

ideas to impact.

ROCKET STOVES AS AN APPLICATION FOR LPG CYLINDERS

ENERGY ACCESS |
LPG CYLINDER PRIZE WINNING SOLUTION (7/7)

SEPTEMBER 2017

ABOUT IDEAS TO IMPACT

Ideas to Impact is an action-research programme designing, implementing and testing innovation prizes, to induce innovative solutions to development challenges in Climate Change Adaptation, Energy Access and WASH. A five year, £10.9m programme, funded by the Department for International Development (Dfid) that supports research and development in climate change, energy and WASH through a variety of innovation prizes. The prizes are designed to stimulate and incentivise development of technologies for low income consumers that will improve poor people's access to affordable clean energy, safe drinking water and resilience to climate change.

ABOUT THE ENERGY ACCESS: LPG CYLINDER PRIZE

As part of the Ideas to Impact the Energy Access: LPG Cylinder Prize launched on July 7, 2015, focused on inducing innovations for recycling liquid petroleum gas (LPG) cylinders across sub-Saharan Africa. Applications were received from more than 180 solvers, from over 40 countries, proposing solutions to address the problem of how to maximise the value of large numbers of aging and unsafe LPG cylinders that might need to be retired in the event of market reforms.

No readily available solution which could be implemented at scale was identified. However, seven winners were selected, who offered solutions which in the view of the judges had potential to address the challenge subject to further research and development.

Here we share one of these winning solutions.

ACKNOWLEDGEMENTS

The Energy Access prize is led by Simon Collings at Energy 4 Impact, and collaboratively designed with Jonathan Slater from The Blue Globe.

Ideas to Impact is managed by IMC Worldwide Ltd. With special thanks to the independent panel of judges who judged the winning solution.

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INNOVATIVE CONTEST PROGRAM

ROCKET STOVES AS AN APPLICATION FOR LPG CYLINDERS RECYCLING ACROSS SUB-SAHARAN AFRICA

2015, September 7th

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This document comes with 04 Appendixes.

Internal note: this document has been made anonymous to fit the challenge description requirements.

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ABSTRACT

This paper proposes a solution to Innocentive challenge number 9933755, aiming at identifying recycling solutions for LPG cylinders when they become unsuited for their primary usage. The proposed solution takes advantage of the very specific context of Sub-Saharan countries development to insert the former LPG cylinders into a new market, where they will significantly improve public health, environment preservation and social standards of millions. Recycled as Rocket Stoves, they may indeed reduce the use of indoor open cooking fires, in a continent where 600,000 people a year die of pollution from solid fuel use. In fact, with around 3 billion people cooking and heating their homes using open fires and simple stoves, one would easily counts this issue amongst the most critical to the world's public health. As a matter of fact, rocket stoves are known to significantly improve the combustion quality, resulting in outstanding improvement of the air quality, aside from bettering the environmental impact, saving huge amounts of money for the households that need it most, and granting them more working time every day – as millions of people dedicate up to four daily hours to wood collection for their gluttonous cooking fires. It appears that former LPG cylinders are very well fitted to solving this problem, as they can easily be transformed into chimney rocket stoves, for a cost that would make them very affordable to most of SSA countries population. On what concerns costs and profits, it seems that even if the stoves are sold / subsidized at a reasonable price in regard with the host country minimum wage, profitability can be achieved as soon as around 600,000 cylinders have been transformed into stoves and distributed. This paper can be seen as a first feasibility study, as it gives an insight on the key specificities of this idea. What can be remembered is that per the six criteria of success provided by the challenge description, the Rocket Stove solution review shows an excellent profile. In addition, such a solution would receive massive support from many very active UN-supported organizations who are currently running similar projects in the area. We do hope the solution pleases you as well as it pleased us, and we wish you a very good reading.

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1 PRELIMINARY WORD

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Dear IMC Worldwide,

It is a great honor for me to introduce you to the solution we prepared in response to your problem statement. Please allow me to say a few words about the conditions in which this project has been led on our side.

This paper has been prepared by my team on behalf of our company, a French corporation which performs general engineering for all industries – even though energy now accounts for more than 40% of its turnover. Our 800 engineers have been involved in many major projects for Energy, Metallurgy, and for Industrial & Production Engineering. Our ability to reach and recruits talents from various horizons has been key to our past and present success.

One thing we value is innovation: our technical department has built a specific innovation program to lead innovation contests, research, and, more generally, product development. As a project manager of this program, it is my role to lead the teams into identifying the solutions that best suit the needs of tomorrow.

Six engineers have been relaying in preparing the solution you are going to read. Starting in section 2, our demonstration falls into six parts:

- The first part (section 2) shortly reminds the reader of the challenge evaluation criteria, and presents a list of hypothesis which have been used during our work.
- The second part (section 3) provides a general presentation of our solution, giving an overview of the whole recycling process, highlighting its key benefits, and giving details on the major specificities.
- The third part (section 4) provides examples of past and current similar projects, so that we can be confident that our solution is not only technically viable, but also totally consistent with the current context of developing projects for Sub-Saharan countries.
- The fourth part (section 5) comes up with a work plan to implement the solution, and gives details on required human resources, raw materials and facilities.
- The fifth part (section 6) is a cost, incomes and profits estimation, based on the work plan detailed in the previous section.
- Finally, the sixth part (section 7) comes back to the challenge evaluation criteria, and determines for each one whether it has been achieved or not.

Given the short amount of time available to produce an answer to IMC Worldwide’s challenge, we have limited ourselves to a preliminary feasibility study. And you will see, while reading our solution, that a few approximations remain. For sure, further study would be required before launching the hostilities.

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One last thing I wanted to communicate to you is that your problem statement required anonymity. This is why we will not give you the name of our company for now, nor would I give you my own. We are by no means connected in any ways to any of the individuals, companies, NGOs and other organizations which are quoted and/or mentioned in this paper. InnoCentive however knows very well where to find us, and you will have no difficulty getting in touch with us through that channel. Should you like our solution, we would be very glad to accompany you through the next steps of your adventure.

Yours faithfully,

AAD,
Innovation Contest Projects Manager



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1.1 LIST OF APPENDIX

This paper comes with the following Appendixes:

APPENDIX 01 – Indoor Air Pollution, Health, and the Burden of Disease – WHO Briefing.

APPENDIX 02 – Assessing Cook Stove Performance (see also [1]).

APPENDIX 03 – Ghana - Reducing Deforestation with Improved Cook Stoves – First Climate Briefing.

APPENDIX 04 – Scaling Adoption of Clean Cooking Solutions Through Women's Empowerment – Global Alliance for Clean Cookstoves Report (see also [1]).

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2 REFERENCE DATA

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In this section, we detail the reference data which will be used as basic hypothesis for the estimations and analysis conducted in the rest of this paper. Section 2.1 recalls the selection criteria set by IMC Worldwide [1]. These criteria will be the basis of the solution's evaluation we detail in section 7. Section 2.2 provides general hypothesis, to be used mainly for resources estimations (section 5) and cost and profits estimations (section 6).

2.1 SOLUTION CRITERIA

This section recalls the selection criteria set by IMC Worldwide for this challenge. Those criteria will be used as a screen for the solution's evaluation in section 7. As per problem statement, the ideal solution shall match the following requirements:

1. **Irreversibility of the new non-LPG cylinders** – proposed solutions must describe a new application that makes it impossible for defective and unsafe cylinders to be returned to use as LPG cylinders. That is, the transformation into non-LPG cylinders must be absolute, one-way, and irreversible. Solutions that additionally address the refurbishment of cylinders (if any) must guarantee that the proposed solution meets safety standards, making sure that there are no possible leakage / noncompliance.
2. **Value** – the solution must generate a high-value application for the recycled cylinders. Solutions that lead to high income, as long as other societal benefits (e.g. job creation, reduction of inequalities and poverty, etc.) will be preferred. At a minimum, proposed solutions must be more cost-effective than the current solution (i.e. cleaning the cylinders and sending them to the hydraulic press for recycling the steel).
3. **Geographical context** – the proposed solution must be adapted to the social, economic and cultural contexts of sub-Saharan African (SSA) countries.
4. **Environmental impact** – the solution must be environmentally more sustainable than the current solution (i.e. cleaning the cylinders and sending them to the hydraulic press for recycling the steel).
5. **Capacity and inventory** – Country A is used as an example of a target country, but solutions should have the capacity to deal with some degree of uncertainty. With that in mind, your solution must give an answer to the greatest part of the inventory (not specific to a cylinder size, material...). The bigger the capacity to deal with the inventory (approximately 1.5 million old cylinders to be removed from circulation, amongst a pool of 3 million that need to be checked for safety) the higher the solution will be rated in this requirement.
6. **Local resources** – the solution should rely on technical and human resources that are available in SSA and use African countries equipment and labor force (nice to have).

2.2 HYPOTHESIS

Here are the basic hypothesis which will be considered for the needs of our analysis. If some of them are limitations to the hypothesis given by the challenge description, and some are even mere assumptions, they will however give a consistent playground for our thoughts and make it possible to estimate quantities

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and to avoid confusion. During all our investigation, and except if explicitly stated otherwise, we will consider the following to be true:

- 6 million cylinders are in circulation in country A, which are distributed as follows:
 - 4.2 million (70%) are 14.5 kg cylinders
 - 1.5 million (25%) are 6 kg cylinders
 - 0.3 million (5%) are other types of cylinders. Unless stated otherwise however, these cylinders will be considered equivalent to the 6 kg cylinders – we will see that this is an assumption of “least favorable” situation.

- The number of cylinders in circulation within country A does not change through time. When a cylinder is retrieved from the market, a new one is instantaneously sold somewhere else.

- All cylinders are expected to go for inspection every 10 years. If a cylinder passes an inspection, it is refurbished and can be considered as if it was new. In particular, it won't be submitted to any further inspection before another 10 years.

- In accordance to the previous assumption, we will allow ourselves to give every cylinder an age between 0 year old and 10 year old. As an example, a cylinder which has been checked two years ago will be considered to be two year old. The previous assumption can then be reformulated: “All cylinders are expected to go for inspection when reaching 10 year old”.

- The age of the cylinders (between 0 and 10 year old) is distributed according to a uniform distribution. A direct consequence of this assumption is that every year, 600 000 cylinders are called for inspection*.

- 50% of the cylinders we submit to checking are evaluated ok for refurbishment. This proportion is evenly distributed towards the type of cylinders (50% of the 6kg are ok for refurbishment, 50% of the 14.5kg are ok for refurbishment).

- From the previous assumptions, it follows that every year, 300,000 cylinders have to be taken out of the market. These cylinders are distributed as follows:
 - 210,000 (70%) are 14.5kg cylinders
 - 90,000 (30%) are 6kg cylinders, or other cylinders considered equivalent to the 6kg cylinders (see our first hypothesis)

- Except if explicitly stated otherwise, no cylinder misses a call for inspection.

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- We assume that country A has successfully implemented a Marketer-Controlled Cylinder model, as per the characteristics of the “Guidelines for the development of sustainable LPG gas markets” [3].
- Whenever necessary, and unless stated otherwise, we will assume that country A globally goes by the same demographics as Ghana.
- The average work time, for one worker, is 8 hours per day, 230 days per year
- No actualization or inflation is taken into account in the costs and profits estimations

*Note on this assumption: this will enable us to analyze the general case. It is also equivalent to assuming that the “3 million currently older than 10 year old cylinders” are to be taken care of in precisely five years.

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3 GENERAL PRESENTATION OF THE SOLUTION

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In this section, we give a general presentation of the recycling solution we propose. Section 3.1 quickly presents the Checking & Recycling process as a whole, and gives the bigger picture of how the global cycle would work. Section 3.2 highlights the estimated benefits the Checking & Recycling process would bring to the stakeholders. Section 3.3 gives more details on the technical specificities.

This section tries to give an overview of what the LPG bottles Checking & Recycling process would look like as a whole, instead of focusing on the sole “transformation phase”, which would have led to missing some key impacts of the solution.

3.1 OVERVIEW OF THE PROPOSED RECYCLING SOLUTION

From a global point of view, the Checking & Recycling process can be considered to have four main phases. These phases are made explicit by sections 3.1.1 to 3.1.4. Figure 2 illustrates the process as a whole.

3.1.1 Phase 1: Collection of old LPG bottles

In this phase, old LPG bottles are extracted from the market thanks to an appropriate network. The bottles are then degassed, cleaned, and submitted to a visual checking. The bottles which seem potentially fit for reconditioning are sent to Phase 2 for safety checking. Those which clearly can't be reconditioned as LPG cylinders are sent directly to Phase 3.

3.1.2 Phase 2: Safety checking

The potentially safe bottles identified in Phase 1 are submitted to valve checking and hydraulic testing. The bottles which flunk the hydraulic test are sent to Phase 3 for transformation, except for the valve, which is taken out and reused when possible. The bottles which are considered appropriate for reuse are painted and marked, and their valve is changed if needed. They are then sent to Phase 4 for being given back to the market.

3.1.3 Phase 3: Transformation of cylinders into Rocket Stoves

All non-reusable bottles are sent to a transformation site, where they are transformed into rocket stoves. A Rocket Stove is a cooking stove using wood fuel burned in a high-temperature. It is a quite simple device composed of a fuel magazine, a combustion chamber and a chimney. These stoves conjugate many benefits with a great simplicity of fabrication (see section 3.3.3) and real market opportunities, as will be described in detail in subsequent sections of this paper.

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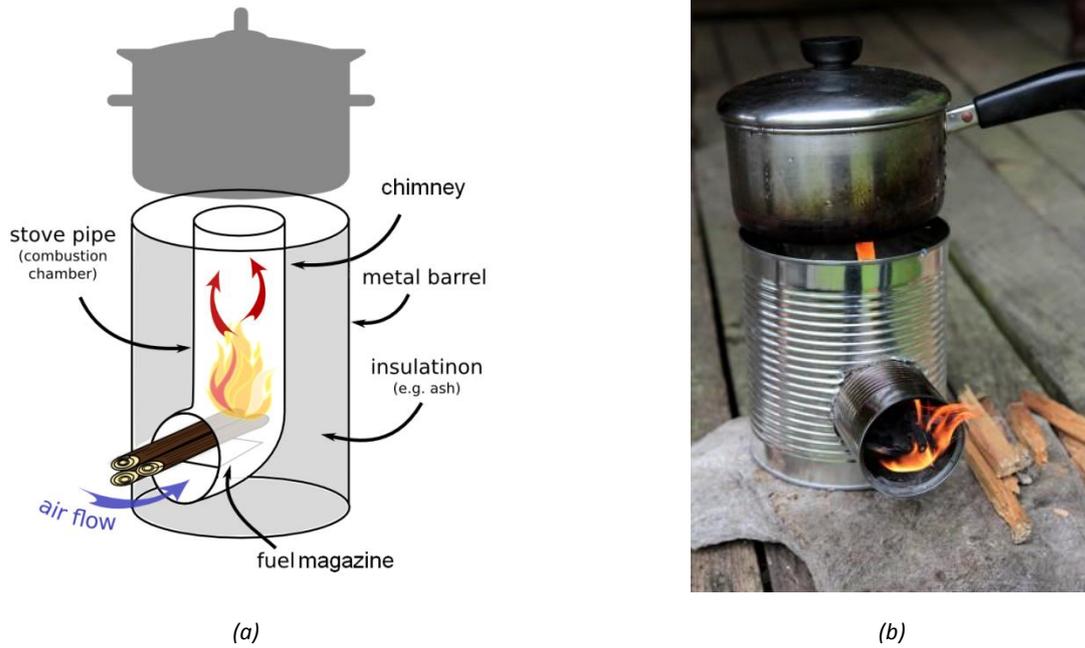


Figure 1 : Working principle of a Rocket Stove (a), and example of a rocket stove made of recycled compounds (b).
Credits: (a) NokoBunva, Wikipedia contributor. (b) logcabincooking.com.

3.1.4 Phase 4: Distribution of validated bottles and new products

Phase 4 actually deals with two flows of distribution. One is the flow of reusable LPG bottles validated through Phase 2, which are to be given back to the LPG cylinders market. The other is the flow of Rocket Stoves fabricated through Phase 3, which are to be distributed to their new markets.

Most probably – and except if potential synergies appear – the two flows will be separated, as the distribution networks involved would be different.

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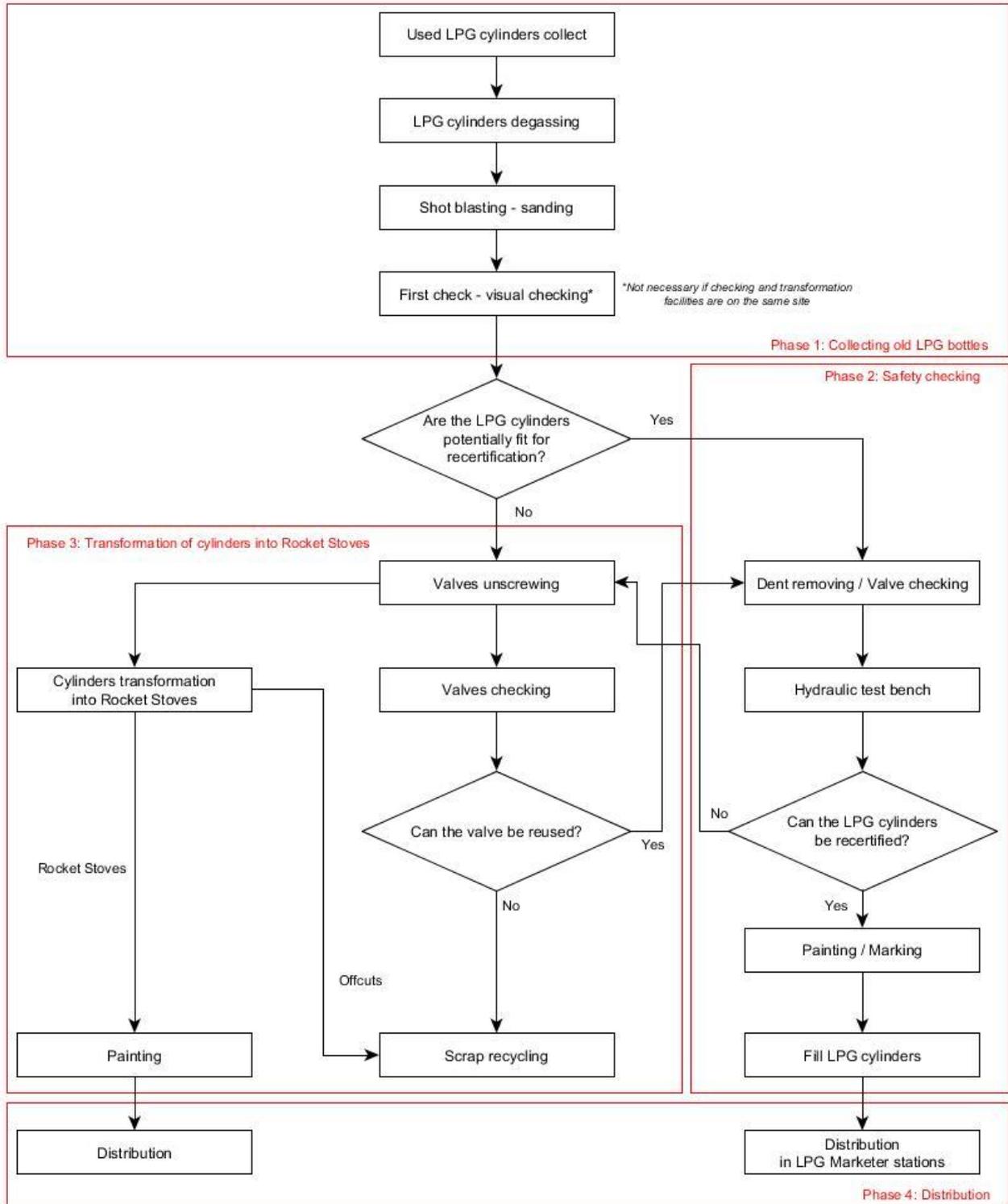


Figure 2 : LPG Bottles recycling's process

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3.2 BENEFITS OF THE ROCKET STOVE SOLUTION

In this section, we focus on the benefits that the Rocket Stoves distribution can bring to country A, and to the countries where the country A may distribute them. We found such a solution mainly brings four kinds of benefits. First, benefits on public health: these benefits are described in section 3.2.1. The second kind consists of other social benefits, and is described in section 3.2.2. Then come environmental benefits: these are described in section 3.2.3. Finally, one can expect major economic impact from this solution, as further described in section 3.2.4.

3.2.1 Benefits for Public health

The general use of open cooking fires within the household counts among the major health issues of many developing countries. Such open fires release a lot of Particle Matters (PM) and carbon monoxide, responsible for respiratory diseases, and respiratory and cardiac disorders respectively. This situation leads to a very dense coverage in the literature, so that information on the subject is easy to find and analyze.

Three billion people cook every meal over an open fire. According to the World Health Organization [2], indoor air pollution from solid fuel use is responsible for about 4.3 million deaths every year, with an estimated 580,000 for Africa only. As an example, expositions cause the premature death of an estimated 16,600 Ghanaians per year.

Rocket Stoves are a solution amongst many that have been proposed to reduce the exposure to PM and CO, as they permit better quality of combustion. It has been estimated that the use of a Rocket Stove in replacement of open fire cooking can reduce the PM emissions up to 74% (Figure 3), and the CO emission up to 76% (Figure 4).

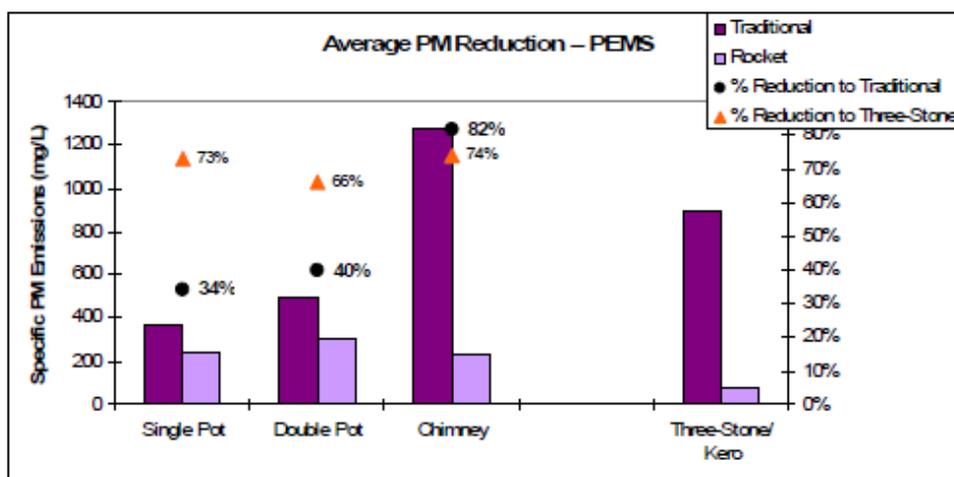


Figure 3 : Average PM emissions in function of the type of stove. The Rocket Stove we propose to do corresponds to a “Chimney – Rocket” model. The Three-Stone (indicated in orange) corresponds to an open cooking fire, as usually set in many households [3].

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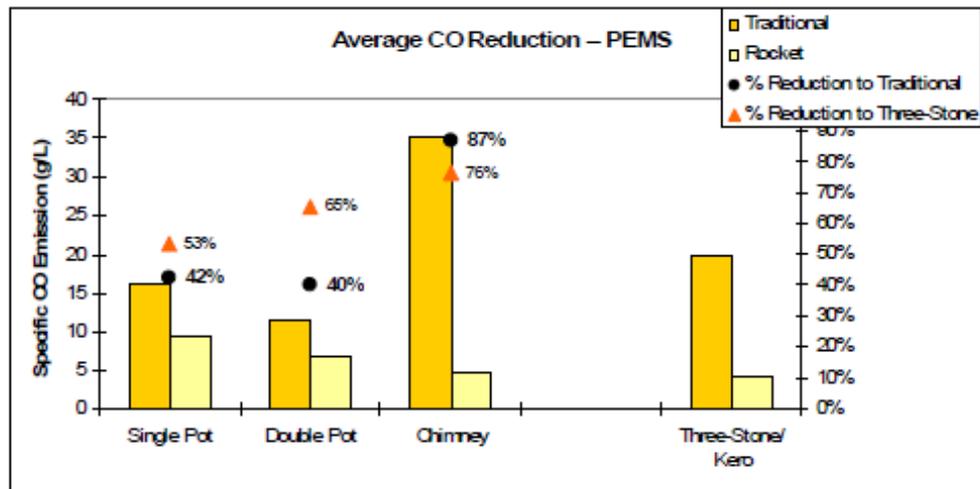


Figure 4 : Average CO emissions in function of the type of stove. The Rocket Stove we propose to do corresponds to a “Chimney – Rocket” model. The Three-Stone (indicated in orange) corresponds to an open cooking fire, as usually set in many households [3].

3.2.2 Social benefits

Various social benefits can be expected from adopting cooking stoves. Women empowerment is one of the most frequently cited, as women can dedicate up to four hours per day – 60 days every year – to firewood collection, with many side effects including lack of security, physical distress, and impossibility to dedicate time for other activities (mainly, economical activities) [4].

According to the Global Alliance for Clean Cookstoves, when families are purchasing fuel, a 30% decrease of fuel consumption (see section 3.2.3 for the gain on consumption that can be expected in our case) can save enough money to send two children to school [4].

3.2.3 Benefits for environment

Two categories of environmental benefits can be expected from the Rocket Stove solution.

First, and as explained in section 3.2.1 above, a massive use of Rocket Stoves will result in a decrease of CO and PM emissions.

Another benefit comes from the reduction of wood consumption. On the cooking fire itself, it has been proven that a 39% decrease of consumption can be expected of shifting from an open cooking fire towards a Rocket “Chimney” stove (see Figure 5).

The impact of cooking fire in the global wood consumption is more difficult to estimate. However, in the Forestry Outlook Studies in Africa (FOSA) report on Malawi [5], which can be found on the Food and Agricultural Organization (FAO) website, it is estimated that more than 90% of the Malawi’s population is using wood fuel for energy. The Efficient Cooking Stove Program for Malawi, led by the FAO estimates the wood fuel consumption of Malawi to be around 10 Mt/year [6].

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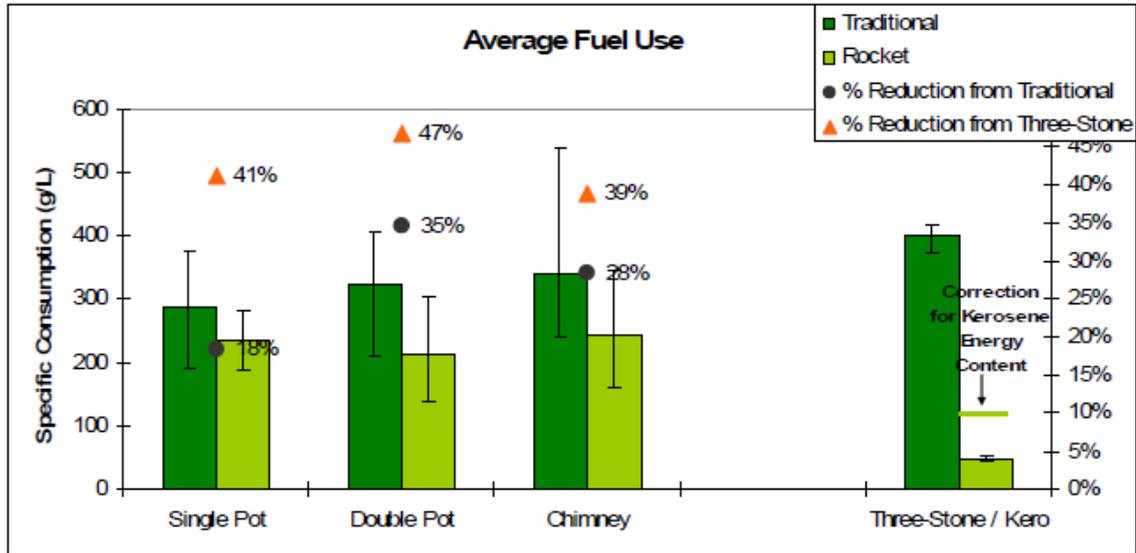


Figure 5 : Average fuel consumption in function of the type of stove. The Rocket Stove we propose to do corresponds to a “Chimney – Rocket” model. The Three-Stone (indicated in orange) corresponds to an open cooking fire, as usually set in many households [3].

3.2.4 Benefits for the economy

For what concerns economics, estimations show that the Rocket Stove can generate more profit than simply recycling the scraps (see section 6), creating value and levelling up the country’s GDP.

Second, recycling of LPG bottles into Rocket Stoves will create numerous jobs, mainly dedicated to transformation and distribution. Under the assumptions depicted in section 2.2, an estimated 1,600 jobs will be directly created by the solution (see complete estimation on section 5).

An impact on job creations for other businesses may also be observed, that would be generated by the activities of distribution, collection, business cooperation with other similar programs, or even by fresh available working time due to lower needs for wood collection. As this impact is difficult to estimate at this stage, it is mentioned here for potential further evaluation only.

3.3 DETAILS ON THE SOLUTION SPECIFICITIES

We have seen, in section 3.2, the many advantages that the Rocket Stove solution cumulates. In this section, we take a deeper look at some of the solution specificities.

3.3.1 LPG Bottles Collection

According to the “Guidelines for the development of sustainable LPG Markets” [7] and assuming that the Marketer-Controlled cylinder model is efficiently implemented, the LPG marketer would be in charge of retrieving the empty LPG bottles.

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In principle, a visual checking would then enable them to identify the LPG bottles which are clearly unsuited for reuse. The flow could then be split into two parts, one part – the unsuited bottles – heading directly towards the transformation site, while the other part – the potentially suited bottles – would be headed towards the checking site.

However, for reasons of simplicity and cost efficiency, it may be a good idea to regroup the checking and transformation sites, so that no visual checking would be required from the staff who collected the bottles at the collection sites. Instead, all bottles could be sent directly to the Checking & Transformation site, where the visual checking, and if necessary the complete checking could be performed by the very same team. Such a disposition would also undermine the possibility of error from the operators located at the collecting sites.

3.3.2 Checking

As the solution we propose introduces nothing new to the safety checking process, we will allow ourselves to skip this section.

3.3.3 Transformation

In this section, we detail the method for fabricating a Rocket Stove out of our LPG bottles.

The fabrication process mainly consists of metal work. For the 14.5 kg bottles, it requires about 90cm of a 6" steel pipe – or equivalent – a welding post and a paint spraying station. For reasons of costs and flow (see also section 5), there should be two teams of operators, one being dedicated to the metal work, while the other handles the painting. We will see (section 5) that this enables to reduce the global number of workers required, eventually resulting in making the process financially viable.

For the 14.5 kg bottles – the 6 kg bottles transformation would be very similar – the transformation process would involve six steps (see also Figure 6):

- **Step 1:** Cut and separate the top of the cylinder, and remove the part used for the gas delivery. Cut a 6" circle-shaped hole on the side of the bottle.
- **Step 2:** For the combustion chamber, take two 6" pipes (square or round). Cut one part of each pipe at 45° and weld the two parts at 90°. The first piece of pipe that composes the fuel magazine is 35 cm long. The second part, the chimney, is 35 cm long.
- **Step 3:** Place and weld the pipe in the cylinder. Be careful to center the chimney with the top hole of the cylinder.
- **Step 4:** Fill the space between the pipe and the cylinder with an insulating material (the recommended material is displayed in section 5.2.3). This step is essential, as obtaining a good thermal isolation is critical to maximize the stove efficiency.

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- **Step 5:** Weld the top part of the cylinder. It will become the support of the frying and sauce pans.
- **Step 6:** Control the weld and paint the rocket stove.

Note: the process generates two pieces which become offcuts of the process. Sending these offcuts to the hydraulic press to sell them as scrap could be a good way to generate extra-revenue. For the sake of simplicity however, this possibility will not be discussed further in the rest of this paper.

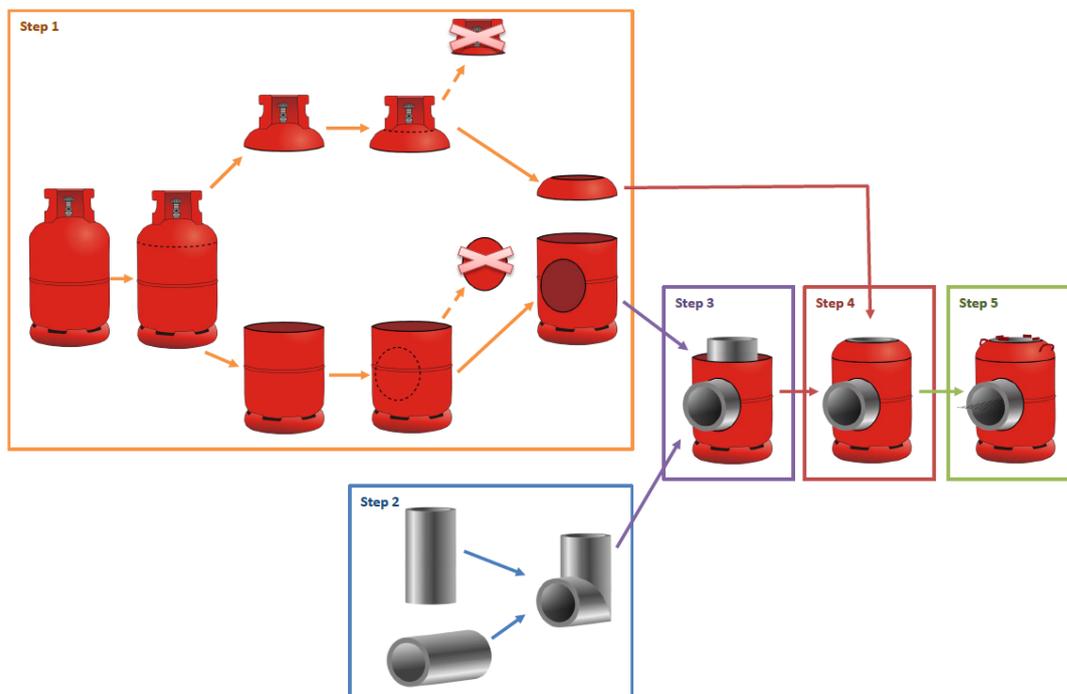


Figure 6: The steps for building a Rocket Stove.

3.3.4 Distribution

Through completing the transformation process, the transformation site will generate two stocks of rocket stoves – one stock of “big” stoves fabricated with the 14.5 kg cylinders, and one stock of “small” stoves fabricated with the 6 kg cylinders.

These stocks have then to be distributed somewhere they can be sold. Under our assumptions, an estimated 300,000 cylinders must be sold each year. Also, as poorer population would take a greater benefit from using the stoves (see section 3.2 for the benefits), it may prove more efficient to find solutions which would permit a deep penetration of market, even in areas which are poorly connected or have little interaction with the main usual commercial flows. Depending on the benefits targeted as main priorities, potentially valuable options include:

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- Selling the stoves to the local/national market, relying on an existing network of distributors
- Selling the stoves to the local/national market, by building your own distribution network. In particular, relying on women empowerment could be a very valuable way of helping the stoves find their ways to the most isolated areas. This is all the more true since we have seen (see section 3.2.2) that such stoves can enable many women to dedicate more time to a professional activity. For instance, rocket stoves ambassadors could be recruited amongst those women, and given the mission to make sure the stoves efficiently penetrate the areas they are responsible of. Similar programs, called “Mahila Mandal”, have been set in India for the same purpose (reaching isolated villages) with great results [8]. For more details on women’s empowerment, please see [4] in APPENDIX.
- Export the stoves at the regional scale, to other SSA countries, through business distributors or thanks to NGOs, FAO, or other helping groups such as the Global Alliance for Clean Cookstoves.
- Export the stoves at the intercontinental scale, to countries like India or others, through business distributors or thanks to NGOs, FAO, or other helping groups such as the Global Alliance for Clean Cookstoves.

Other possibilities may apply, and mainly depend on the benefits targeted in priority amongst those detailed in section 3.2.

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4 EXAMPLES OF SIMILAR EXPERIENCES

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This section aims at proving the achievability of our solution, by producing a list of existing projects and/or organizations the example of which may comfort us into trusting the practical feasibility of our theoretical plan.

In section 4.1, we give brief examples of similar cook stove projects led in Sub-Saharan Africa. Because they succeeded in making a reality out of very similar plans, these projects prove that the local context of Sub Saharan Africa is fitted to the solution we propose.

In section 4.2, we present a few organizations whose role is to promote and support cook stove projects all over the world, along with governmental organizations whose help can be expected for this kind of projects. By their very existence, and by the intensity of their activity, these organizations prove that all practical assistance for IMC Worldwide project would be available when required.

4.1 EXAMPLES OF SIMILAR PROJECTS IN SSA COUNTRIES

4.1.1 First Climate and the Ghanaian cook stoves

In Ghana, fuel wood and charcoal meet approximately 75% of Ghana's fuel requirements and almost 70% of Ghanaian use charcoal, especially for cooking process [9].

As a pioneer in environmental asset management as well as voluntary and compliance carbon trading and consulting for the carbon emissions markets, First Climate decided to promote sales of improved charcoal stoves in Ghana, in order to reverse Ghanaians' habits of using equipment which presents any health risks and environmental impact.

According to First Climate, the use of the Rocket Stoves enables a drop of 35% of fuel consumption while cooking compared to a traditional cooking using an open fire [9]. An average family also saves about 300kg of wood per year in addition to creating a healthier cooking environment.

4.1.2 Mary's Meal in MALAWI

Considered as one of the poorest country in the world, Malawi faces a widespread problem of child malnutrition. Many factors, including difficult weather conditions, low agricultural productivity and poverty, contribute to high food insecurity for the population.

Mary's Meal is an NGO specialized in providing at least one meal per day to some of the poorest children in the world. Mary's Meal takes action in numerous countries including Malawi, Haiti, Ecuador, or Kenya.

Mary's Meal's initiative in Malawi allows to feed almost 800,000 children every day in this day and age. According to the British newspaper The Telegraph, school attendance has risen up to 50% since the beginning of Mary's Meal's program in Malawi [10].

Mary's Meal decided to use Rocket Stoves in order to help Malawi's primary schools to provide food to school children. These Rocket Stoves are used to cook school children meals on large pots, where one pot

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can feed up to 330 pupils. With 53 Rocket Stoves in service in Malawi, the device has come to feed around 176,000 pupils, and to save around 1 m³ of wood per stove each month [11].

4.1.3 Rocket Stove as alternative to the open fire cooking – KENYA / ETHIOPIA

Paradigm Project is a social enterprise that works with donors and investors to create scalable business models and deliver social, economic and environmental value within developing world communities. Their objective is to offer the opportunity for people to lift themselves out of poverty instead of trying to do it for them.

In the Paradigm Project model, community members buy stoves from other community members who make a small profit on the sale and thus have an interest in making sure customers are satisfied. Local competition drives resellers to keep prices low and to provide good service to their customers.

By replacing open fires with fuel-efficient cook stoves, the Paradigm Project dramatically impacted lives and reduced degradation of the environment. Launched in 2008, the project is now claiming outstanding results [12]:

- 23 million dollars in family income savings due to reduced fuel consumption
- 12 million productive hours saved by women thanks to a reduced wood collecting time
- 1.4 million trees saved from deforestation
- 400,000 tons of CO₂ offset

4.2 EXAMPLES OF ACTIVE ORGANIZATIONS

4.2.1 Global Alliance for Clean Cook Stoves

The Global Alliance for Clean Cook Stoves is a public-private partnership hosted by the UN Foundation which aims at creating a global market for clean and efficient household cooking solutions. The Alliance's 100 by '20 goal calls for 100 million households to adopt clean and efficient cook stoves and fuels by 2020.

In particular, the Alliance can provide extensive documentation on cook stoves and their impact on the developing world. They also have a database of every country characteristics [13], and a database of partners, who, for most of them, are involved either in cook stove manufacturing or in fuel distribution.

As the Alliance also indicates to be a partner to the IMC Worldwide Challenge [14], we believe there is no need for more introduction!

4.2.2 Other Governmental Organizations

Other governmental organizations may also be very resourceful. The Food and Agriculture Organization, for instance, has been very active on the question of cook stoves. Other agencies, like the Agence Française de Développement (AFD), or the African Bank of Development, have a long history of financial assistance to this kind of projects. Renewable Energy Agencies, like the IRENA, also supported many cook stove initiative due to the impact on green-house gases of such a solution [15], [16]. The questions of

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interaction between cook stoves and LPG markets have even been the topic of an IRENA seminar in June 2015! [17]

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5 WORK PLAN

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In this section, we estimate the resources which are necessary for implementing the solution (section 5.1 to section 5.2), and we give a list of six partners we believe IMC Worldwide could turn to as a start when considering implementation.

Most of the resources we estimate in the following sections are used in section 6 for cost and/or income estimation. Due to the limited time available for the study, we focused on major elements only – with a deliberate focus on the stove fabrication – and discarded the cylinders collection (which is the responsibility of the LPG Marketer) and safety checking.

5.1 FLOWS OF PRODUCTS BETWEEN SITES

This section simply evaluates an order of magnitude for the transportation of products to occur during our process. If we assume that all fabrication and checking are centralized in one facility, and based on the assumptions detailed in section 2.2 and the process described in section 3.1, 1.2 million products are to be exchanged each year, according to the flows of Figure 7.

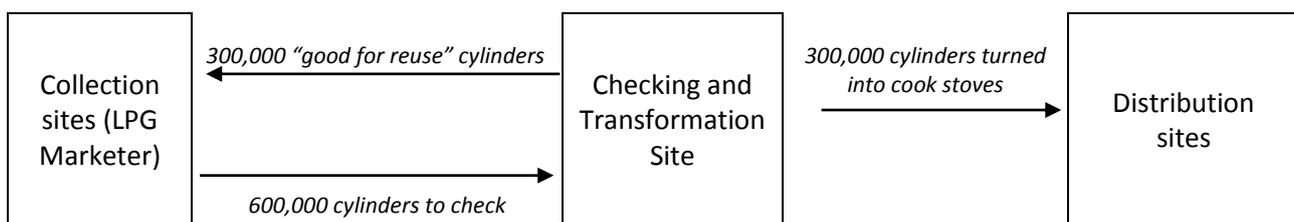


Figure 7 : Yearly flows of products going between sites under this paper hypothesis

Hence, if we stick to Ghana as a representation of country A, and if we imagine that IMC Worldwide decides to go for distribution on a national scale, the key figures are as follow:

- **Distance from North Ghana to South Ghana:** approximately 600 km
- **“Average distance of distribution” for one convoy (hypothesis):** 250 km
- **Capacity of one truck, based on European truck standards:** 1070 cylinders/stoves per truck
- **Number of cylinders to be convoyed:** 1.2 million per year
- **Minimum number of convoys:** 1122 per year
- **Total number of kilometers run by all convoys:** 280,500 km per year

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5.2 PRODUCTION CAPACITIES

According to our assumptions (section 2.2), the production facilities must be able to transform 300,000 cylinders per year into rocket stoves. This would require the following estimated capacities.

5.2.1 Operators

Due to the thickness of the cylinders, our metal work experts estimated the required time to go through the six steps of the cylinders transformation (see section 3.3.3) to approximately 8 hours per bottle (painting time excluded). With our hypothesis (section 2.2), this means that a single operator can transform 230 cylinders per year. Hence, 1305 metal work operators are required to transform 300,000 cylinders per year. The operations however are not complex, and no prerequisite is necessary for learning to do the work.

An estimated 15 minutes are necessary for painting each rocket stove at the end of the process. Under our assumptions, this means that a single operator, if dedicated to painting, can paint 32 rocket stoves per day. Hence, the team dedicated to painting can be limited to 41 people.

Number of cylinders to recycle per year	300,000
Man-hour for one rocket stove	8 hours
Painting time for one rocket stove	15 minutes
Work days per annum	230 days
Number of required painting operators	41 operators
Number of metal work operators	1305 operators
Human resources estimation – operators	1346 operators
Human resources estimation – management and support (assuming 1 per 5 operators)	269 employees
Total human resources (operators + non operators)	1615 employees

Table 1 : summary of needed human resources

5.2.2 Equipment

As the cylinders transformation mainly consists of metal work and painting, some pieces of equipment will prove necessary. Table 2 gives our estimation for the required equipment. This estimation is actually very pessimistic, as it gives each metal work operator one jigsaw, one circular saw and one welding machine. Should the required time of use of each tool be carefully reviewed, major improvement could be made on that need, as part of the metal work operators could specialize in the jigsaw operations, others in the circular

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saw and a third group in the welding, resulting in buying less equipment. For this paper however, the pessimistic estimation will do.

Jigsaw	1305
Circular saw	1305
Welding machine	1305
Individual Protection Equipment	1346 sets
Paint sprayers	41

Table 2 : summary of needed equipment (Note: spare equipment has not been considered)

5.2.3 Raw materials

In addition to the LPG cylinder, the rocket stove fabrication will need some extra materials. Table 3 and Table 4 give our estimations of what is necessary for producing a rocket stove out of a 14.5 kg cylinder and a 6 kg cylinder respectively. An interesting thing to note is that noble materials are not necessary in general: the chimney steel pipe can be replaced by steel cans with no impact on the quality of the stove, and vermiculite, which is often proposed for thermal insulation, can advantageously be replaced by expanded clay. These two easy simplifications already lead to a major decrease of the global cost.

Item	Quantity (for one stove)
14.5 kg LPG cylinder	1
Steel cans (H: 12 cm)	8
Expanded clay (6-9 mm size, density 480 kg/m ³)	26 L
Welding materials – steel rod 2mm (for welding the cans together)	25
Welding materials – steel rod 4 mm (for welding the cans to the cylinder)	15 to 20
Paint	0.15 L

Table 3 : summary of needed raw materials – 14.5 kg cylinders

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Item	Quantity (for one stove)
6 kg LPG cylinder	1
Steel cans (H: 12 cm)	6
Expanded clay (6-9 mm size, density 480 kg/m ³)	11 L
Welding materials – steel rod 2mm (for welding the cans together)	25
Welding materials – steel rod 4 mm (for welding the cans to the cylinder)	15 to 20
Paint	0.06 L

Table 4 : summary of needed raw materials – 6 kg cylinders

5.2.4 Facilities

Finally, we need the facility on the transformation site to host all our operators, the equipment and the various stocks, spare, etc. that will have to be disposed around the factory.

Under the assumption that all workers work on the same site, each one of them would require a minimum of 4 m² working area. For 1346 operators (see Table 1) that makes a total of 5384 m². Then, some space must be saved for the managing team (say 200 m²), for movement through the factory, and for storage (around 500 m²). In total, we counted around 6,000 m² of facility.

For cost and simplicity reasons, we recommend to use non-permanent building, as much as possible. The need for utilities (water, energy, etc.) and extra buildings (restaurant, etc.) have not been considered in this preliminary study.

5.3 POTENTIAL PARTNERS

We strongly recommend IMC Worldwide to get help on this topic, as the subject has been widely debated and tested already. Major potential partners include (see also section 4.2):

- The Food and Agriculture Organization of the United Nations, who would help finding the appropriate program for this topic amongst the many they already have launched.
- The Global Alliance for Clean Cook stoves, and most of their own partners, whose help would be unavoidable for making the project a reality.
- The Paradigm Project, to learn from their success on a very similar ground.

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- The IRENA, as they have major means of action and seem to truly master both the LPG and the Cook Stoves areas.
- The Agence Française de Développement, which has a long history of cooperation with SSA countries, or the African Bank for Development, for potential funding issues
- Country A's appropriate governmental organization, if possible.

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6 COST & PROFITS ESTIMATION

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This section evaluates the costs and profits of our solution. The chosen approach is as follows: capital expenditure are estimated based on the required equipment and facilities (section 6.1). Operating expenditures are estimated based on the product transportation needs, the human resources estimation, and the required raw materials (section 6.2). Several potential rocket stoves selling prices are then calculated depending on how many years we give ourselves to reach profitability (section 6.3).

Obviously, the costs and profits calculated in this section 6 form an approximation, based on the core costs of the solution. At this stage, some costs are missing, and others are overestimated. However, this section gives a good idea of the order of magnitudes that shall be observed if the solution were to be implemented.

All costs and prices estimations are in US Dollars.

6.1 CAPITAL EXPENDITURE

6.1.1 Equipment costs

The estimation we make in this section is based on the estimations made in section 5.2.2 of the work plan. Based on professional equipment, and according to the prices observed on the market, we can assume the associated expenses to be as per Table 5.

Item	Unit Cost	Nb of Units	Global Cost
Jigsaw	150 USD	1305	195,750 USD
Circular saw	150 USD	1305	195,750 USD
Welding machine	300 USD	1305	391,500 USD
Individual Protection Equipment	100 USD	1346	134,600 USD
Paint sprayers	115 USD	41	4,715 USD
TOTAL COST FOR EQUIPMENT	-	-	922,315 USD

Table 5 : Estimated equipment costs

6.1.2 Facilities

The estimation we make in this section is based on the estimations made in section 5.2.4 of the work plan. Based on prices observed on similar projects, we can assume the associated expenses to be as per Table 6.

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Item	Surface	Achievable cost per square meter (modular building)	Cost
Factory	6,000 m ²	300 USD / m ²	1,800,000 USD
Provision for installation work and other expenses (+50%)	-	-	900,000 USD
TOTAL	6,000 m²	-	2,700,000 USD

Table 6 : Estimated cost for the factory and facilities

6.2 OPERATING EXPENDITURE

In this section, all expenditures are calculated per year, based on the volume assumptions of our base hypothesis (see section 2.2).

6.2.1 Transportation costs

The estimation we make in this section is based on the estimations made in section 5.1 of the work plan. Based on prices of international logistic companies, we can assume the associated expenses to be as per Table 7.

Item	Cost per unit	# of units	Global Cost / year
Transportation (80 m ³ truck)	1.90 USD	280,500 km	533,000 USD

Table 7 : transportation costs per year

6.2.2 Human Resources costs

The estimation we make in this section is based on the estimations made in section 5.2.1 of the work plan. According to the World Bank, the Ghanaian salaries respect the conditions of Table 8. In the end, we can assume the associated expenses to be as per Table 9.

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Type of salary	Monthly revenue	Daily revenue (20 days / month)	Safety coefficient (provision for taxes, etc.)	Cost per day of work
Minimum	34 USD	1.7 USD	+40%	2.38 USD
Average	129 USD	6.45	+40%	9.03 USD

Table 8 : Cost assumptions on Ghanaian salaries, based on the world bank database and on the safety coefficient usually applied for SSA countries in our company

Type of employees	# of employees	Reference HR cost	Cost per year
Operators	1346	2.38 USD per working day	736,800 USD
Management/Support	269	9.03 USD per working day	558,686 USD
TOTAL	1615	-	1,295,486 USD

Table 9 : human resources costs

6.2.3 Production costs

The estimation we make in this section is based on the estimations made in section 5.2.3 of the work plan. Based on prices we usually observe on the market, and assuming the LPG cylinders are bought to the LPG Marketer at scrap price, we can assume the associated expenses to be as per Table 10.

Item	Unit Price	Quantity / year	Cost per year
LPG cylinder (14.5 kg)	2 USD	210,000	420,000 USD
LPG cylinder (6 kg)	2 USD	90,000	180,000 USD
Steel cans (H: 12 cm)	0.25 USD	2,220,000	550,000 USD
Expanded clay (6-9 mm size, density 480 kg/m ³)	58 USD / m ³	6,450 m ³	374,100 USD
Welding materials – steel rod 2mm (for welding the cans together)	0.21 USD / rod	7,500,000	1,575,000 USD

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Welding materials – steel rod 4 mm (for welding the cans to the cylinder)	0.85 USD / rod	6,000,000	5,100,000 USD
Paint	6 USD / L	36,900 L	221,400 USD
TOTAL	-	-	8,420,500 USD

Table 10 : production costs (materials only)

6.3 COSTS INTEGRATION

From the expenditures estimated in sections 6.1 and 6.2, it comes that the estimated cost for the solution can be expected to be as per Table 11.

Type of Expenditure	Includes	Cost	Unit
CAPITAL EXPENDITURE	Equipment cost Facilities	3,622,315	USD
OPERATING EXPENDITURE	Transportation costs HR costs Production costs	10,248,986	USD / year

Table 11 : Integration of the solution costs, as per the estimations of the previous sections

6.4 SELLING PRICE AND PROFITABILITY

6.4.1 Hypothesis on sales

When considering selling prices and profitability, we will consider the additional assumptions:

- All fabricated Rocket Stoves are sold
- Every Rocket Stove is sold within the same year when it has been produced. For the calculations we will make, this is equivalent to assuming that the sales are uniformly distributed

6.4.2 Selling price depending on the time to profitability

Based on the CAPEX and OPEX estimated in Table 11, we can decide of a selling price in accordance with the time we give ourselves to reach profitability. In this paper, three scenarios have been considered. These scenarios have been reported to Figure 8. They are defined as follows:

- Scenario #1: profitability is expected within the first 2 years of operations
- Scenario #2: profitability is expected within the first 5 years of operations
- Scenario #3: profitability is expected within the first 10 years of operations

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The recommended selling prices, as per this analysis, are gathered in Table 12. It is to be noted, in this calculation, that we did not differentiate the large rocket stoves fabricated with the 14.5 kg cylinders from the small rocket stoves fabricated with the 6 kg cylinders. In practice, the target prices displayed in Table 12 are to be reached with a weighted average of the prices of both large and small stoves.

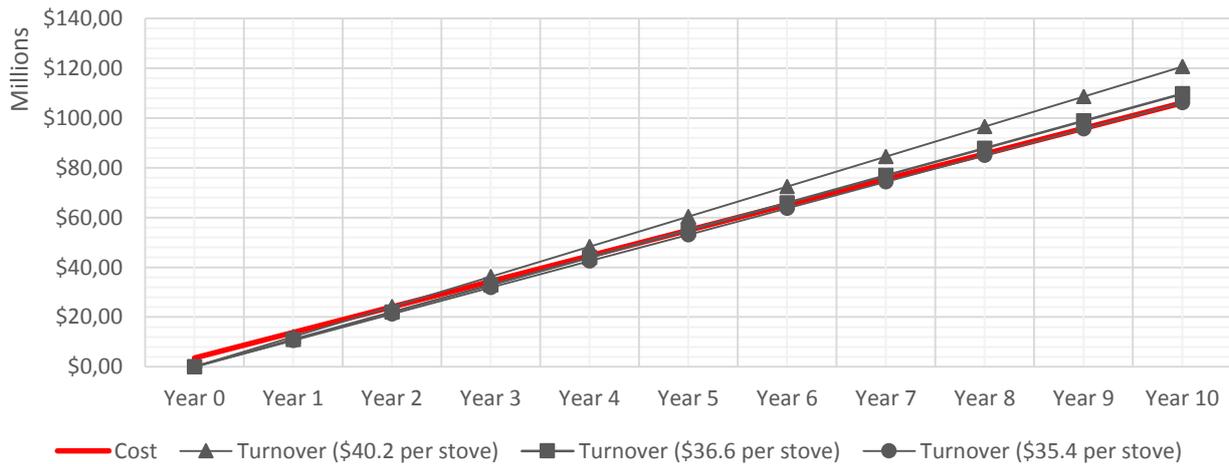


Figure 8: Costs and turnover projections, in function of the pricing strategy

	Time to Profitability	Minimum Recommended Price
Scenario #1	2 years	40.2 USD
Scenario #2	5 years	36.6 USD
Scenario #3	10 years	35.4 USD

Table 12: recommended selling prices according to the considered scenario

6.4.3 Elements of reference for pricing local indicators

In the next sections, we will compare the Minimum Recommended Rocket Stove Price, as established per Table 12, with reference elements of the local Sub-Saharan market. The core idea of such comparison is to ensure that the Minimum Recommended Rocket Stove Price is relevant towards the market characteristics, so that the Rocket Stoves we produce have a real chance of being sold in the end.

For this paper, two reference elements have been identified:

- The first reference element is the average yearly income of the population of SSA countries. The example of Ghana, which has been chosen as the reference country for this

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paper (see section 2.2) is particularly relevant, as the World Bank indicates that this country's population average yearly income (1,620 USD) is very close to the SSA countries average yearly income (1,720 USD).

- The second reference element we chose is the sales price of the Rocket Stove used by the Paradigm Project (see also 4.1.3). This Rocket Stove the EzyStove®, is on sale on Amazon for 80 GBP (121 USD).

6.4.4 Comparison of the Minimum Recommended Price with the monthly income

In this section we compare the impact of buying our Rocket Stove for SSA families with the impact of buying a European stove for European families. France will be our European reference country for this estimation.

According to the French national statistics, the average monthly revenue in France is 2,394 USD. The minimum French monthly revenue is set to 1,261 USD. The average stove sale price on the French market can be estimated to 330 USD. Hence, for the average French individual, a stove acquisition represents around 13% of a month salary. For a French individual earning the minimum revenue, a stove acquisition represents around 30% of a month salary.

By comparison, according to the World Bank, the average monthly revenue in Ghana is 129 USD and the minimum monthly revenue is set to 34 USD. With the highest price in Table 12 – 40.2 USD – a rocket stove acquisition would represent 31% of a month salary for the average Ghanaian individual, which seem very reasonable. For a Ghanaian individual earning the minimum revenue however, the acquisition of one of our rocket stoves would represent 118% of a month salary. The proportion is definitely higher. Yet, the acquisition of the rocket stove still seems very acceptable, considering the major improvement that such a stove would bring to the daily life of this individual.

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	EUROPE	SUB-SAHARAN AFRICA
Country of Reference	France	Ghana
Stove Price	330 USD	40.2 USD
Average monthly Revenue (AMR)	2,394 USD	129 USD
Proportion of Stove Price in comparison with AMR	13 %	30 %
Minimum Monthly Revenue (MMR)	1,261 USD	34 USD
Proportion of Stove Price in comparison with MMR	30 %	118 %

Table 13 : comparison of the stove prices with the monthly incomes

6.4.5 Comparison of the Minimum Recommended Price with the EzyStove® price

Our highest Minimum Recommended Price (40.2 USD) is three times smaller than the EzyStove® price (121 USD). This is a very encouraging indicator, particularly when considering the results achieved by the Paradigm Project with the EzyStove® (see section 4.1.3).

Should this price difference be confirmed, a suggestion could even be to sell our Rocket Stove to the Paradigm Project, who may gain enough leverage, then, to expand even further their current actions.

This pricing difference also gives room for a little more R&D. it would probably be interesting to build a prototype of our Rocket Stove, and to compare its quality of combustion with the quality of combustion achieved by the EzyStove®. Should a significant difference appear, further investment could be afforded to fill the gap and improve our Rocket Stove.

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7 SOLUTION'S EVALUATION

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In this section, we come back to the six challenge criteria presented in the challenge description and recalled in section 2.1, in order to check whether these criteria are achieved or not.

7.1 IRREVERSIBILITY OF THE NEW NON-LPG CYLINDERS

As all defective and unsafe cylinders are cut into pieces, the solution presented in this paper makes it totally impossible to reuse them as pressure vessels. The transformation is absolute, one way, and irreversible.

Our solution did not really study the refurbishment of reusable cylinders. It assumed that this was possible, and organized logistics so that it can be managed. However, if refurbishment of safe cylinders is finally judged impossible, it will still be possible to transform all collected cylinders into Rocket Stoves. Comparatively to the flow hypothesis made in this solution, this would result in doubling the number of Rocket Stoves to produce – which we consider totally manageable.

7.2 VALUE

We estimated (sections 6.4.2) that a 40 USD average sale price would make the entire operation profitable within two years, and would generate around 120 million dollars of income if applied to 300,000 cylinders. This makes the solution presented in this paper much more cost-effective than the current “hydraulic press” solution – which only grants a few dollars of value per cylinder.

In addition, we also showed (section 6.4.5) that a very similar projects manages to use stoves which are three times more expensive, which means that our selling price may potentially be set to a higher level if required.

Finally, we have to count the societal benefits, in terms of job creation (more than 1,600), or reduction of inequalities and poverty. A similar project, started in 2008, has already saved 23 million dollars in family income savings due to reduced fuel consumption, and 12 million productive hours thanks to a reduced wood collecting time (see section 4.1.3).

7.3 GEOGRAPHICAL CONTEXT

The closest similar experience we found on this topic have been successfully performed in Sub-Saharan countries (section 4.1). In addition, most of the active organizations we found (section 4.2) on Rocket Stove initiatives count SSA countries amongst their core targets.

7.4 ENVIRONMENTAL IMPACT

One of the key assets of the Rocket Stove solution is its environmental impact. Thanks to the better combustion they permit, rocket stoves have massive impact on CO emissions and PM emissions. A 30 to 40% decrease of fuel consumption can be expected for households who shift from open fire cooking to rocket stove cooking, preventing huge greenhouse gases emissions and deforestation (see section 3.2.3).

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7.5 CAPACITY AND INVENTORY

The solution presented in this paper would work for any Sub-Saharan country, and for almost any cylinder size or material. We are very confident that the entire inventory of cylinders can be managed, as there is no minimum or maximum size to the Rocket Stove that can be fabricated, nor any real constraint on the cylinders variations of shape.

For keeping its generality, we made a little change to the context exposed in the challenge description, shifting from “3 million bottles to recycle” to “300,000 bottles a year to recycle”. These two starting assumptions, however, can be made equivalent provided you lead the project on exactly five years.

Actually, the solution would even have room for going on a higher scale – this is the very reason why we made this little variation on the basic hypothesis.

7.6 LOCAL RESOURCES

The solution presented in this paper is fully compatible with the human resources, materials and equipment that are available in Sub-Saharan Africa. Performing it relying solely on Sub-Saharan countries equipment and labor force is totally no big deal.

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8 CONCLUSION

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The solution described in this paper proposes to recycle the former LPG cylinders into Rocket Stoves, so that they can be used to improve the health and life quality of up to 1.5 millions Sub-Saharan households.

Transforming an LPG cylinder into a rocket stove is rather easy. All cylinders can be transformed. Benefits include drastic improvement of public health, social impact on education, huge money savings for the families, and thousands of job creations. As similar projects have been performed already, and as the cooking stove problem is one of the core issues of Sub-Saharan countries development, a lot of assistance could be expected if the project were to be led.

This paper is to be considered as a preliminary feasibility study. Many hypothesis have been made, and a few questions have been kept unassessed. But a work plan has been established, as well as a costs and profits estimation, which both have shown very encouraging results. We do believe that recycling LPG cylinders into Rocket Stoves would be technically suited to Sub-Saharan capacities, economically profitable, and very impacting on a social point of view.

Should IMC Worldwide be interested in going further into this solution, we would be glad to provide assistance in any possible way. We kindly invite IMC Worldwide officials to contact us in case they would be willing to engage in such collaboration. Also, please don't hesitate to transmit your questions to us – through Innocentive – in case you need any further details on the solution we proposed to you.



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