueling during use

For details: http://www.bioenergylists.org/content/mus-multi-use-stove

Paal cooking on MUS

MUS with two pots

Top view of MUS

Photos: left Christa Roth, above http://www.bioenergylists.org

‘Champion’ Designs by Paul Anderson (USA)

Paul Anderson, (aka ‘Dr. TLUD’ and a major contributor to this manual) has been working on the TLUD concept since he saw it demonstrated by Tom Reed in 2001. His design that won the award for cleanest burning natural draft cookstove at Stove Camp 2005 led to the name “Champion.”

The Champion-design constitutes only a burner unit and requires a separate pot-support structure to become a cook-stove application that can carry the weight of the cooking vessel (pot, pan, griddle, mitad etc.), so that the burner unit can be moved during operation.

It is a very simple TLUD design that offers options for air control

- very clean-burning, char-making pyrolytic TLUD gasifier unit
- allows for separate control of primary air and an option for secondary air control
- very simple to make from any type of metal, ideal for replication
- can be scaled from household sizes to institutional and small-business sizes

Technical features: The fundamental features are the concentrator lid and associated secondary air gap, developed independently by Anderson but essentially similar to construction elements in Wendelbo’s Peko Pe. Differences between the Champion and the Peko Pe are the riser, the handle on the separate concentrator disk and a provision to control air supply, both primary and secondary.

- Fuel chamber/inner cylinder with (adjustable) primary air inlet and fuel grate
- Outer cylinder with secondary air inlet (can be adapted to be controlled)
- Concentrator lid for mixing of wood-gas and preheated secondary air, with handle
- Riser to enhance draft, can be combined with a coupler and concentrator lid
- Handles for easy exchange of ‘fuel cartridge’ and easy dumping of char.

Handling: top-lit, batch-fed, cooking time depending on volume and mass of fuel, up to 75 minutes with one load of dense fuel is possible. To extend cooking time, the fuel canister (reactor of the gasifier) can be exchanged.

Construction plans and detailed operational instructions and explanations of concept, illustrated by many photographs and graphs, can be downloaded from http://www.bioenergylists.org/andersontludconstruction (Construction Plans 1.3MB)

A video showing the basic design features and operation of the Champion is found on http://www.youtube.com/watch?v=SaeanoWZE7E

		
A Champion reactor made in Malawi with movable tripode-stand for the pot (Photo: Christa Roth)	A Champion reactor made in Mozambique with a fixed stand for the pot (Photo: Carmel Lloyd)	A Champion reactor made in Uganda, partially loaded with vertically placed bamboo sticks (Photo: Christoph Messinger)

Two pilot projects based on the Champion model have just started in December 2010 in Mulanje (Malawi) and Pemba (Mozambique). A 2-year project under BEIA-ESMAP funding by Worldbank is going to start in 2011 in Uganda with the Centre for Research in Energy and Energy Conservation (CREEC). This project is expected to create more good examples of Championand other TLUD applications based on further participatory technology development.
Factory-finished stainless steel version is produced by Servals in Chennai, India (see Section 1 of this Module). Other artesian versions in use in Cambodia, and the Marshall Islands.

An edited excerpt of Anderson's document on options applying the Champion concepts to many contexts and requirements:

1. "Hobbyist": produced at a residential garage workbench in the USA with materials from common hardware stores. It is most appropriate for tinkerers, Scouts, and serious stove developers/experimenters.
2. "Refugee": produced using a minimum of tools and recycled materials found in refugee camps. It is most appropriate for humanitarian relief efforts.
3. "Artisan – factory finished": produced as a commercial product in a modest metalwork shop e.g. in Chennai, India. It is most appropriate for primarily manual production as a commercial product by small factories.
4. "Industrial": Full-fledged mechanized production. Much of the production could be accomplished in factories that already make metal containers.

The designs can be scaled to larger units for cottage industry, restaurant and institutional use.

More information from Paul S Anderson via email: psanders@ilstu.edu
Further reading by Paul Anderson:
Micro-Gasification: What it is and why it works" by Anderson, Reed, and Wever (2007), at:
http://www.hedon.info/docs/BP53-Anderson-14.pdf
An overview of gasification (2004) is at:
http://bioenergylists.org/stovesdoc/Anderson/GasifierLAMNET.pdf
The exceptionally clean combustion of TLUD stoves (2009) is presented at:
http://www.bioenergylists.org/andersontludcopm
Paul Andersons draft version of a TLUD-handbook:
http://www.bioenergylists.org/tludhandbookdraft-1
'Bonustrack': a humorous summary of the 'Family of tincanium stoves' by Paul Anderson can be found on http://www.bioenergylists.org/andersonethos2010
The test results on http://www.bioenergylists.org/content/testing-andersons-tl from April 2010 in Cambodia are not representative for a proper operation of the stove. The photos show excessive flames, which is probably due to too much air while in use and excessive gaps between the 10 cm length stick-wood fuel.

Examples for adaptation and 'hybrid' models

Michael N Trevor's TLUD version from 2010 shows the flexibility of combining elements from Anderson's Champion, Wendelbo's PekoPe and Reddy's 'smokeburner MAGH' built in the Marshall Islands: http://www.bioenergylists.org/node/2427

Larger TLUD stoves based on a 5-gallon bucket for institutional use can be found on http://www.bioenergylists.org/node/2404.
More details on the Stove Workshop organized by the Seattle Biochar working group (http://www.seachar.org) on http://seachar.org/wordpress/?p=176.
As a result of the workshop, Art Donnelly, the co-founder of SeaChar, started the transfer of the concept to Costa Rica and started the promotion of a biochar-making stove, which is presented next.

This is a good example how since February 2010 the TLUD-concept was applied in a new situation following the demand of a specific target group with specific needs. In a few months a working ‘stove’ and an in-country supply chain was developed with a local farmers association and a group of women. The stove is now retailed at 40 USD.

ESTUFA FINCA in Costa Rica by Art Donnelly (USA)

Starting point: Organic coffee farmers in Costa Rica were looking for a solution to

- provide migrant workers with clean-burning cook-stoves to improve their health
- use farm-residues that need to be burnt for plant pathology reasons for cooking
- create biochar for soil amendment to reduce fertilizer use on an organic farm
- carbon negative cooking to possibly subsidize with carbon credits the placement of stoves in the make-shift homes of 100,000 seasonal migrant workers.

The result was a TLUD with preheated secondary air:

- Designed for bigger pots, based on an off-the-shelf 20-liter paint bucket
- Converts a multitude of biomass from a coffee farm to biochar: coffee plant trimmings, to a certain extent coffee husks, corn cobs, goat droppings, blackberry vines
- Primary air through the bottom for easy char-quenching, air control can be added.
- Easy to manufacture using patterns, guides and jigs to create pre-cut assembly kits, that can be assembled with simple hand-tools and rivets.

People’s reaction to the fuel-flexible clean burning stove: “this is re-inventing the fire.”

<table>
<tr>
<td>
ESTUFA FINCA in the Santos Region</td>
<td>
Designed for big pots</td>
<td>
Burner unit with primary air control</td>
</tr>
<tr>
<td colspan="2">Retail price 40 USD, excl. shipment (June 2010), production by APORTES women group. For a sample stove contact Carolina Abarca mandarinaynaranjas@hotmail.com,
More info on the ‘Proyecto Estufa Finca’from February 2010 on http://www.hedon.info/1681/news.htm
An update from June 2010 and more photos on http://www.biochar.bioenergylists.org/content/proyecto-estufa-finca-update-seattle or http://www.hedon.info/1825/news.htm

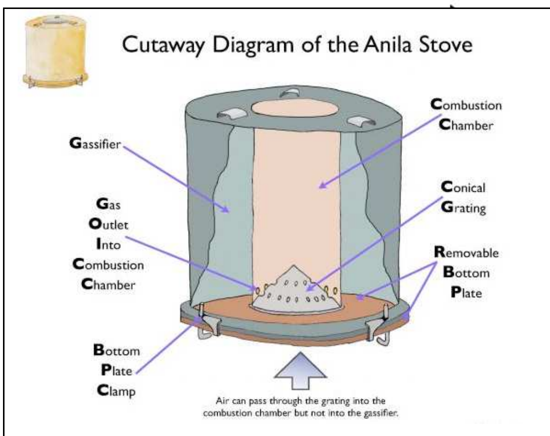
Contact the designer: art.donnelly@seachar.org</td>
<td></td>
</tr>
</table>

Photos: Art Donnelly, co-founder of Seattle Biochar working group (http://www.seachar.org)

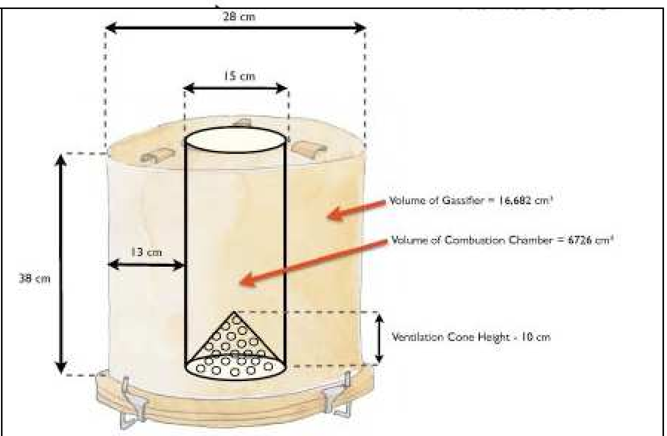
The latest video from Costa Rica gives a good insight in the stove program and the context of the coffee growing area. See http://www.youtube.com/watch?v=eGIVh-zMWgY
The next challenge is to see if the TLUD concept can be applied to dry coffee.

ANILA stove by Prof. Ravi Kumar (India)

Charring small biomass without electricity, just by natural draft.
Design is a bit more challenging concerning craftsmanship, as some joints need to be made air-tight to avoid smoke escaping from the allothermal pyrolysis zone.
Design consisting of two concentric cylinders of different diameters (see diagram).
The inner is a TLUD, filled with chunky biomass that allows flaming pyrolysis with natural draft. The outer ring is filled with small-size biomass (like husks, sawdust etc.), which would not work in a TLUD without forced convection. The fire is lit on top in the center cylinder, the TLUD. Heat from the central fire pyrolyzes the concentric ring of small biomass fuel without flame (allothermal). The gases can only escape downward and to the center where they add to the cooking flame as the ring of biomass turns to char. The stove produces two types of char: autothermal from flaming pyrolysis in the TLUD-part, very pure allothermal char from the outer ring. Secondary air supply not shown in diagram. Developed by U.N. Ravikumar, at India's National Institute of Engineering.
(Adapted from: http://www.biochar-international.org/technology/stoves)



http://www.bioenergylists.org/node/2203



http://www.bioenergylists.org/en/node/2201

More information on http://www.bioenergylists.org/anila, report with examples from use in communities in Tamil Nadu province in South-East India can be downloaded http://www.bioenergylists.org/stovesdoc/ravikumar/Biochar_Anila.pdf (9.8 MB)
Anila type stoves were recently compared to other models in Cambodia, details on http://www.bioenergylists.org/content/testing-anila-stove. Over 2,500 units were made, see http://biocharinnovation.wordpress.com/2010/11/02/anila-stove-manufacture-2500/

MAGH and AVAN series - Designs by Dr. Reddy (India)

Dr N. Sai Bhaskar Reddy Nakka, founder and CEO of Geoecology Energy Org. is a very productive designer of TLUD gasifiers and other biomass stoves. He has designed over 40 models for different fuels, varying in construction materials, production costs, sizes and optional fans. All designs are open knowledge. A selection is presented here, others can be found on http://www.goodstove.com/ and http://www.e-geo.org/ .

The MAGH-series: Several charmaking TLUD gasifier designs are summarized in the MAGH 'smokeburner' series. The MAGH CM is a very low cost version of the MAGH series, for the common man. The community retail price based on production from recycled material is quoted to be less than 8 USD.
Details on http://e-maghcm.blogspot.com/ and http://www.bioenergylists.org/node/2410 (source photo right)
The MAGH IV includes an option to provide light during operation. http://e-maghlampstove.blogspot.com/.

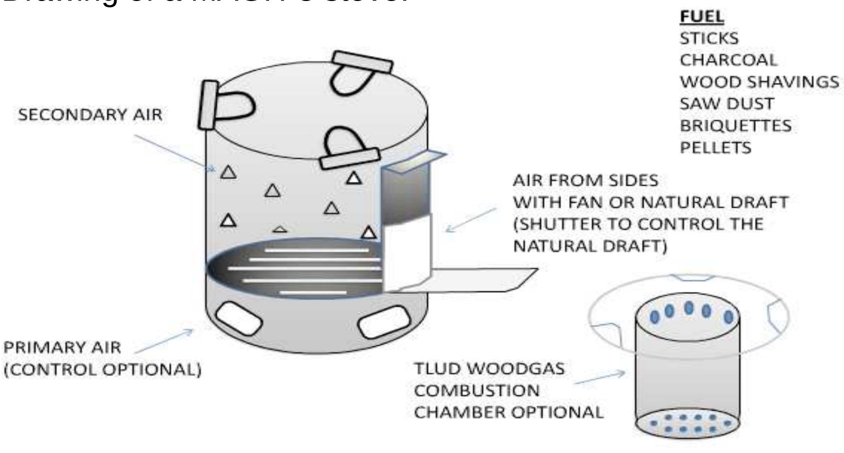
A factory-finished fan-powered MAGH-1 was found at Aprovecho Research Centre in Oregon (photos Christa Roth). It is very lightweight and simple, but according to Dr. Reddy not manufactured regularly. Thus it was not included in section 2.1.

The MAGH-3G represents an interesting concept of flexible multi-fuel 'all-in-one' stoves, that can be adapted to burn all types of biomass for cooking: wood (in form of sticks, chips or shavings), leaves, pellets, briquettes, cow dung cakes and charcoal.
It has a micro-gasifier insert, a shutter for air control and a grate that can be adjusted in height: as a TLUD it burns small-size biomass cleanly, with an optional fan.

MAGH 3G stove in use as fan-powered TLUD, as rocket stove with firewood and as charcoal stove.
(Source: http://www.bioenergylists.org/content/magh-3g-stove-all)

With the shutter open, the grate at the bottom, and without the gasifier insert, it can be used as a rocket-type stove for firewood. Putting the grate higher and closing the shutter to control the excess air, it becomes a conventional charcoal burner.
It was found that many families have at least two or three types of stoves in rural areas for using types of biomass as fuel. Now with just one stove they have the freedom to use all types of Biomass as fuel. There is an option to control primary air, to control air from the fuel feed side opening, and secondary air (when using TLUD adapter). Weighs 1.3 kgs, 9 " high, 7 " diameter, price is Rs. 120 (less than 3 US$), easy to transport, efficiencies from 25% to 40% based on the type of fuel and mode of operation, easy to cook in open air conditions, low transportation cost, can meet the cooking needs of 5 to 10 people, all types of food can be cooked, less time required to train people on how to operate it. Detailed description, plans and a video are found on http://e-magh3g.blogspot.com/ or
http://www.bioenergylists.org/taxonomy/term/843

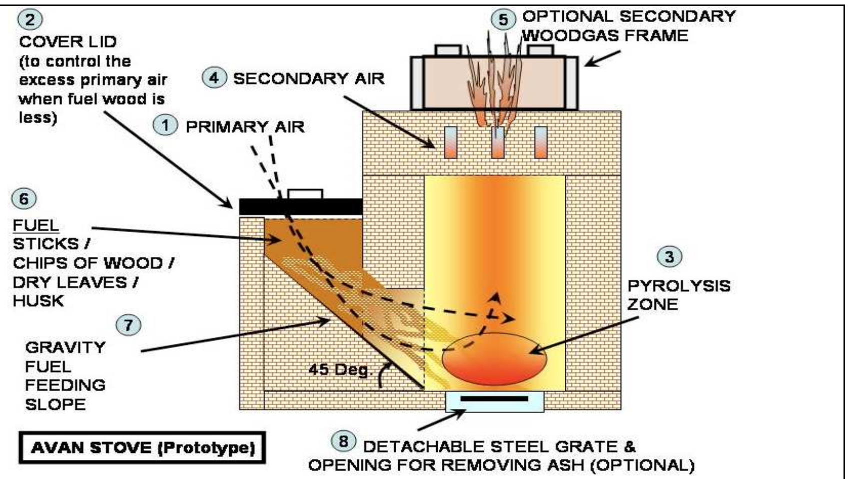
Drawing of a MAGH-3 stove:



Stove Design by: Dr. N. Sai Bhaskar Reddy, CEO, GEO (April, 2010) http://www.goodstove.com

AVAN series of fixed and portable continuous-feed gasifiers

The AVAN models combine bottom-burning continuous feed gasifiers and rocket stove principles with insulated vertical combustion chambers. The fuel is gravity-fed (semi-automatic feeding) continuously through a hopper from the side just above the pyrolysis zone.



Source: http://www.bioenergylists.org/node/1932

The fixed model is made up of 25 ordinary bricks, four bricks with slits, one piece of flat tile, one steel grate 7x7 inches and clay mixed with cow dung. The approximate cost of construction is $ 2 (USD). All types of biomass can be used as fuel (Sticks / twigs / chips of wood / dry leaves / grass / saw dust / cow dung cakes / paddy husk etc.).
More info on: http://e-avanstove.blogspot.com/ http://www.bioenergylists.org/geoavanstove

2.3 'Tincanium' and other low-cost prototypes of micro-gasifiers

This is the 'do-it-yourself' section on how to demonstrate the principle of micro-gasification and create awareness. Unlike the factory-finished, ready to use campstoves, it is not 'learning-by-observation' but 'learning-by-doing' for own experience and understanding of the processes. Not only for school kids.

It features micro-gasifier burner units which are

- not yet proven in extended field tests
- not commercially available and
- not directly suitable for large-scale replication,

but

- very educational to trigger interest in an initial phase and start experimenting with gasification, because they
    - rely on existing construction elements like discarded tin-cans
    - have clear and easy step-by-step instructions how to make them
    - are easy to construct even by people without tin-smithing skills
    - need few special tools, mainly a 'church-key' can opener, tin-snips and nails
    - are very educational to prove the technical concept and general viability of micro-gasification
    - based on natural draft, no electricity needed for operation
    - have clear and easy instructions that might serve to build some local trial versions in a new area and inspire local adaptation by local artisans and users
- suitable to generate prototypes of burners to convert conventional stoves into fuel-flexible gasifier-stoves

Caution: The use of gloves is highly recommended when handling tin cans, as the edges can be very sharp!

4 models of 'burner concepts' were selected with the main features and properties:

Name of burner concept =>Properties	iCan	Toucan	EverythingNice	Grassifier
Preheated secondary air	No	No	Yes	Yes
Concentrator disk for thorough mixing of wood-gas and air	No	Yes	Yes	No
Ability to save char	Yes	Yes	Yes	Yes

'iCan' concept presented by Jock Gill

Simplest All-in-One TLUD made from one tin-can, just 17 holes in the right places in one can. No tools needed other than a can opener and a nail or punch, takes less than 10 minutes to make. Very suitable for school projects or elsewhere to demonstrate the TLUD principle and have people cook something on the 'stove' they just made themselves. Similar concepts have been presented by other designers (like Paul Anderson's 'Willie-OneCan), but the most recent and nicely illustrated version was posted by Jock Gill on http://www.bioenergylists.org/content/peacham-ican-tlud-st.

More designs by Jock Gill on http://www.bioenergylists.org/taxonomy/term/1508/0 and on http://www.greaterdemocracy.org/archives/1116

'1G Toucan' by Hugh McLaughlin

Probably the second simplest TLUD micro-gasifier made essentially out of two cans placed on top of each other: typically a 1-gallon paint can and another slightly smaller can (called a "Number 10 tin" or a coffee-can in the USA) for the secondary air. The 'Toucan' is very educational to demonstrate the TLUD-principles. The combustion zone is very visible so that the convection flows and flame shapes are easily understood.
It is very suitable for the production of small quantities of consistent high-purity and easy-to-use biochar.
This is due to its unique construction features: primary air is fed through the bottom of the 1G-can (which is slightly raised) and secondary air through the second can on top.
The main fuel container has no air holes on the side. Thus char-gasification (which depends on the availability of oxygen) might easily be halted by sealing off the air supply: once the tin is placed directly on the ground and covered on the top with the paint can lid, it prevents char-gasification in an oxygen-starved environment.
This ensures the safe and easy saving of the char inside the container without having to quench the char in water or dump glowing char out of a hot container at the end of the wood pyrolysis stage. Makes also a good and powerful burner unit, ideal for a camp-stove or a make-shift stove as backup for power-cuts.
Can also be used as a fireplace insert.

Photo: Various 1G Toucans with risers at CHAB-camp in Massachussetts in August 2010

For further information see http://www.bioenergylists.org/mclauglintoucan, from where you can download easy and clear instructions at http://www.bioenergylists.org/files/1G%20Toucan%20TLUD%20for%20Biochar%20Jan%202010%20-%20final_0(3).pdf (0.6 MB)

'Everything-nice Stove' by Nathaniel Mulcahy (WorldStove)

The only construction instructions with flexible and relative measurements. This allows to adjust plans to the dimensions required and/or to available material like existing cans in various parts of the world. Ideal for easy construction of a gasifier burner unit for retrofitting in existing stoves and make them multi-fuel stoves (below see photos of a retrofitted charcoal stove from Benin or a carbon-negative grill).
For easy and clear construction instructions: click on the link at the left edge of the window at http://worldstove.com/products/#

Burner unit made out of two cans with a slight difference in diameter, so that one fits inside the other with a small gap for the secondary air. Features preheated secondary air. The publication of these plans in 2009 lead to multiple versions tried out all over the world:
http://worldstove.com/album/your-versions-of-the-everythingnice-stove/
Many of them are demonstrated in youtube-videos. Some examples come up through this link:
http://www.youtube.com/results?search_query=worldstove&search=tag

It also inspired Andrew Ma to make an ultra-light and most accessible burner unit by wrapping some woodsticks in aluminum foil. Not so practical to cook with, but great to show-case the concept of woodgas-application
http://www.bioenergylists.org/node/2762

An unnamed contributor used it to make a wood gas lamp and a stove:
http://www.youtube.com/user/jw934, http://www.youtube.com/watch?v=6XxL6pPGGCE

The concept also inspired Kelpie Wilson from the International Biochar Initiative to come up with instructions on how to make micro-gasifiers in a school project:
http://greenyourhead.typepad.com/files/how-to-make-dome-school-biochar-stove.pdf
http://dome-school-biochar.wikispaces.com/3-03-10+PH+Testing+and+Stove+Construction?responseToken=05f38338739a98240e47606ff31c5446a

The same 'Everythingnice' burner unit made from standard European size cans (425 ml and 580 ml) used in different applications.

		
Retrofitted in a charcoal stove from Benin for the alternative use of un-charred biomass instead of charcoal. Here run on pellets made from straw.	The stove can still be used with charcoal, if the hole for the riser of the gasifier burner is covered with a perforated piece of metal as a grate.	As a burner unit to power a make-shift carbon-negative barbeque-grill with 150 g raw wood-pellets. A lamp-glass was used as a riser to be able to see the flame.

(Photos Christa Roth, June 2010)

'Grassifier' by Crispin Pemberton-Pigott (Canada)

It shows the viability of grass-pellets as a cooking fuel, which can be potentially an important source of solid biomass energy especially in developing countries.
Can be made in 30 minutes with some more metal-working skills and simple tools: tin snips, a sharp punch, a hammer, a fat washer for making 'spouts' (not just holes) and a ruler or tape measure. It helps to have a piece of steel pipe which is shown being used as an anvil to fit the bottom plate.

General info and video on http://www.bioenergylists.org/taxonomy/term/1518.
Construction descriptions http://www.bioenergylists.org/en/crispin_25-kw-grasifier
No downloadable plans (yet).

The design is based on the 'Vesto'-principle (see previous section) and it can burn grass pellets but also a wide range of other solid fuels. The secondary air is preheated in a sleeve between the double walls, all the way up to the top of the unit, well above the secondary air entry holes.
The jets of well-preheated secondary air 'shoot' into combustion chamber through small holes and thoroughly mix with the wood-gas. The burner unit has no concentrator disk and still burns cleanly. It manages to keep the flames rather low above the fuel bed.
The designer estimates, it would cost about $1.00 to produce from thin stainless steel.

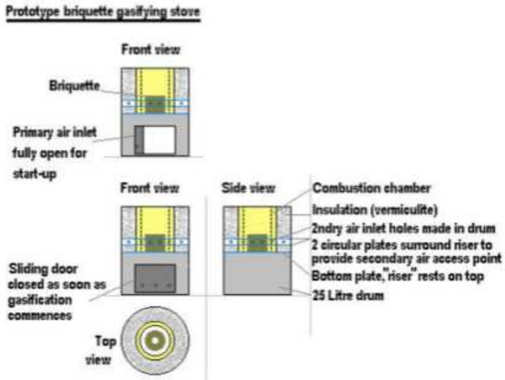
2.4 Other inspiring micro-gasifier concepts

Many gasifier concepts have been developed in the past to various levels of sophistication. Some never went into sizeable production, but might still be valuable for specific applications where they can be developed further. Some examples:

Designs developed by AD. Karve from the Appropriate Rural Technology Institute ARTI in Pune, India:
The 'Vivek' stove for sawdust and the 'Agni' stove for briquettes and wood chips, More info on:
http://www.arti-india.org/index.php?option=com_content&view=article&id=76:improved-cook-stoves-for-the-rural-housewife&catid=15:rural-energy-technologies&Itemid=52

Other special design for briquettes:
Richard Stanley and Kobus Venter: Holey Briquette Gasifier Stoves (2003)
http://www.bioenergylists.org/stovesdoc/Stanley/BriqGassstove.htm
http://vuthisa.com/

Holey Briquette Gasifier Stove, rated at 1,1 KW power output with 35% efficiency



Source: Bhattarcharya and Leon, 2005: Prospects for Biomass Gasifiers for Cooking Applications in Asia, page 5,
http://www.retsasia.ait.ac.th/Publications/WRERC%202005/AIT-gasifierstove%20for%20cooking-final.pdf

Gasifier conceptualised in 2004 in India by Krishna Kumar
http://www.bioenergylists.org/stovesdoc/kumar/KK NDG.pdf

Woodgas stove made out of ceramic by Saibaskar Reddy: Interesting alternative for gentle 'one-armed-cooking' with only light stirring: http://e-woodgasstove.blogspot.com/. Unknown practicality for 'two-armed-cooking' involving heavy stirring for which a certain physical strength of the structure is needed. In this case retrofitting a simple gasifier burner unit in a sturdy (clay) stove might be an easier option.

Example of a cross-draft gasifier mentioned in a report from GERES in Cambodia:
In the efforts from RETSASIA, some cross-draft gasifier models were developed, the one mention in the report on page 12 is was adapted by Planète Bois to be used for extended cooking times e.g. in cottage industry production (tested in Cambodia for sugar-extraction from palm juice) or where space heating is needed (field trials in Morocco). The gas-generator and the gas-combustor are both vertical chambers, connected in the lower part by a horizontal channel to take the pyrolysis gases across into the combustion chamber. Power is regulated by the primary air supply. For easy comparison a graph of a TLUD is depicted next to it.

A cross-draft stove in Morocco

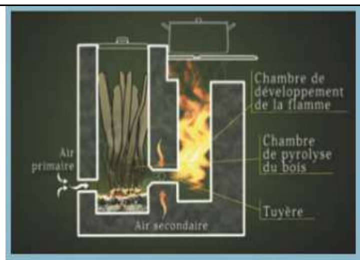


Figure 4 : le principe de la combustion bois
CLIP, GERES (2009)

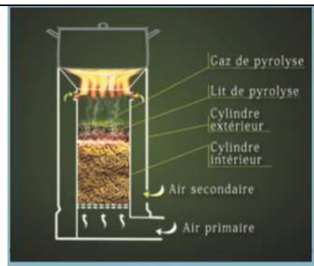


Figure 3 : le principe de la combustion bois
T-LUD, GERES (2009)

Source: http://www.geres.eu/fr/etudes/122-publi-etude-nls, page 12

Videos and other instructions:
There is a multitude of contributions found on the internet these days. Some selected high-lights:

Lanny Hanson: a very productive designer of useful prototypes who shares his inventions on http://www.youtube.com/user/lannyplans

Robert Flanagan (China)
Robert Flanagan has some designs that are being tested especially with bamboo as a fuel in China. Videos on
http://www.youtube.com/watch?v=Y5OAkmum7gU&feature=related

http://www.youtube.com/watch?v=Wubjh8_b4Xg&feature=related

Or documents on:
http://terrapreta.bioenergylists.org/terrabiocharstove
http://www.carbon-negative.us/burners/docs/RFlanaganCookstove.pdf
http://www.unccd.int/publicinfo/poznanclimatetalks/docs/Natural%20Draft%20Stove.pdf

Module 3

Biomass feedstock and fuels for micro-gasification

Samples of natural and densified fuels

Table of content Module 3

3.1 Solid biomass suitable as fuel in a micro-gasifier

Micro-gasifiers can handle a great variety of biomass that must be solid, relatively dry, and of sizes that allow the proper passage of primary air. Although mineral coal could be used in a significantly altered micro-gasifier, the focus here is on the vast resource-base of RENEWABLE SOLID BIOMASS FUELS that other burners cannot handle. A wide range of renewable biomass residues beyond conventional firewood sticks or charcoal can be used as cooking-fuel in a properly designed micro-gasifier.

...using biomass that does not require the destruction of timber resources means less stress on the local environment[17]:

For optimal fuel use and combustion efficiency the biomass fuel should

1) Be **dry**: moisture content preferably below 20%. High moisture content results in less stable stove operation and decreased available energy output of the fuel because more energy is used simply to evaporate the moisture.

2) Be slightly **chunky** to allow air/gas passage: particle size should exceed 4 mm in the smallest dimension. For finer feedstock like sawdust and rice husk, a fan-powered micro-gasifier, using forced convection to control the flow of air, is advisable

3) Have relatively **uniform particle size distribution** to avoid compacted zones or oversized voids in the fuel container which would prevent the uniform progression of the pyrolysis front through the fuel-bed

4) Be sufficiently **energy-dense** enough to achieve a reasonable balance of the 'burnable mass' in a given volume of a fuel-container with cooking duration and refueling efforts.

There are some general issues about choices of biomass fuels to be considered:

- The fuel should not compete with resources necessary for food production (like land, water, labour etc.) or a higher value use, such as a building material.
- Fast growing fuels should not negatively impact the biodiversity of the locality.
- Any fuel must be economically available in the long-term.
- Fuel must be convenient to use and appropriate for the intended use.
- The supply of any biomass should be sustainably managed, so that it can be a truly renewable energy source
- The fuel should not contain or release any toxic or harmful substances. In general, any previously living material is non-toxic when combusted, but some fuels may have been treated with toxic substances required by a previous use, such as treated lumber for insect and rot resistance. Such treated materials should be avoided, especially in cooking applications where humans are often in close proximity of the combustion gases.

In areas with irregular and scarce rainfall, drought tolerant species are preferred. Many 'anti-desertification plants' that are suitable for restoring vegetation cover in arid areas can also provide good biomass fuels. A selection of suitable plants is found on http://desertification.wordpress.com/3-interesting-plant-species/. Some examples mentioned are pigeon peas, flax, jatropha, bamboo, switchgrass etc.
Here are some examples of biomass successfully used as cooking-fuel in gasifier stoves in Haiti e.g. peanut shells, rice and coconut husks, corn stalks and stover, small twigs and branches, sugar cane bagasse, wheat chaff, animal waste, bamboo, citrus fruit rinds, man-

[17] Partially quoted from http://www.charcoalproject.org/2010/05/a-man-a-stove-a-mission/

go pips, cardboard, wood shavings, processed biomass briquettes or pelletized grasses, sawdust, lumber yard scrap (Photos Courtesy of WorldStove):

All Photos: WorldStove 2010

Although not all are yet tested for use in a micro-gasifier for cooking, additional candidate fuels and biomass resources are discussed at
http://www.gocpc.com/biomass-resources.html

3.2 Factors influencing fuel properties

3.2.1 Moisture content

What is the impact of moisture in the gasification process?
Moisture reduces the net usable energy output of a fuel: Any moisture contained in a fuel is water that will consume 3,21 MJ of energy per kilogram (litre) of water to be evaporated in the process of heating the fuel from ambient to the pyrolysis temperature around 400°C.[18] This energy is not available for cooking, yet increases the weight of the fuel that needs to be provided to the stove.

What is the right moisture content?
There is no definite answer to this question. The fuel should be as dry as possible in tropical climates. A moisture content between 8 to 20 % seems to be best. Though some stoves with forced air claim to be able to burn fuel up to 30% moisture content, this is definitely not desirable, as too much energy will be wasted to dry the fuel.

What happens if the fuel is too wet?
- Lighting wet fuel is much more difficult than lighting dry fuel.
- Some micro-gasifiers handle wet fuel better than others:
    - Micro-gasifiers with a flaming pyrolysis front have a limited tolerance for wet fuel, as the cooling effect caused by fuel moisture cools the flames in the zone of flaming pyrolysis: Imagine the evaporated steam, mixed with the combustible gases, acting as a fire-extinguisher putting out the flaming pyrolysis. In that case the ‘engine’ of the wood-gas production comes to a halt and the micro-gasifier goes on to a slower oxidation mode known as “smoldering pyrolysis”. This oxidation mode does not generate enough useable heat to allow cooking, wastes the fuel, and has a negative effect on the emissions.
    - allo-thermal (retort) gasifiers, where pyrolysis is only caused by heat in the total absence of oxygen handle moist fuel better. They just lose fuel efficiency due to the energy expended during the fuel drying phase inside the retort.
- Super-heating water vapour causes cooling of the pyrolysis zone, resulting in less efficient use of the fuel and slower cooking times.

Not enough information was found on the effect of higher moisture content in fuels on emissions. This is an open issue for further research.

Conclusion:
Moisture has negative effects on fuel economy and emissions.
A substantial amount of the energy generated through the combustion of fuel is wasted due to the moisture present. The higher the moisture content of the fuel, the bigger the energy loss through evaporation and less energy value of the fuel is available for the intended purpose of fuel use like heating a cookpot.

[18] An example with a detailed calculation can be found in the Annex to this module.

3.2.2 Particle size and particle size distribution

What is the impact of fuel size on the gasification process?

The size of the fuel in the fuel-bed determines how easily gases can flow and travel through the fuel-bed, whether this is incoming air or outgoing wood-gas or char-gas. The fuel size also dictates how fast the heat from the flaming pyrolysis conducts down the fuel stack. The fuel size and shape is not generally critical to a stove operation, but the fuel has to be in the range of the acceptable properties to allow use of proven stove designs without modification. Any new fuel needs to be tested and the operating conditions adjusted for the particular properties of a new fuel source.

What is a suitable size of fuel for a micro-gasifier? What is 'too small or too big'?

In general, granular and 'chunky' material, which will enable an appropriate and steady gas-flow through the fuel-bed in the combustion chamber is preferred for a natural draft device.
In general particle sizes seem to work better when the minimum is 6 mm length for the smallest dimension,, so the dimensions should preferably be between 6x6x6 mm - and 60x60 mm x height of the combustion chamber (like a big briquette or straw bundle, that can be placed vertically in the combustion chamber).
A rule-of-thumb by Hugh McLaughlin says that the average of the lengths in all 3 dimensions of a fuel particle should be less than 10% of the diameter of the fuel container. In other words, if a fuel container is 15 cm in diameter, the particles should not exceed an average of 15 mm length over the 3 dimensions.

Too small particles will block the gas-flow. The restrictive effect of fine particles like sawdust or rice husks on flow can be overcome either by forced convection through a fan or a blower, or (less desirably) with more draft through a tall chimney.
Large chunks of fuel create three problems. First, a thick object takes longer for the pyrolysis to reach the center of that biomass particle. The initial pyrolysis leaves behind a layer of charcoal that actually insulates the center of the particle. As air continues to reach that part of the pyrolysis front, this favors the conversion from char to ash and can result in a considerable increase in temperature (which may cause physical stress on the material of the fuel chamber). It adversely affects the char yield, which is an unwanted effect if char should be saved for further use. It is also harder to get the flaming pyrolysis front to progress compactly and uniformly down a bed of larger particles, with the result that the end of the burn is less precise, resulting in some uncarbonized material in the center of the lowest large particles and other sections of char being burned to ash.

The second problem is that too big chunks create big spaces between the fuel, which are filled with air under normal conditions. Unrestricted air-flow might lead to excessive primary air in the fuel-bed.
The particle size distribution defines the 'pore space' between the fuel and therefore the ease of gas passage: Gas will follow the 'open corridors' that are not blocked. So if fine particles block gas passage in a particular zone of the fuel bed, the gas will find its alternative ways through other zones in the fuel bed with bigger gaps between bigger fuel chunks. This will lead to a very uneven flaming pyrolysis front, likely to result in smoke and incomplete fuel use.

Third, when big chunks create cavities between them and finer particles rest above, ignited finer material can fall by gravity in the cavity beneath the pyrolysis front. This will cause an abrupt increase in the gas production, which often cannot be combusted with the available secondary air. The result is undesirable smoke.

Paul Anderson suggests that the longest dimension of the fuel particles should not be greater than 25% of the diameter of the fuel container, so that fuel that is casually dropped into the container can fill in the voids between the particles.

An exception to this is the use of longer fuels that are intentionally placed (not casually dropped) vertically into the fuel container. Examples include segments of bamboo, bundles of grasses, and some stick-wood that is not excessively contorted. These vertical piles often have many long channels for the primary air. In this case, a second type of fuel that is smaller can be added to the top and (usually with some shaking) loosely fill those channels, preventing any ignited fuel from dropping to lower positions.

In general, the initial difficulties about fuel selection and loading are soon overcome when local people gain experience and have their own preferred fuels and procedures.

Conclusion:
a fuel should be reasonably **uniform** to prevent blockages and unequal movement of the pyrolysis front, as this may create smoke.
However:
Micro-gasifiers have a big comparative advantage in the range of fuel sizes, including those fuels that are otherwise too small to easily be burnt cleanly in other stove models.

3.2.3 Fuel density and Bulk density

What is the impact of fuel density on the gasification process?

The density of a material usually relates to 'mass per volume', measured e.g. in kg per cubic litre or even per cubic metre. However, in the context of fuel as an energy source, the term '**fuel density'** is often used relating to the **available energy in a fuel on a weight basis**. It indicates how much burnable carbon-material is contained per kg of a fuel, and how much are other unburnable substances like water, solid minerals (ash content) are contained in 1 kg. This gives an **energy value**[19] of a fuel, commonly expressed in Megajoule per kilogramm (MJ/kg), or in America as Btu per pound.

Energy values vary mostly due to variable levels of moisture and unburnable components ('ash') of a fuel feedstock. If the fuel is moist, it has an increased mass (it is heavier) in relation to the combustible components, and the total energy value is lower, as 3,21 MJ have to be used per kg to evaporate the water from the fuel during combustion.

The **bulk density** is the ratio of weight over total volume of a solid substance when it is poured into a container. Bulk density includes the volume of air between the fuel pieces, and measures how well the fuel packs together. The bulk density of a fuel determines, how much 'burnable mass' of the fuel can be fitted into the volume of a fuel container at any one time. This determines how much biomass feedstock is available for the creation of woodgas and char and how much energy can be created from one batch of fuel. There are great differences in bulk density of biomass feedstock, depending on size and shape of the loose particles:

A 1 litre-volume fuel container can approximately accommodate either 100 g of lose rice husks or 700 g of densified wood pellets. So density does matter!

The following table gives more answers to the questions, based on the comparison of selected fuels:

Solid density = How much would 1 solid m3 of the fuel weigh, if it were compressed to a solid block without air gaps (equivalent to grams per litre)?

Bulk density = How much mass of a fuel can fit in 1 litre volume of a fuel container?

Energy per weight (or technically per mass) = What is the net energy value (lower heating value) or the energy yield of 1 kg of fuel if it is completely combusted?

Energy per volume = How much energy can I get out of fuel loaded in a fuel container per litre volumetric capacity (without compressing the fuel)?

[19] There are 'lower heating values' (LHV) for net energy released and 'higher heating values' (HHV) for gross energy. The main difference is in the assumptions about the water content. For the LHV the energy used for evaporation of water is subtracted. LHV is used here as it is more relevant for applications. Individual samples may differ. Heating values can vary greatly even for one single species because biomass originates from previously living plant organisms, that can be different depending on the growing conditions in each location. More information on http://www.fpl.fs.fed.us/documnts/techline/fuel-value-calculator.pdf

Fuel type	Moisture content	Solid density	Bulk density	Energy per mass	Energy per volume
	Percent	kg/m3	g/litre	MJ/kg	MJ/litre
green saw dust	50%	1,100	367 g	11,85	4,3
air-dry saw dust	10%	800	250 g	17,06	4.6
green woodchips	50%	1,100	550 g	11,85	6.5
forest-dry wood chips	10 %	800	400 g	17,06	6.8
dry pellets (wood, saw-dust, peanut shells etc.)	6-8%	1,000 – 1,250	650-700 g	19,75	13.9

Source: table of fuel densities on http://www.woodgas.com/fuel_densities.htm

Values for individual samples may vary with the moisture content, size and shape of the fuel particles.
For comparison some other LHVs (rounded in MJ/kg):
LPG 48, Kerosene 43, Ethanol 27-30.
The values for charcoal can range between 25-30 MJ/kg, depending on the quality of the charcoal, the temperature and the feedstock that it was made from.

It is clear, that saw-dust from green, freshly cut wood has a similar solid density as dry compressed pellets from woody biomass. Yet the energy yield per load of fuel per litre of fuel container is less than a third of the pellets: reasons are the high energy losses from the need to drive out moisture and the low bulk density of the sawdust.

If the fuel is neatly stacked with a minimum of empty spaces in between, nearly double the mass can be accommodated in the same volume[20].
Vertical stacking is a good way to pack straw or stick-type fuel in a fuel container. However, vertical stacking can cause problems with the uniform progression of the burn within some stove designs (the class of stoves known as TLUDs), where the flames travel down individual sticks of fuel and ignite the entire fuel mass from below – leading to excess smoke production.

Conclusion: The relevant questions for a cook operating a stove are how much power and heat can be generated at any given time, over the course of the entire cooking cycle and per batch of fuel. This 'how much cooking can be done with one fuel load' is especially important for batch-operated micro-gasifiers.

Net energy yields from a fuel depend greatly on the type of biomass, the moisture content, size and shape, way of stacking and the resulting bulk density of the fuel.

Low-grade biomass residues with high volume can provide better energy yields in a gasifier if they are dried, properly sized, compacted and densified.

Some biomass is 'ready-to-use' in a micro-gasifier, for other feedstock some processing steps might be required to prepare biomass feedstock for optimal use as cooking fuel in a micro-gasifier: **Drying, sizing and densification.**

Biomass for cookstoves comes in three sizes: too small (so make briquettes, etc.), just right, and too large (so cut it smaller). All other fuels are processed or sized, some at great expense as in oil refineries. It is reasonable to expect the biomass fuels supply industries to substantially grow and mature as gasifier devices become widely used.

[20] An example can be found in the Annex.

3.3 Feedstock ready to use without major processing

The list of usable feedstock is nearly endless and depends on what is readily available in a certain location. The following table from FAO gives some ideas, where to look for appropriate feedstock. Municipal by-products are not recommended for use in micro-gasifiers for cooking or space-heating, due to high variability and the presence of potentially toxic ingredients, such as used motor oil and rechargeable batteries.

Table 2: Classification of Biofuel sources by different characteristics

		woody biomass	herbaceous biomass	biomass from fruits and seeds	others (including mixtures)
		WOODFUELS	**AGROFUELS**		
Energy crop	direct	- energy forest trees - energy plantation trees	- energy grass - energy whole cereal crops	- energy grain	
By-products*	direct	- thinning by-products - logging by-products	crop production by-products: - straw	- stones, shells, husks	- animal by-products - horticultural by-products - landscape management by-products
By-products*	indirect	- wood processing industry by-pro-ducts - black liquor	- fibre crop processing by-products	- food processing industry by-products	- biosludge - slaughterhouse by-products
End use materials	recovered	- used wood	- used fibre products	- used products of fruits and seeds	**MUNICIPAL BY-PRODUCTS** - kitchen waste - sewage sludge

Source: Unified Bioenergy Terminology ftp://ftp.fao.org/docrep/fao/007/j4504e/j4504e00.pdf, page 9

Agricultural residues are generated in large volumes season by season and often discarded as waste - not put to use at all. Crop residues are the largest source of non-timber biomass fuel: straw, stem, stalk, leaves, husk, shell, peel, lint, stones, pulp, stubble, etc. which come from cereals (rice, wheat, maize or corn, sorghum, barley, millet), cotton, groundnut, jute, legumes (tomato, bean, soy), coffee, cacao, olive, tea, fruits (banana, mango, coco, cashew) and palm oil. In the developing world, most agricultural residues that are burnt as fuel are used in their natural state with some pre-treatment like drying, and cutting, and compacting in rare. Compared to wood-fuels, crop residues typically have a high content of volatile matter, lower density and lower burning time. The next table provides a comparison:

Advantages	**Disadvantages**
• Agricultural residue is a fuel which is available free of cost to the poor rural families. • It is also a useful way to dispose of the crop residues in the field, instead of burning them *in situ*. • Agricultural wastes remain safer than LPG which poses some safety concerns in local transport and use; • It is easy to handle and transport; • Low impact on women's time for harvesting • Agricultural wastes are much easier to light than wood and charcoal	• It is responsible for extreme cases of air pollution when it is burned in open fires or traditional improved stoves. But it can burn well in gasifier stoves. • It is very bulky and has to be carried to the homes. • The seasonal availability of crop residues can be limit for its use. • Its burning time is shorter. • Its storage requires more space inside a house or shelter and protected from rain.

Some of the disadvantages associated with the bulkiness of the residues can be addressed by shaping and compressing the raw fuel, a process called “densification”. Unfavorable burning properties of native residues when used in conventional burners can be overcome by the use of micro-gasifier burners that can handle this type of fuel best. Some other examples show that use as fuel can contribute to decreased environmental pollution. People get encouraged to use waste biomass that otherwise would be left to rot or burn, accumulate in large piles or unnecessarily consume precious land-fill-space.

	An example of an unprocessed feedstock with excellent fuel properties to be used in a gasifier stove: the rind of some kind of large citrus fruit called ‘chadeck’ commonly found in Haiti. According to Nathaniel Mulcahy in March 2010, they got 37 minutes of pure blue flame with the rind of only 3 chadeck fruits. Source: http://tweetphoto.com/13064693, courtesy of worldstove	
		Also from Nathaniel Mulcahy, unprocessed sugarcane stalks forming one load of fuel for a locally made Lucia stove in Haiti, burning with a clean flame. Courtesy of WorldStove, http://tweetphoto.com/14266639 and 14266747

3.4 Fuel processing techniques

A homogeneous fuel with uniform sizes and shapes, like 6-10 mm diameter pellets are a very recommendable fuel for a gasifier. Therefore Nathaniel Mulcahy concluded after the assessment of available fuel sources in post-earthquake Haiti, that *'clearly pellets are the single best fuel option for Haiti right now'*.[21]

The following table provides some guidance on feedstocks and their potential processing needs:

Size	**Examples**	**Problem**	**Solution**	**Processing needs**
Too small particles	Sawdust Rice husks	Small particles block gas flow	Produce bigger chunks	Densification
Inhomogeneous particles size distribution	Wood shavings mixed with sawdust	Small particles block gas flow	Produce chunks of homogeneous size	Densification
Too bulky (high volume, low value)	Groundnut shells, straw, hay, etc.	Big volume combustion chamber needed, transport cost	Needs to be made more compact	Densification
Correct size	Anything that can be used directly in the fire chamber: wood shavings, twigs, nut shells, sheep dung, rabbit droppings, corn stovers etc. (see 3.1)			(drying)
Too big particles	Wood chunks, bamboo, coconut shells	Cannot fit in combustion chamber	Produce smaller chunks	Sizing: cutting, chopping, shredding etc.

Carbonisation of biomass is not a processing technique described here, as micro-gasifiers can handle uncarbonised biomass very well, unlike conventional charcoal burners which depend on carbonised fuel. In the Annex there is a description of some techniques, how to convert the char created in pyrolytic gasifiers into briquettes.

[21] Find the full article on http://www.bioenergylists.org/content/fuel-options-post-ea

3.4.1 Drying

Drying by sun and wind are feasible and cheap options in most scenarios where drying of biomass cooking fuel is needed. Subsequent dry storage complements the efforts to keep the fuel from regaining moisture from the elements.
One has to differentiate between core moisture of a fuel and surface moisture. Surface moisture (when e.g. a core-dry fuel got wet in a rain shower, but the moisture has not penetrated to the core of the fuel) can be removed in a couple of hours, while core-moisture needs days, weeks and even months to be removed, depending on the diameter of the fuel pieces.
Biomass fuel can easily be pre-heated with the effect to remove residual moisture if the fuel is kept close to the stove before use. Some stoves offer special options like a warming-drawer for fuel underneath the stove for that purpose. Drying by kilns and ovens is typically irrelevant for household fuels, so it is not discussed here.

3.4.2 Sizing

Sizing is understood here as **Size reduction** of compact, high-energy fuels to micro-gasifier-compatible size by chopping, cutting, chipping, grinding, breaking, sawing, etc. This applies mainly to wood or other solid predominantly woody biomass that comes in too big chunks to fit in the fuel container of a micro-gasifier for cooking.
For 'up-sizing' to create bigger chunks from small or inhomogeneous particle sizes the processing needed is 'Densification' which is dealt with in the next paragraph.

A word of caution: in an area with abundant supply of wood in the form of big logs or sticks, it has to be considered carefully, if down-sizing of fuel to a micro-gasifier-friendly format is the most feasible option, or if there are other alternatives to burn that type of biomass cleanly. Chopping of wood by hand is a big physical effort which most people dislike and therefore complain about. In a scenario where there is no scarcity of big-sized wood, other stove-models like e.g. rocket stoves, that can burn stick-wood well and cleanly, might be more acceptable and appropriate for household cooking. If the production of biochar is the major interest and household cooking not required, bigger units such as the Adam Retort should be considered.
Sizing-requirements by hand can be a make-or-break- factor for the acceptance of micro-gasifiers in an area. If too much additional effort is required to prepare the fuel, gasifier stoves will not be liked and successful adaptation is less likely.

If possible, it is recommended that a fuel-supply chain of down-sized wood (e.g. wood-chips) be established at reasonable cost and convenience using mechanised equipment. For areas without other smaller sized naturally occurring fuels, this will improve the acceptance of micro-gasifier for cooking.
The main tools for manual sizing operations are knives, axes and splitters. For mechanical operation there are some shredders and chippers with fly-wheels driving rotating blades and grinders. Hammer-mills use mainly impact forces, whereas cutting-mills cut the material to pieces with rotating cutting 'teeth' out of hard metal[22].
The most common equipment for larger-scale operations depend on external power by combustion engines or electricity: Larger equipment might be needed as a pre-processing step for densification: the input material has to be smaller than the densified output product. In other words, to produce a pellet of 6 mm diameter, the feedstock has to be smaller. Industrial equipment is based on shredders, grinders, or hammer mill-type choppers. Equipment of all sorts of sizes exists and has to be selected according to the specific needs of a location and scale of operation.

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[22] http://wiki.gekgasifier.com/w/page/6123688/Chippers,-chunkers,-loppers,-splitters,-shredders,-disintegrators,-etc gives a good overview on available wood-sizing equipment

3.4.3 Densification

The most important processing need is densification of bulky low-grade biomass materials, available as wastes and in high volume that can otherwise not be used well as cooking fuel. Compacted and densified fuel has several advantages:

- It has a higher heating value per volume (more carbon per volume).
- It reduces transport costs (more fuel, less air to be transported)
- It has more predictable performance in a stove due to more uniform size, shape, density etc.
- It is often easier and cleaner to handle (less dust, easier packing etc.)
- It is more convenient as it comes in the right size ready-to-use (no chopping required)
- It has better storability (less moisture absorption, less mould, less spontaneous fires through self-ignition, less insect-infestation than natural fuel)
- It can be a solution to waste management problems
- It adds value to low-value residues, often creating employment in the process

However, densified biomass is not the magic bullet! Additional equipment and labor are required. To establish this capability locally, outside investments are recommended.

- Only where fuel is already a commodity (like in many urban areas)
- Only where households have purchasing power
- Only where there is a large source of un-used 'wasted' residual biomass (do not compete with the use as manure or compost)
- Only where there is a feasible link between the source of biomass and the market of the densified fuel (relation of distance, transport costs and the value of the fuel)
- Only where fuel densification can be run as an income generating business
- Only where there is electricity so that larger scale operations can be done without electricity only manual production at a small scale is feasible

How can materials be densified for use in micro-gasifiers?

Various binding and compaction methods are used to 'glue' the loose biomass material together to form a compact dense shape, which does not immediately fall apart during drying, handling and use a fuel. The intended use of the product and the envisaged scale of operation determine size, shape and the needed degree of compaction of the product.
The processes of biomass densification can be clustered in three main groups[23]:

The wet, ambient temperature, low pressure (10-15 bar) process: an added binder is optional, as binding is effected through random rearrangement of softened and detached natural fibres in a wide variety of agricultural residues and in other waste feedstock. The process accepts sawdust, rice husks, bagasse, coffee/ peanut shells, and other granular feedstock as well as charcoal dust and crumbs -or purposefully charred agricultural residues- as part of the matrix, as long as the fibres can encapsulate them into a tight non-elastic mass when compressed. Emphasis is on careful blending and pre-preparation of feedstock for pliability, combustibility and other behaviours. Once the principles are mastered, a far wider variety of ingredients are possible as compared to other processes. Densification and shaping can be done using a hand to squeeze the material into shape, or human force to press the material in a mould. Over 25 designs of hand operated or mechanized versions of presses are in use, based on various ways to create pressure: levers, hydraulic jacks, screw platens, treadle/peddles etc.
Costs range from $50 to $750. The density of product is commonly 0.3 to 0.5 gm/cc.

[23] based on an email by Richard Stanley from the Legacy Foundation in May 2010.

The moist-dry ambient temperature, low-medium pressure (10-50 bar) process: The next level would usually start at similar the pressure as the previous process, but go far beyond, depending on the type of machinery. It uses some form of binder (clay, starch, banana peel paste, waxes, glues, molasses, etc.). Temperatures are still near ambient but the water is minimal or absent. The relatively dry feedstock mix allows the use of loose augurs (‘screws’) and rams or pillow compression cylinders, as well as the above "wet process" presses. Over 10 designs of hand driven or mechanized presses using various augurs and rams are in use. Costs can start at 50 USD for hand-driven devices. Fuel density ranges from .3 to .7 gm/cc. The product range includes waxed logs and products from char dust products, finding increased acceptance in the third world.

Dry high-pressure process: The next kind of densification involves a great jump in pressure (400 to 600 bars), and requires drying equipment to assure a moisture content below 20%. Compression by ram or augur often requires added heating jackets which raise the barrel/cylinder/die temperatures up to around 200° Celsius. This combination of pressure and temperature effectively scorches the exterior wall of the resulting log, and tends to melt the lignin of the biomass to accomplish binding. The process requires an assured supply of feedstock of a known type, grade and moisture content. These are more industrialized machines costing between 3,000 and 30,000 USD.
The term ‘**briquette**’ is used for a sizeable ‘chunk’ of densified product of any shape and compaction level where the smallest side-length is above 2 cm size.
If the final product of a high-pressure compaction is a short roundish stick of 6-12 mm diameter, the term ‘**pellet**’ is used. Pellets are shaped by pressing dry biomass at very high pressure through a die with many holes (like an oversize spaghetti-maker).

Various briquette- and pellet- presses are available mostly for the industrialized world. Fuel densities can even go beyond 1.0 gm/cc, as some highly densified briquettes and pellets are heavier than water and don’t float (an easy test to determine fuel density). There is a risk that dense but super dry pellets and briquettes tend to crumble apart in more humid conditions, as they regain moisture. In general the product quality increases with rising compaction pressure, which entails:

- Higher temperatures: causing the lignin contained in the feedstock itself to ‘melt’, so it can act like wax as the sole binder. Added binders become unnecessary.
- Less water needed for the feedstock preparation: thus less drying time and space needed afterwards; lower moisture content of product, thus higher heating values
- Rising electricity requirements and higher costs for investment and operation
- Decreasing labour intensity which reduces job creation in the production phase, with the potential of more local job creation in the fuel distribution chain

Many factors influence the feasibility of biomass densification in a given scenario.
The following tables attempts to give guidance for the choice of densification options according to the desired pressure and intended throughput per hour. It reflects methods of feedstock preparation and compaction, binders, etc.
The availability of required inputs like water, electricity, capital, labour, space etc. is critical to the success of any densification project. These can potentially be limiting factors for the feasibility of a densification option and should be used initially as part of the ‘make-or-break’ arguments. Please note that the factors described are in a continuum and have no clearly defined concrete values that would determine a clear-cut boundary to the next category.
Examples for some technologies are shown in continuation after the table.

Guiding tool to identify appropriate biomass densification options

Developed by Christa Roth

Pressure and build-up of temperature	low	moderate	high		
Preparation process	watery slurry (solid in water)	wet / moist (water in solid)	dry < 20% moisture		
Binder	natural fibres rearranged	needs binder: clay, wax, starch, molasses,	melted lignin from biomass		
Shaping process	hand moulded	pressed into a mould	extrusion through a die		
Means to build-up pressure	hand	light levers, screws	strong levers, screws	screws, pistons	rollers and dies (flat or round)
Electricity input needed	none	optional	single phase < 5KvA	triphase > 5KvA	
Labour intensity	high	moderate	low		
Scale of business (output in kg per hour)	low	< 50 kg per hour	> 1000 kg per hour		
Capital investment	low	moderate	high		
Business premises	drying space	storage space, electricity			

Low-pressure moulding by hand or low-cost light levers require a wet preparation of the feedstock and drying space after production. It might yield enough output for single household consumption or a family-business. Economies-of-scale with outputs of densified product above 1,000 kg/h require capital-intensive machinery and tri-phase electricity supply above 20 KvA, which might be limiting factors in certain locations. Some examples of options are presented in the following paragraphs.[24]

[24] There is also a fuel briquette online network - a great resource for sharing information, further support and/or broadcasting your own work: fuelbriquetting@googlegroups.com.

I) Manual briquetting options (wet pulp, low pressure)

a) Hand shaped briquettes

	The simplest way to make small briquettes: a slurry of biomass in water is left soaking for some days to enhance binding properties. The pulp is either squeezed by hand or pressed into a mould e.g. an ice-cube tray. Rearranged fibres assisted by a binder like paper pulp to keep the briquette in shape during drying and use. Feasible for small-scale production.

b) Briquette shaped with a simple mould from a perforated bottle

Another simple manual method for small-scale production is promoted by the Foundation for Sustainable Technologies (FoST) in Nepal: The wet biomass slurry is fed into a perforated bottle, intermittent with some discarded CDs to separate small 'pucks'. Pressure is exerted with a stick from the open end of the bottle and the water squeezed out through the holes of the bottle. FoST also promote larger lever-presses.

 Photo Christa Roth	Left: 'Bottle' press shown at the PCIA conference in Uganda in March 2009 by the founder of FoST, Mr Sanu Kaji Shrestha. Right: Various shapes and sizes of briquettes for sale in Nepal	 Photo: http://www.fost-nepal.org/

II) Lever-presses (wet pulp, low-moderate pressure)

Levers are good tools to create elevated pressure just with the input of human power. Longer or multi-compound levers increase the achievable pressures. Levers are faster to use than screw platens or hydraulic jacks.
There is a multitude of different lever presses out there. This section showcases only a selected sample of models which are easy to replicate or where plans for replication are available.

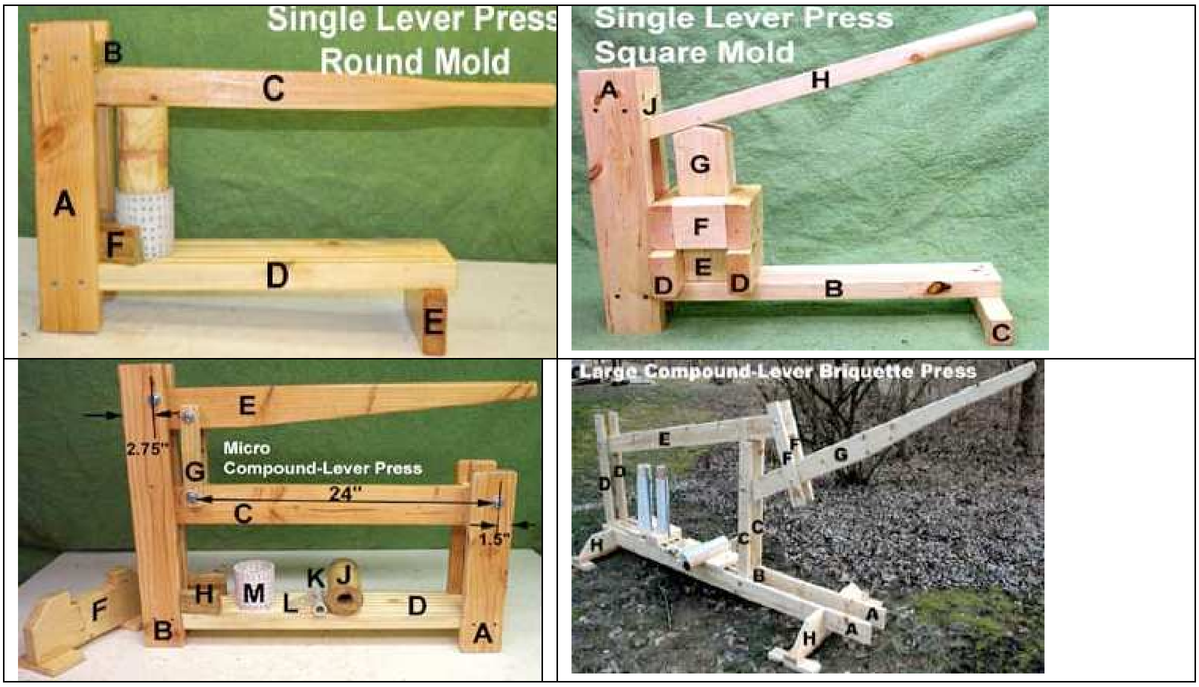
a) Paper-brick Maker

from Newdawnengineering at ca. 300 ZAR
Makes a 230x90mm fuel brick out of waste paper which can be mixed with other combustible fuels

like wood chips, grass or coal dust. Paper is a very good binder and should be used in combination with any other waste fuel that is available. Pressure generated by two small levers.
Ideal for decentralised small-scale production. More details at http://www.newdawnengineering.com/website/paper/brick/.
Reference to a bigger unit from the same company is made at http://www.newdawnengineering.com/website/stove/firecube/

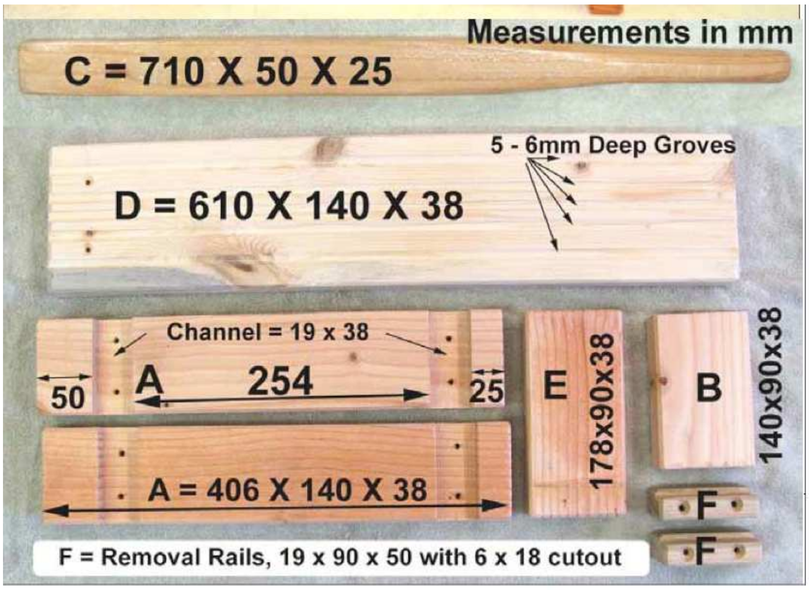
b) Wooden presses by Leland Hite

A very simple and low-cost biomass fuel briquette press made from wood can be found on http://www.youtube.com/watch?v=Mt0QQe6Eetw. The very instructional video showcases simple yet powerful and versatile versions of wooden single-lever and multi-compound lever briquette presses, which can produce square or round biomass briquettes at a speed of less than 1 minute per briquette. Measured drawings in inches or metric measurements in english and french language (incl. link to the video) can be found on
http://www.home.fuse.net/engineering/ewb_project.htm



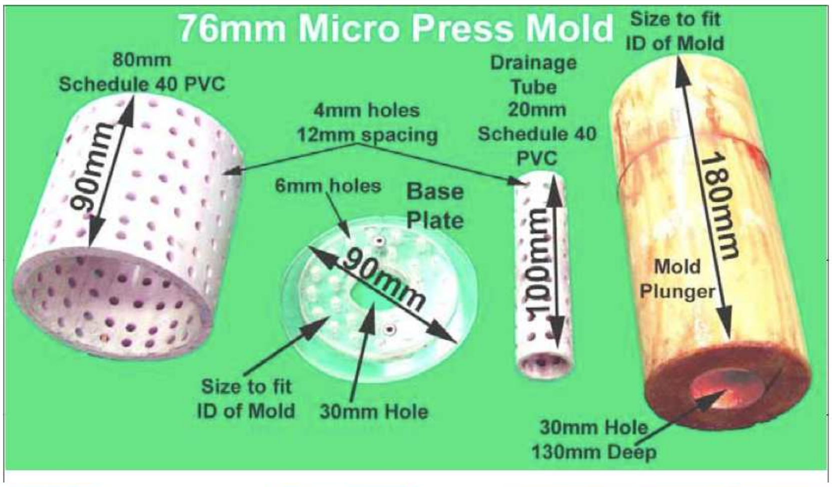
Source: http://www.home.fuse.net/engineering/ewb_project.htm

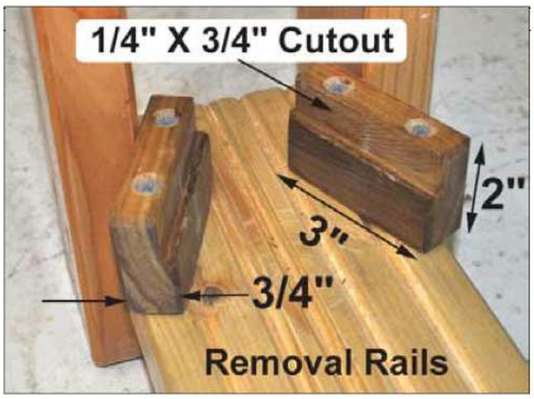
Example from the instruction manual with metric measurements in English language http://www.home.fuse.net/engineering/documents/Single_Lever_Round_Press_ENGLISH.pdf



EWB Cincinnati, Ohio, USA, Lee Hite, April 23, 2010, Micro Single-Lever Press

Micro Single-Lever Press ENGLISH



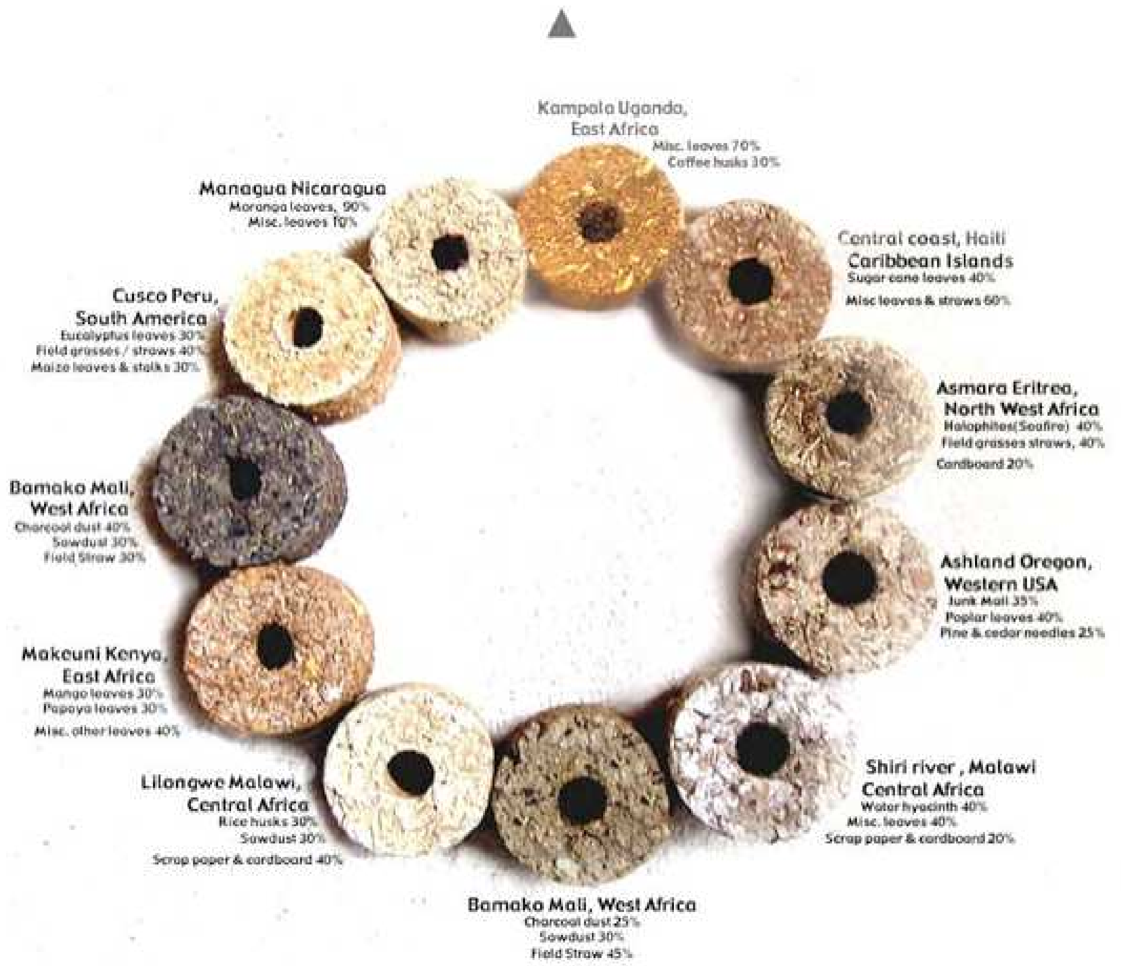


c) Wooden presses by Richard Stanley and the Legacy Foundation

Richard Stanley and the Legacy Foundation are probably the most active promoters of manual biomass briquetting all over the world. The website http://www.legacyfound.org/ has comprehensive resources on manual briquette-making and numerous publications (for sale)

There are various versions of the common ram-type press, cheaper ones from wood, stronger lever-presses can also be made from more durable metal at a higher cost.

Samples of biomass briquettes from all over the world



Source: http://www.legacyfound.org/html/photoGallery.html

III) Briquetting options: medium pressure, moist-dry feedstock

This category comprises versions of presses, that can be either mechanically powered, e.g. by a large fly-wheel or electrically, with electricity requirements depending on the pressure and the intended throughput. The speed of densification or achievable throughput per hour, the energy consumption of the press and the quality of the briquettes produced depend largely on the properties of the feed material (flow ability, cohesion, particle size and distribution, etc.) The moving parts, which generate the pressure against a die are either rotating screws or back-and-forth-moving pistons.
Typically outputs per hour are limited by the diameter of the die. Operation times depend on temperature build-up, with stopping required before the machine gets overheated.

a) Screw-type extruder presses

In a screw press / extruder a rotating, often conical screw takes the biomass feedstock from the hopper and compacts it against a die which assists in the build-up of pressure against the screw. The friction between the material and the die cause the material to heat to 300 ° C when the lignin gets mobilised as a binder.
A heating mantle around the die is common to enhance this. The created log-shape briquette exits at the front in a continuous stream and needs to be broken off to the correct size. The screw is subject to wear-and-tear and the material quality of the screw greatly influences its life-span. In developing countries extruders can often be manufactured by skilled artisans.

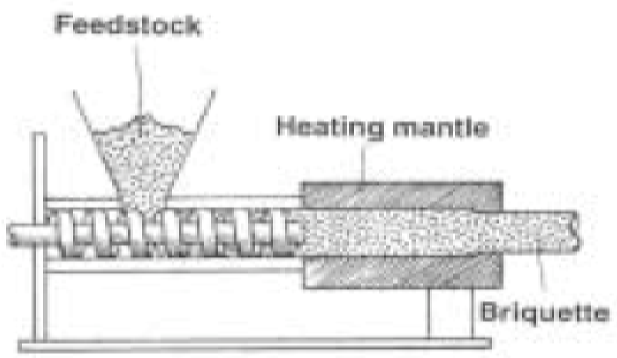


Figure and text quoted from:
http://www.gate-international.org/documents/techbriefs/webdocs/pdfs/e019e_2003.pdf, page 5

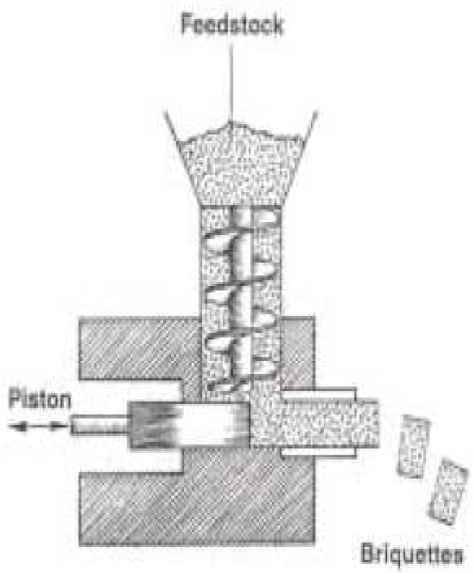
Depending on the shape of the die, the log is usually cylindrical or hexagonal. The produced briquette typically has a hole in the centre from the screw (hollow-core). From the partial torrefaction of the biomass by heat ('toasting') and the high degree of mobilisation of the lignin the surface of the briquette becomes dark and shiny like wax ('waxed log'). This type of briquette is becoming increasingly popular in urban areas of Asia like in Bangladesh.

Briquette sale by bicycle in Dacca
(Photo Robert Heine, 2010)

Hollow-core briquettes have been used in micro-gasifiers, but no test results for performance or emissions are known. They are expected to perform slightly better than the compact briquettes produced by piston presses described in the next section. More testing is needed to judge the behaviour of these fuels in micro-gasifiers.

b) Piston presses

A usually vertical screw transports the feedstock from the hopper into a feedzone in front of the die. A horizontally moving piston punches the feed material from the feedzone into a die with very high pressure ('die-and-punch'). The press can be a mechanical ram-type version powered by a massive fly-wheel, or hydraulically operated. The briquette is solid (no centre hole) and naturally breaks off at a less-dense layer between two blocks created with each impact of the piston. The product looks more like 'pucks' or flat disks.
Hydraulically operated presses are very heavy, as the hydraulic oil adds to the weight. For tropical climates added oil-coolers might be necessary to prevent overheating of the machine, which also limits their operating time, as they need to cool off every couple of hours. Piston-presses have less wear-and-tear than the screw-presses.



Source of diagram:
http://www.gate-international.org/documents/techbriefs/webdocs/pdfs/e019e_2003.pdf.

Briquette-making from saw-dust with a hydraulic press in Karamoja (Uganda)
Photos: Christoph Messinger

Suppliers of briquette presses should be selected according to the continent and the availability of after-sales services. Here a selection of reputable manufacturers with very long-standing expertise on hydraulic briquetting equipment from Germany. They could serve as an entry point for a more detailed product overview.
Gross, http://www.gross-zerkleinerer.de/english/index-english.htm and Ruf http://www.ruf-brikett.de/herstellung.php. Useful discussions of mechanical versus hydraulic equipment and briquettes versus pellets can be found on the site of a Danish supplier http://www.cfnielsen.com/briquetting.php?id=7.

IV) Pelletising Options[25]

In a pellet press, the feed material is pressed with high pressure between a roller and a hard-steel die. One of the parts is moving, while the 'counterpart' remains stationary. The feedstock has to be dry (within 10-16% moisture content) and ground finely to sizes smaller than the final diameter of the pellet. Common pellet diameters are 6 mm (standard size of wood pellets for automated space heaters in Europe), and 8 mm. Some 'maxi-pellets' with 20 mm diameter are currently being tried out in Germany for use in micro-gasifiers. No binder is needed as the lignin melts under the extremely high pressure, which forces the feedstock through the small hole of the die. Pellets exit the machine at high temperatures and often need to be cooled before packing. The achievable throughput is determined by the fuel properties as well as the size and the total square area of the holes in the die.
Electricity requirement is generally high and increasing with output per hour of the machine as well as hardiness of the feedstock. Woody material has less output per hour than softer materials, thus needs more electricity per kg of pellets produced.
The main types of pelletisers are differentiated by the die, whether flat or ring-shaped.

a) Flat-die presses

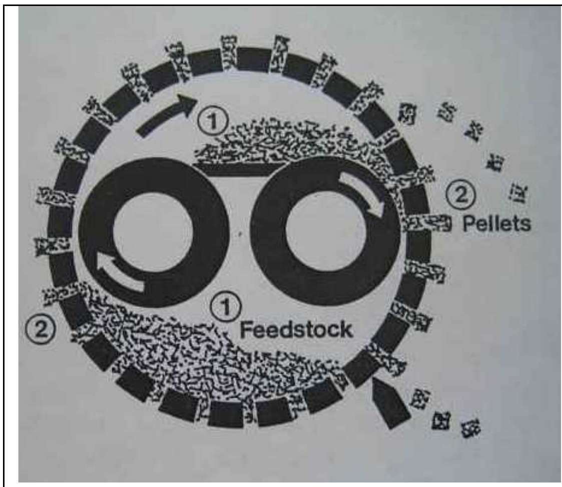
In a common flat die press, the rollers move and the die is a stable, flat disk of a hard steel alloy with a dense array of holes, normally placed horizontally in the machine, so that the pellets fall off by gravity. As the die is a flat piece, its diameter is the prevalent factor determining the material throughput. Flat-die presses rarely exceed 1,000 kg per hour, otherwise the diameter of the press would become too large.

	
'Maxi-pellets' pressed through 20-mm-holes of a flat-die at a rate of 50-80 kg/h, depending on material	Rollers pushing sawdust through the holes of a small 210 mm diameter flat-die disk below. Photos displaying an Ecoworxx Pelletiser

[25] Pelletising was originally developed as a method to create uniform densified animal feeds. Only in recent years wood-pellets have become the number-one renewable clean energy source in Europe, with growing importance worldwide.

b) Ring-die presses

In a ring-die the die is in a ring/drum shape and moves against fixed 'rollers'. This is normally used for bigger machines with outputs starting at 200 kg per hour. Ring-die presses are normally more expensive than smaller flat-die presses, but can achieve usually higher outputs per hour, as there are many more holes in the outside walls of the drum-shaped ring die than in a flat sheet-style die. Most industrial-size pelletising plants use ring-dies.



Ring-die press: the die is fixed and the rollers move, thus pressing the feedstock through the lateral holes. Source: Reed/Bryant, Densified Biomass p. 9

Ring-die press from AgriconSA in action (Photo Christa Roth)

The choice for the appropriate pelletising equipment is highly dependant on the material specification of the envisaged feedstock and the envisaged scale of operation. Hardly any experience on the topic has been gathered so far, thus it is difficult to make recommendations. Many small-scale pelletisers seem nowadays to be made in China. The life-span of the Chinese dies is not well known yet, but expected to be the most vulnerable part. Pelletisers often need to be combined with hammermills or other sizing equipment to bring the feedstock to the right size.
Ecoworxx in Germany have started in 2010 to produce an 'all-in-one' pelletiser with an included grinder http://www.ecoworxx.de/index_en.html. The machine seems promising for initial trials. Required electricity input is only 3 KWh, but tri-phase. Some manufacturers in the USA also have single-phase equipment running on 220 V e.g. http://www.pelletpros.com/id68.html or http://www.buskirkeng.com/.

On the African continent the only currently known manufacturer of pelletising equipment with self-regulating feed-options to avoid clogging of material is Agricon in South Africa. Their machinery is designed for less-skilled users for handling. They make larger-scale robust ring-die equipment focusing on agricultural uses.
For further information see http://www.agricon-pelleting.co.za/.

Summary of benefits of densified fuel for use in micro-gasifiers

	Advantages	Disadvantages
Fuel USER	• Easy and clean handling • More heat per batch load or Longer cooking period with same size and volume of fuel container • Less handling tasks • Predictable performance • Uniform properties • Better storability (easy to stack) • Less storage space needed • Less moisture • Fuel ready to use (like charcoal) • Less transportation issues • Less transaction costs • Less insects in the fuel	• Densified fuel is more expensive than 'natural' fuel
Fuel PRODUCER	• Add value to biomass residue materials • Reduce transport requirements	• Investment costs into densification equipment • Poor collectors of natural biomass fuels might not participate in value chain of densification
Environment	• Make use of biomass otherwise too small for fuel use, thus reducing the pressure on forests • Less spontaneous fires of large crop residue heaps • Waste management: turn uncontrolled dumping sites into mining sites for fuel, while reducing methane emissions • Biochar creation better from densified fuel	• Organic material used as fuel instead of green manure on the fields, can be overcome by feeding biochar and/or ash back to the soil

Pellets achieve one of the highest bulk densities and have proven to be an ideal fuel in micro-gasifiers: they have very uniform burning properties and provide more energy output per given volume of a fuel container. The created char promises good properties for further use. In a test done by Christa Roth in July 2010 in a gasifier burner unit made from tin-cans, the result was that 200 g of raw 6 mm diameters softwood-pellets burnt for 120 minutes and yielded 55 g of char. The volume of the char was roughly 50% of the initial volume of the raw pellets.

ANNEX

Annex for Module 3:

Here some rough calculations to demonstrate the magnitude of energy needed to deal with moisture in a fuel:

It takes approximately energy in the order of 1 MJ (MegaJoule) to convert 1 kg of dry wood into char, but much more energy if the wood has high moisture content.

The calculation is based on the following assumptions:
It takes 0.00417 MJ to heat 1 kg of water by 1° Celsius (= 4,186 Joule per g and 1°C)
It takes 0.33 MJ to heat 1 kg of water by 80° from 20°C to boiling point at 100°C
It takes 2.25 MJ to evaporate 1 kg of water, meaning to bring it from its liquid stage below boiling point into the vapor stage just above boiling point
It takes 0.63 MJ to heat 1 kg of water vapor from 100 °C to 400° C.
Conclusion: Every kg of water contained in a fuel takes up to 3,21 MJ of energy with it when it exits as steam or water vapor.

Let us imagine two equal-sized piles of 2 kg of wood with different moisture contents to see the difference in energy needed to convert both piles into wood-gas and char:

Input in pile: 2 kg of	oven-dry wood[26]	fresh-cut wood
Moisture content in %	0 %	50%
Kg dry biomass contained	2 kg	1 kg
Kg water contained	0 kg	1 kg
Energy needed to evaporate water content	0 MJ	3,21 MJ
Energy needed to convert wood content to char	2 MJ	1 MJ
Total energy need to convert wood-pile to char	2 MJ	4,21 MJ
Calculated energy need per 1 kg of dry biomass	1 MJ	4,21 MJ

Conclusion: A substantial amount of the energy generated through the combustion of fuel is wasted due to the moisture. The higher the moisture content of the fuel, the bigger the energy loss through evaporation and less energy value of the fuel is available for the intended purpose of fuel use like heating e.g. a cookpot.

To chapter 3.2.3: Density of stacking
The method of stacking fuel in a container also influences the air gaps in between, which has an impact on the gas passage and the energy per volume.
According to data from http://www.ruf-brikett.de/quality.php?lang=en, the difference can be considerable of the mass contained in 1 cubicmeter:
380 kg/m3 for solid softwood with no air spaces in between
323 kg/m3 for neatly stacked split logs of 33 cm length, including the empty spaces
270 kg/m3 for stacked piled round timber of 1 m length with the empty spaces
190 kg/m3 bulk of loose dumped split logs of 33 cm length

[26] Of course this thought experiment is based on the rather theoretical use of oven-dry wood, a typical moisture content of wood after drying for 3 months is 10-20%. Still, it shows the advantage of letting the sun and air drive out the moisture from a fuel for free than using fuel to generate the extra energy to do that in the 'burn' process.

‘Bonus Track’: BIOCHAR

The ability of pyrolytic gasifiers to produce charcoal as a by-product of heat generation is gaining increased interest, as the debate on climate change has sparked the search for global carbon-negative bio-energy systems. If the created char is not used for heat production and the carbon converted to carbon dioxide, but used as soil amendment, it can both enhance soil fertility and fix the carbon in the soil. Such an approach takes the carbon in the char out of the atmospheric carbon cycle for hundreds of years. Recent controversial discussions on biofuels and the need to strike a balance between ‘food´ and ‘fuel´ to ensure the nutrition of the fast growing world population, is drawing even more attention to pyrolytic gasifiers and ‘biochar´[27]. The following figure gives a simplistic insight to biochar.

Biochar Simplified (source http://terrapreta.bioenergylists.org/)

How Biochar-Producing Stoves Can Benefit Climate, Health, and Soil

By Kelpie Wilson, International Biochar Initiative (IBI) Communications Editor

There are many challenges faced by stoves designers who are helping to bring cleaner cooking technologies to the millions of people who still cook on open fires. At the same time, there are many new objectives other than clean cooking that stoves are asked to meet, such as reducing deforestation and greenhouse gas emissions. New objectives also include generating electricity with Thermo Electric Generators (TEGs) and producing biochar for use in soil and removing carbon dioxide from the atmosphere.

Stoves that work on the principle of pyrolysis can easily produce charcoal in addition to heat for cooking and other purposes. Charcoal has many uses, but perhaps the most beneficial use overall is to add it to soil as biochar.

Biochar is charcoal that possesses measurable characteristics making it suitable for use as a soil amendment. In almost every case, charcoal produced in household stoves will be suitable for use in soil, either directly as is, or in combination with nutrients like compost or urine. Biochar can free small producers from the need to purchase fertilizers, increasing food security. Biochar can also help with sanitation in several ways: it can be used to filter water and it can help in the processing of human waste into fertilizer.

Finally, biochar is highly recalcitrant – its half-life in soil is hundreds to thousands of years. Biochar can store biomass derived carbon in soils, resulting in a net drawdown of CO2 from the atmosphere. According to a recent study of various geoengineering alternatives (Lenton and Vaughan 2009) biochar can potentially sequester nearly 400 billion tonnes of carbon over the next century, reducing atmospheric CO2 concentrations by 37 parts per million

[27] **Biochar** is charcoal created by pyrolysis of biomass, and differs from ‘conventional’ charcoal only in the sense that its primary use is not for fuel, but for biosequestration or atmospheric carbon capture and storage (source http://en.wikipedia.org/wiki/Biochar).

What Is Biochar and How Does It Work?

Biochar is found in soils around the world as a result of vegetation fires and historic soil management practices, used most extensively in the Amazon where it is known as Terra Preta. Japan also has a long tradition of using charcoal in soil, a tradition that has been revived and exported over the past 20 years to countries such as Costa Rica. Scientific investigation of legacy Terra Preta soils in the Amazon, along with recent field and greenhouse trials, has led to a wider appreciation of biochar's unique properties as a soil enhancer.

Biochar has physical, chemical and biological facets which interact to produce a beneficial impact to soils. Physically, biochar is a very recalcitrant (not easily oxidized or metabolized by microbes) form of soil carbon with a highly porous structure resulting in a large amount of surface area where nutrients may be adsorbed and chemical exchanges can take place. Biochar-amended soils are better able to hold water in drought conditions, have reduced bulk density, and retain air and other gases. The pores in biochar provide a suitable habitat for many microorganisms by protecting them from predation and drying while providing many of their diverse carbon, energy and mineral nutrient needs. Studies of Terra Preta show a dramatic increase in soil biodiversity compared to adjacent, unamended tropical soils.

Recent studies have indicated that incorporating biochar into soil reduces nitrous oxide (N2O) emissions and increases methane (CH4) uptake from soil. Methane is over 20 times more effective in trapping heat in the atmosphere than CO2, while nitrous oxide has a global warming potential that is 310 times greater than CO2. Although the mechanisms for these reductions are not fully understood, it is likely that a combination of biotic and abiotic factors are involved, and these factors will vary according to soil type, land use, climate and the characteristics of the biochar. An improved understanding of the role of biochar in reducing non-CO2 greenhouse gas (GHG) emissions will promote its incorporation into climate change mitigation strategies.

Biochar can be an important tool to increase food security and cropland diversity in areas with severely depleted soils, scarce organic resources, and inadequate water and chemical fertilizer supplies. Biochar provides a unique opportunity to improve soil fertility for the long term using locally available materials. Used alone, or in combinations, compost, manure and/or agrochemicals are added at certain rates every year to soils, in order to realize benefits. Application rates of these can be reduced when biochar is a component of the soil. Biochar remains in the soil, and single applications can provide benefits over many years.

International Recognition of Biochar Potential for Climate Mitigation and Food Security
In 2008 and 2009, leading up to the Copenhagen climate meeting, multiple countries and the UN Convention to Combat Desertification (UNCCD) made submissions in support of biochar to the UNFCCC. The countries include Micronesia, Belize and a consortium of African governments (made by Swaziland on behalf of Gambia, Ghana, Lesotho, Mozambique, Niger, Senegal, Swaziland, Tanzania, Uganda, Zambia, and Zimbabwe). The submission by Belize suggested the need to develop global baselines of soil carbon pools, and monitoring systems that will allow soil carbon improvements based on the use of biochar as a soil amendment for mitigation and adaption, under the existing Clean Development Mechanism (CDM) and under other mechanisms that may be considered in the future. The joint submission by the consortium of African governments signaled a desire to include the potential of dryland soils in sequestering carbon, including with the use of biochar. The submission highlighted "the intricate linkages between climate change and frequent and severe droughts, land degradation and desertification," and its particular impact on developing countries, the poor and vulnerable inhabitants of dryland areas.

The submission from the Federated States of Micronesia noted that biochar also has potential as a "fast-start" strategy to mitigate climate change in the immediate near-term. For instance, substituting low-emissions biochar-making cook stoves for traditional, high emissions cooking fires can reduce formation of soot and the impact of black carbon particulates on atmospheric warming and ice field albedo changes resulting from soot deposition, while protecting people's health and productivity. There will be a double savings if charcoal-making stoves can replace charcoal-using stoves.

Additionally, both the FAO and UNEP have submissions that would potentially support biochar. The Food and Agricultural Organization (FAO) made an in-depth submission on the use of soil carbon sequestration as a scientifically valid and previously recognized mitigation technology which should be further adopted and enabled in the post-2012 process. The United Nations Environment Programme (UNEP) also has a submission that supports increased carbon sequestration through improved land use and reduced land degradation.

The 2009 UNEP Climate Change Science Compendium (a review of some 400 major scientific contributions to our understanding of climate that have been released through peer-reviewed literature since the close of research for consideration by the IPCC Fourth Assessment Report) highlights biochar as "an innovative approach to soil carbon sequestration" that "may offer a low-risk and very efficient way to mitigate climate change and replenish soil fertility." While acknowledging that biochar's impact on soil fertility is not completely understood and more research is needed, the report notes: "However, farmers are moving ahead with the use of biochar because of its ability to reinvigorate degraded soils."

Rapid Adoption of Biochar in Africa and Elsewhere

Biochar science as a modern endeavor is still very new. While scientific field trials underway had showed good results, only a few years of data exist. Still, the need for solutions to current crises in food security, energy and the climate, has prompted many knowledgeable individuals, organizations and companies to explore the potential of biochar by initiating extensive pilot projects.

One of the most successful projects is Biochar Fund's work in Cameroon with poor farmers who typically make less than $300 a year from their crops. A 2009 field trial involving hundreds of villagers farming 75 different test plots showed that adding biochar at the rate of 10 or 20 tonnes a hectare was as effective at increasing yields as heavy application of fertilizer. The farmers are reported to be pleased with the result and are enthusiastic about continuing the experiment.

World Stove Corporation is operating a multi-faceted biochar-making stove manufacturing and distribution program that is operating in several African countries. World Stove also launched a relief effort in Haiti following the January earthquake that will eventually include a soil-building and watershed restoration effort using biochar in Haiti.

Another example of biochar in use is an Organic Farmers Association (APODAR) in Costa Rica. The 26 members supply the main supermarket chains with organic vegetables. All the farmers have been using biochar with bokashi, a microbial inoculant developed in Japan, for their organic production for the last 15 years. Productivity using these organic methods is comparable to the productivity of conventional farms, and the technology is spreading to other Central America countries.

Biochar gives poor farmers a self-sufficient alternative to expensive fertilizers that must be trucked in. Once they have the knowledge of the techniques for using biochar, the only barrier remaining is the technology to produce charcoal cleanly and efficiently from agricultural waste or other local biomass feedstocks. Developing and disseminating charcoal making cookstoves and small kilns is a task that must be undertaken in order to realize the full potential of biochar

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