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Potential and Feasibility of Solid Municipal Waste Treatment with Gasifiers in a Developing Country: A Review for Burkina Faso

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Authors' contributions

This work was carried out in collaboration between all authors. Author JFN designed the review, performed literature search, statistical calculus and wrote the first draft of the manuscript. Authors JK and BGS analyzed statistical calculus and preliminary results and corrected the manuscript. All authors read and approved the final manuscript.

Review Article

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ABSTRACT

In this paper, a review is made in order to broaden our knowledge on the management systems of household waste in the five largest towns of Burkina Faso and propose an environmentally sound thermal way for their treatment. Data from the General Population and Housing Census of 2006 and the statistical handbook of the environment of year 2010 was used to estimate the five largest cities of Burkina Faso inhabitants' waste production, management and disposal methods. Descriptive statistics have been used to evaluate waste production, thermal energy and improvement to organized household waste collection rates. These cities produce continuously growing quantities of household waste, but infrastructure to manage it is insufficient or almost inexistent. Furthermore the majority of Burkina Faso's citizens poorly handles or disposes of their household waste. This results to an unhealthy urban environment. It appears that treating municipal waste in gasifiers will give an economical value to waste and possibly improve its collection rate. Gasification has been used several decades ago in Europe, USA end Australia and offers the advantage of accepting a big variety of feedstock. Municipal waste in Burkina Faso that mainly consists of carbonaceous materials appears as a good candidate for gasification. This review suggest that gasifiers represents a good opportunity for

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municipal waste treatment in Burkina Faso and downdraft gasifiers appears the most suitable technology that could be built, operated and maintained by local technicians without a need for very high special training.

Keywords: Municipal waste; waste management; gasification; environmental impact; energy.

1. INTRODUCTION

There is no satisfactory definition of waste. This definition varies from a place to another. The United Nations Statistics Division (UNSD) [1] says that: "Wastes are materials that are not prime products for which the initial user has no further use in terms of his/her own purposes of production, transformation or consumption, and of which he/she wants to dispose. According to the Basel Convention, the United Nations Environment Program defines: "Wastes' are substances or objects, which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law [2]. In Burkina Faso, reference [3] describes municipal waste as "solid, liquid or gas rubbish from the living homes and related, administrative buildings, recreational, restoration and room and any other public installation receiving people". According to [4], in France, waste is defined as "any residue of a process of production, processing or use of any substance, material, product or more generally, any personal property abandoned or which its holder intends to abandon".

In many of developing countries, the management of waste is sidelined. Meanwhile, pollution transforms the environment into an epidemiologic space [5]. Waste management is one of the major challenges of urban management in Sub Saharan African countries. Burkina Faso, a country of more than 14,000,000 inhabitants, with seven (07) cites having more than 50,000 inhabitants [6], is no exception to this. Only Ouagadougou the political capital and biggest city of the country has a controlled waste land filling centre with a 20 years lifespan. By year 2025 this land filling centre will reach its end of life. However it has been proven that the remaining life span could be 3 times longer if incineration treatment can be associated to this land filling facility as of year 2015 and using incineration with sorting at this landfill centre was suggested [7].

Gasification, one the three thermal waste treatment methods is the process of partially oxidizing carbonaceous feedstock with an oxygen-containing reagent, usually oxygen, air, steam or carbon dioxide, generally at temperatures in excess of 800°C. This requires that oxygen be added but in insufficient amounts so that the fuel cannot be completely oxidized and full combustion doesn't occur. This process is largely exothermic even when some heat is required to initialize and sustain the gasification process [8].

Though gasification has almost gained maturity in developed countries [9,10], these facilities cannot simply be transposed in developing countries because:

- Gasifier's performances depend of the fuel used. In the case of municipal waste, composition is very different,
- Latest gasifiers are of high thermal capacity , these are not suited for small scale testing,
- Gasifiers available on the international market are highly sophisticated equipments; these are too expensive and not convenient for developed countries contexts.

One concern we should keep in mind for development of gasification is sustainability. Fundamentally, gasification use coal, an inherently depletable and geologically limited resource. When used with very heterogeneous feedstock as municipal waste, non carbonaceous components such chlorine, metals, glass are sources of environmental pollution. That is why gasification is often opposed by environmental lobbying organizations [11,12]. They argue that gasification is as pollutant as incineration. However several studies [13,14] explain how gasification is different from incineration. Anyway, thanks to more strict environmental regulations, incineration is not pollutant anymore and is considered as an important solution for waste management in many countries. Today, gasification is proven to be environmentally harmless if an appropriate feedstock is used. These concerns will be kept in mind all along our study.

This prospective review paper will have four steps:

- a review of waste disposal methods and schemes in the five (05) biggest cities of Burkina Faso,
- a review of energy consumption in Burkina Faso
- proposition of which gasifiers are more adapted to developing countries,
- discussion of required conditions for gasifiers to be economically sound and environment friendly in the local context.

2. MATERIALS AND METHODS

2. 1 Study Area

This study is carried out in the five (05) largest cities of Burkina Faso, namely Ouagadougou, Bobo-Dioulasso, Koudougou, Banfora and Ouahigouya. Burkina Faso is a south Saharan country located in West Africa between 9°20' and 15°5' North latitudes, 2°20' East longitude and 5°30' West longitude (Fig. 1). Burkina Faso experience a mostly dry season with only a 4 months duration for rainy season [15]. The five largest cities of Burkina Faso concentrate a total population of 2,202,444 inhabitants.

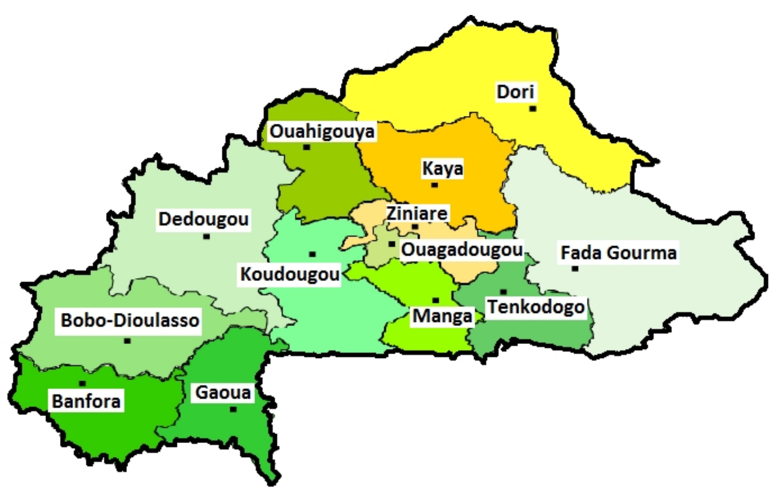

Fig. 1. The 13 administrative regions of Burkina Faso

2.2 Methodology

Firstly, statistical data was extracted from the General Population and Housing Census of year 2006, year 2010 statistical directory of the environment, monographs of the Cascades, Centre-West and North regions and the report of theme 9 "Urban growth" analysis of the general census of population and housing 2006. Collected data about these cities populations were: their number, waste management and disposal methods and energy consumption. Secondly a literature survey was made about gasifiers with respect to their thermal capacity and the best feedstock material. Thirdly, after calculating the probable available feedstock in each of the five cities, choice of the most suited gasifiers technologies have been made.

3. RESULTS AND DISCUSSION

3.1 Waste Management and Production in Burkina Faso

Waste management is one of the first concerns of cities in Burkina Faso. It is complicated by the rapid growth of cities which induce proliferation of waste of any kind in a difficult economic environment. This makes the city of Ouagadougou, the largest in the country struggles to collect and treat waste generated by its residents whose the number continues to grow.

In 2009 there was about 750,000 tons of municipal waste produced in Burkina Faso [15]. Only waste production in Ouagadougou and Bobo-Dioulasso are roughly exact. Those of medium cities, namely Koudougou, Banfora and Ouahigouya are estimations from regional municipal waste production [15]. Populations' figures are from the 2006 general census [6]. Table 1 summarizes present state of waste management in the main cities of Burkina Faso.

Table 1. Waste management data of the five largest cities in Burkina Faso

City	**Population**	**Land filling facility**	Annual municipal waste production
Ouagadougou	1,475,223	Yes : 2005-2025	330,000 tons [(a)]
Bobo-Dioulasso	489,967	Yes : not used	100,000 tons [(b)]
Koudougou	88,184	No	15,162 tons [(c)]
Banfora	75,917	No	13,077 tons [(c)]
Ouahigouya	73,153	No	10,379 tons [(c)]

(a): according to [16], (b): according to [17], (c): estimated from references [15 and 21]

We estimated data about annual municipal waste production from regional annual municipal waste production available in reference [15] and [21] as follows:

- Summation of the regional population weights of official municipal cities in the region, this gives a number W;
- Division of each municipality weight by W, this give us a number M_i ;
- Multiplication of M_i by the annual regional municipal waste production: these give us figures of footnote (c) in Table 1.

Of the 750,000 tons of municipal waste produced in Burkina Faso in year 2009, about 660 000 tons were sent to landfills (usually uncontrolled), gutters, old quarries; which carries the potential of groundwater contamination, proliferation of disease vectors such as rodents, flies, etc…The anaerobic decomposition of organic matter by methanogenic bacteria present in solid waste landfills is the source of greenhouse gas emissions such as methane [18]. Waste recycling is very important to several socio-professional groups: the direct recuperators, intermediaries, dealers and processors artisans. Recovered items are bottles, cans, scrap metal, shoes, aluminum and various packages. If their condition permits, these recovered items are sold directly to consumers or to processors and generate revenues. There also exists a recycling of compost in the country: topsoil resulting from the decomposition of garbage mixed with soil. This product is used as organic fertilizer for urban agriculture and gardening.

For the five biggest cities of Burkina Faso, organized municipal waste collection rate was less than 40% of the resident populations in 2009 [19]. Waste disposal methods in these cities are summarized in Table 2.

Waste disposal is complicated by bad habits of citizen who, despite the existence of waste collection structures continues to dump waste elsewhere. Table 2 show that 28,8% citizens of Ouagadougou, 34,6% of Bobo-Dioulasso and more than 60% of Koudougou, Banfora and Ouahigouya dump their household waste into piles of garbage. Only around 5% of the populations in medium cities have their household waste collected by organized services. This rate come to 31% at Bobo-Dioulasso and culminates to 40% at Ouagadougou. It is true that often waste collection infrastructure doesn't suffice and the reason why population doesn't uses organized collection seems to be financial limits and weight of tradition [19]. Indeed, it turn out that people do not take the full extent of adverse consequences of poor disposal practices of household waste. They mention lack of financial resources as a pretext, but in truth, it is a bad cultural predisposition; given the relatively low cost of subscriptions to the organized waste removal services offered by the associations. It is difficult to understand that working families prefer to throw their garbage in the street or on piles of garbage than paying about US $1.00 per month for the organized removal of their household waste.

Table 2. Waste disposal methods in the five largest cities of Burkina Faso

Waste disposal method	**Ouagadougou**	**Bobo-Dioulasso**	**Koudougou** [(a)]	**Banfora** [(a)]	**Ouahigouya** [(a)]
Piles of garbage	28,8	34,6	61,1	65	62,8
Gutters	7,7	9,2	9,7	18,7	8,5
Street	9,7	16,1	15,2	3,4	9,6
Organized collection	40,2	31	4,2	3,6	6,9
Tank	8,3	6,2	4	3,7	5,9
Other	4,3	2,2	5	5,1	5,6
Unknown	1	0,8	0,8	0,5	0,8
Total	100	100,1	100	100	100,1

(a): Figures shown are those of "Urban grown" from references [19]

Only Ouagadougou has a functional modern land filling facility since 2005. That of Bobo-Dioulasso wasn't still functional by October 2011 [17]. Koudougou, Banfora and Ouahigouya don't have controlled (modern) landfills.

Municipal waste compositions vary from a city to another. Table 3 summarizes these from 2003 to 2009.

Table 3. Municipal waste production in Burkina Faso from 2003 to 2009

	2003	2004	2005	2006	2007	2008	2009
Paper/Clipboard	47 934	51 948	56 252	60 860	65 784	71 037	76 629
Textiles	24 244	25 070	25 903	26 740	27 578	28 415	29 246
Plastic	60 141	69 260	79 696	91 625	105 241	120 763	138 429
Glass	15 504	16 552	17 655	18 816	20 035	21 311	22 645
Metals	19 041	19 509	19 972	20 428	20 875	21 311	21 733
Food and garden waste	196 996	207 914	219 256	231 016	243 180	255 733	268 654
Other inorganic waste	150 443	158 208	166 236	174 520	183 046	191 800	200 763
Total	514 303	548 460	584 971	624 004	665 739	710 369	758 099

Source: National Statistics and Demography Institute [19]

Data in Table 3 above suggest that waste production continuously grow from 2003 to 2009, however more information could be gathered if we use descriptive statistics tools. Firstly, let us plot these waste productions as depicted in Fig. 2. That figure suggests that:

- Metals, textiles and glass annual production are almost constant,
- Paper and clipboard production slowly increase from a year to another as do other inorganic waste,
- Food and garden waste rapidly increase with a linear slope,
- Plastic is the most increasing municipal waste in Burkina Faso with an exponential slope.

Nevertheless, using descriptive statistics tools again, more information could be extracted from this table. Let us defines the following parameters:

$$G_V = \frac{Q_{2009} - Q_{2003}}{Q_{2003}} \quad (1)$$

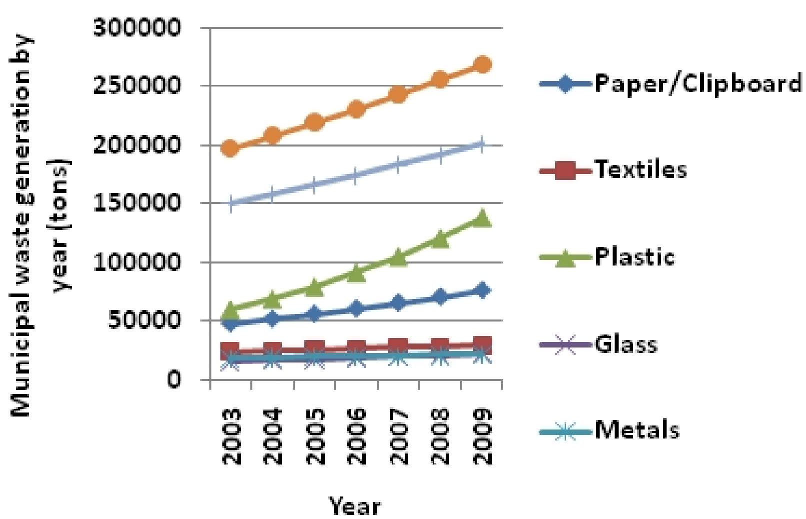

Fig. 2. Municipal waste production by category in Burkina Faso from 2003 to 2009

$$Y_{AV} = \frac{1}{6}\sum_{i=3003}^{2009}\frac{Q_{i+1} - Q_i}{Q_i} \tag{2}$$

$$A_{PCW} = \frac{1}{6}\sum_{i=3003}^{2009}\frac{Q_{i+1} - Q_i}{Q_i * P_i} \tag{3}$$

Where: G_v = global variation expressed in % (relative variation)
Y_{AV} = yearly average variation, expressed in %
A_{PCW} = annual per capita waste production expressed in kg/inhab/year
Q_i = waste production in year i
P_i = municipal population of the five largest cities in year i

We obtain data in Table 4. Several observations could be done:

- Plastics exhibits global variation of 130% from 2003 to 2009. This denotes the great increase in plastic production from municipal waste in Burkina Faso.
- Second are Paper/Clipboard with global 60% increase from 2003 to 2009,
- Glass ranks third with 46%,
- Food and garden waste (36%) and Other inorganic waste (33%) are at the fourth and fifth ranks,
- Textiles ranks sixth with 21%,
- Metals shows the lesser global variation from 2003 to 2009 with 14% increase.

When we consider yearly average variations (Y_{AV}), the same observation applies, except that Food and garden waste and Other inorganic waste now have the same yearly average variation (5%).

Table 4. Waste by category parameters of the five largest cities of Burkina Faso from 2003 to 2009

	Global Variation (%)	**Y_{AV} (%)**	**A_{PCW} (kg/inhab/year)**
Paper/Clipboard	60	8	5,854
Textiles	21	3	1,103
Plastic	130	15	14,768
Glass	46	7	1,489
Metals	14	2	0,609
Food and garden waste	**36**	**5**	15,206
Other inorganic waste	**33**	**5**	10,742
Total	47	7	49,773

Finally, considering the annual per capita waste production lead to some different trends:

- Food and garden waste comes to the first rank with 15.206 kg/inhab/year,
- Plastics goes to the second rank with 14.768 kg/inhab/year,
- The third place now goes to Other inorganic waste (10.742 kg/inab/year),
- Paper/clipboard drops to the fourth rank (5.854 kg/inhab/year),
- Glass goes to the fifth rank (1.489 kg/inhab/year),

- Textiles (1.103 kg/inhab/year) and Metals (0.609 kg/inhab/year) remains at their sixth and seventh ranks.

Using XLSTAT 2013, we have calculated the Pearson's correlation matrix that shows values varying from 0.991 to 1. This suggest good correlations between different waste categories productions at a significance level of $\alpha = 0.005$. All p-values given by XLSTAT are < 0.0001 (α=0.005).

Average values by category are drawn on Fig. 3 below:

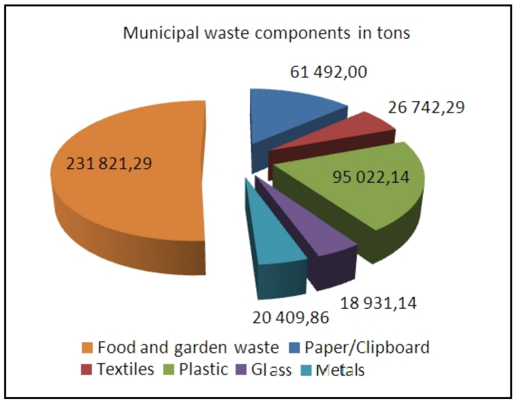

Fig. 3. Municipal waste composition in Burkina Faso

Food and garden waste are the dominant components of municipal waste in Burkina Faso with more than 50% of its' composition.

Food waste, garden waste, paper and clipboard plus textiles are organic materials with basic components similar to that of wood.

These can be therefore assimilated to wood as done in reference [20]. In this case we have the Fig. 4 distinguishing municipal waste components according to their combustion properties.

Because several items such as bottles, metal, and packaging materials have some economic value in Burkina Faso, these are scarce in municipal waste. This is why glass and metals only represents 3% of municipal waste in Burkina Faso.

3.2 Energy Bill of Burkina Faso

Burkina Faso faces two major problems: energy challenge with a big anthropogenic pressure on natural resources and poor waste management in cities with several negatives environmental effects.

Energetic bills for each year are found in megawatts per hour (MWh) from reference [15]. In Physics energy is expressed by the equation below:

$$P = \frac{w}{t} \tag{4}$$

Where:

- W is energy expressed in joule (J);
- P is power expressed in watts (W);
- t is time expressed in seconds.

A year account for 366 days, a day account for 24 hours, thus time is

$$t = 366\ x\ 24 = 8784\ h \tag{5}$$

Using equations (4) and (5), we derive Fig. 4 below from references [15] and [21]:

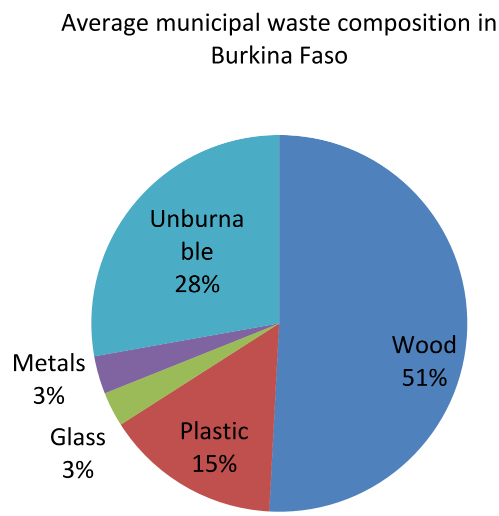

Fig. 4. Average municipal waste composition of the five largest cities in Burkina Faso

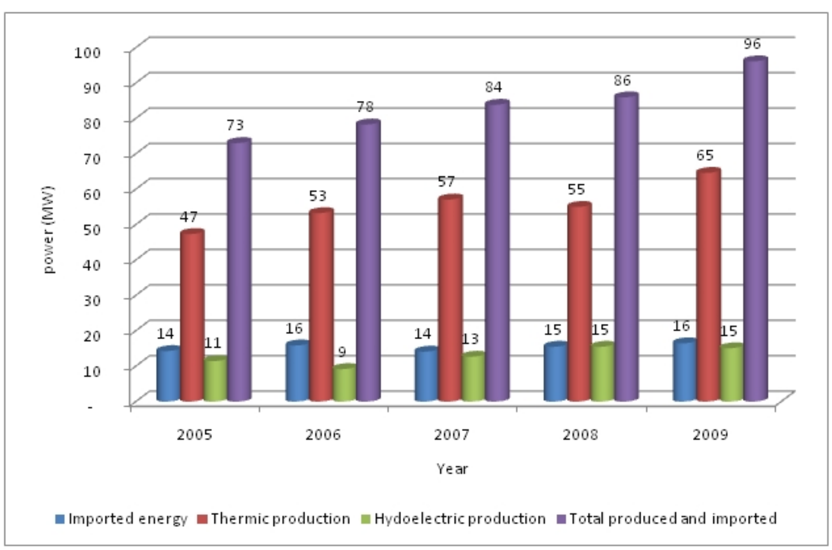

Fig. 5. Electric energy production and importation in Burkina Faso from 2005 to 2009

This Fig. 5 shows that electrical energy production mainly comes from thermal sources. This electricity is produced with thermal generators powered by fuel oil. This is not a sustainable energy and with the continuously growing price of oil derived products on the international marked, the Burkina Faso's energetic bill continues to grow and becomes more and more difficult to bear.

3.3 Technical Context of Waste Gasification in Burkina Faso

The main difficulty faced by the gasification of waste in developed countries is to achieve an acceptable energy balance (that is to say, positive) in terms of power production. The good performance of the conversion of synthesis gas into electrical energy is actually offset by a high energy consumption in the pretreatment of waste by the need to produce or inject large amounts of pure oxygen (which is often used as a gasifying agent), and the cost of disposing of the gases. Another problem arises when one implements the process at commercial scale: the maintenance time of a site because it is essential to clean the reactors after a few months of activity, and thus stop production, unless you have plants taking over. Today several gasification of waste projects are known, but few have really been developed and tested, and among the few that have been implemented in real waste treatment plants, they have always been associated with the employment fossils fuels [22].

However the economical context is quite different in Burkina Faso. Setting up energy independent municipal waste gasifiers in Burkina Faso would have the following advantages:

- Simple and affordable technology that can be handled by local technicians;
- Added value to household waste;
- Create more economic value from municipal waste by converting it to energy
- Production of electricity with the excess that could be resold to the National Electricity Company (SONABEL);
- Modernization of transit centers and sorting of municipal waste and the landfill through the use of electrical energy produced locally, mechanical sorting, mechanical cutting bulky waste if necessary
- Possibility to produce methanol, which could be used in vehicles of municipal waste collection;
- Improving livelihoods of people working on landfill
- Best gasifiers performance in respect of low waste moisture content as more of the time, Burkina Faso experience a dry season that last 8 to 9 months a year [23]
- Reduce space required for land filling.

Let us suppose that waste collection rate is 40% in Ouagadougou, 30% at Bobo-Dioulasso and 20% at Koudougou, Banfora and Ouahigouya (20% collection rate can be set as an objective to reach in first time). If gasification is considered, glass, metals and inorganic waste (inert materials) should not feed gasifiers. These must be picked out at the upstream. Therefore maximum available waste as gasifiers' feedstock would be as depicted in Table 5.

Table 5 show that in Burkina Faso, only Ouagadougou and Bobo-Dioulasso can feed updraft gasifiers (1.1 to 12 MW thermal capacity) or bubbling fluidized bed gasifiers (1 to 50 MW thermal capacity). Medium cities of Burkina Faso could only feed downdraft gasifiers (1 to 1000 kW thermal capacity). Electrical output is calculated with 30% conversion efficiency.

Table 5. Combustible feedstock and reachable power by municipal waste gasification in Burkina Faso

		Ouagadougou	Bobo-Dioulasso	Koudougou	Banfora	Ouahigouya
Textils +Paper) Wood (Food+	50,85%	67 120,98	15 254,77	1541,95	1 329,9	1 055,5
Plastic	15,10%	19 927,72	5 434,83	457,79	394,8	313,4
Glass	3,01%	3 970,18	1 082,78	91,21	78,7	62,4
Metals	3,24%	4 280,29	1 167,35	98,33	84,8	67,3
Unburnable	27,80%	36 700,89	10 009,33	843,12	727,2	577,1
Total	100,00%	132 000,06	32 949,06	3 032,40	2 615,4	2 075,8
Daily feedstock (kg)		183 390,66	41 679,69	4 212,98	3 633,6	2 884,0
Maximal thermal capacity (W)		8 490 308,19	1 929 615,50	195 045,53	168 223,88	133 516,53
Maximal electrical power(Wk)		1 698,06	385,92	39,01	33,64	26,70

3.4 Proposal for Gasification Technology Aimed at Household Waste Management

Gasifiers' construction is a relatively simple task and can be accomplished in any well-equipped shop using basic sheet metal and welding techniques [24]; according to Kaupp and Goss [25] "The construction of a small gasifier, including the purification system, does not require sophisticated equipment or highly skilled mechanics. It can be built in workshops comparable to the auto repair shops found in most third world countries." Nowadays, gasification is a rapidly spreading technology in USA, Europe, Australia and India [26-32]. Although high thermal capacities gasifiers can be setup in Ouagadougou and Bobo-Dioulasso, it is better to star with small and medium capacity downdraft gasifiers. These small capacity gasifiers will represent the following advantages and are more likely to succeed [33]:

- require no sophisticated technology for setup;
- be built by local technicians;
- use locally available materials;
- allow thorough field testing;
- allow learning errors and improvements.

Per recommendations found in reference [34], Burkina Faso has the following advantages:

(i) Gasifiers are meeting the technical, economic and operational expectations of Burkina Faso because it's a poor country with abundant and cheap labor, but well enough trained, especially for craft where its reputation is recognized throughout the African continent;
(ii) Sorted municipal solid waste constitute fuel resources and operating conditions most likely to ensure successful operation of gasifier technologies projects that could be feed with abundant municipal wood and plastic like waste;
(iii) Only few aspects of the technology need of additional research and development for adaptation purpose.

At our side, laboratory work is already in progress. We are now carrying out laboratory experiments for wood, cardboard and plastic's gasification at temperatures of 700 to 1100°C with a 100°C step. At first, these essential municipal waste components are studied alone and at the second step, we will mix these according to municipal waste proportions. Work in progress aim to simulate municipal waste gasification and serve as a starting point for laboratory scale gasifiers construction, testing and adaptation with firstly model waste and afterward real municipal waste as feedstock.

4. CONCLUSION

The situation of municipal waste management in the largest fives cities in Burkina Faso represents big challenges and call for innovative solutions in order to avoid negatives environmental impacts. In the context of a developing country, this situation also represents good opportunities if economic and technological adaptations are made. This way, continuously growing quantities of municipal waste may be turned to a gold mine. Downdraft gasifiers introduced at small scale appear the most affordable technology that can be setup, adapted and maintained by local technicians. Ouagadougou and Bobo-Dioulasso can also feed updraft or bubbling fluidized bed gasifiers with respectively about 8.5 and 2 MW thermal capacity. Koudougou could feed a 200 kW thermal capacity downdraft gasifier where as Banfora and Ouahigouya could feed a 170 and 130 kW downdraft gasifiers.

We highly recommend that gasification of municipal waste be introduced and developed in Burkina Faso. This action could lead to waste collection rates improvement, waste reduction at landfills, modern landfill operation, jobs creation, and production of energy.

Though the first responsibility is on municipalities managers because they have to set up appropriate infrastructure and waste management facilities, researchers and technicians also have to demonstrate the suitability and economics profits of small downdraft gasifiers for waste management in Burkina Faso. It appears that upstream waste sorting is the key to insuring the required feedstock quality for optimal operation of small gasifiers and less environmental impact of these facilities. Local available working man force at affordable cost is an advantage for Burkina Faso who should promptly catch that opportunity. Under this scope, demonstrations plants at small scale should be quickly setup in the five largest cities of Burkina Faso for further study, field testing and adaptation to the country's context.

COMPETING INTERESTS

Authors declare that there are no competing interests.

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