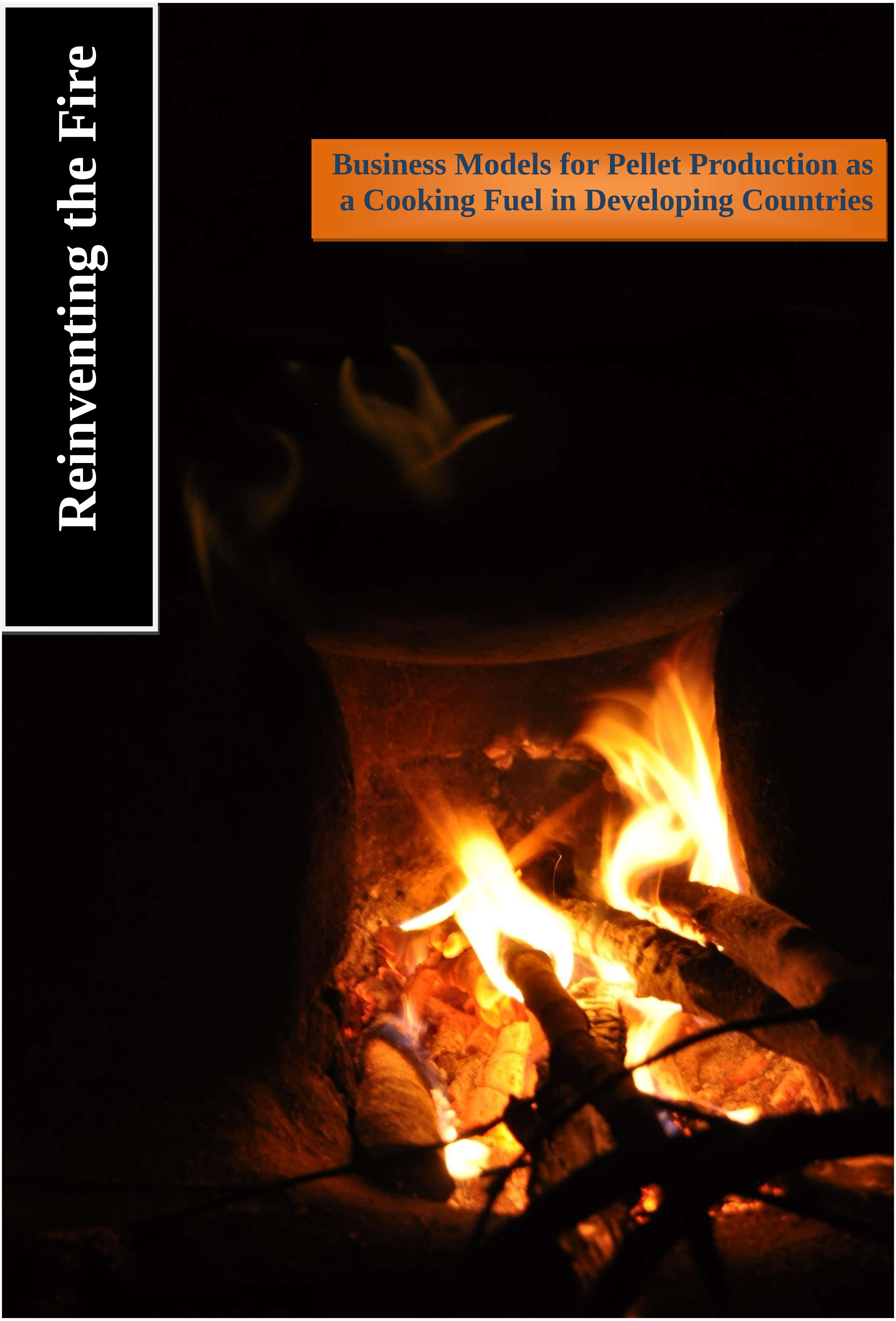
Reinventing the Fire

Business Models for Pellet Production as a Cooking Fuel in Developing Countries



SYNOPSIS

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ABSTRACT

The use of wood and charcoal for cooking is a major cause of increasing deforestation, indoor air pollution and associated environmental problems (desertification, erosion, floods, etc.) in developing countries. Apart from low fuel efficiency in the open fires, the traditional stove designs, cooking culture such as using cow dung and architectural custom also contribute to harmful smoke, which is considered the worst health problem for children under 5 years old in developing countries. According to WHO, around two million people die worldwide due to indoor smoke impacting more women and children compared to men. In past cook-stove programs, various efforts have been made by companies, governments and international organizations in research and implementation of improved cook-stoves in the rural and urban areas and in many countries it is introduced with subsidies. The advanced cook-stoves are more efficient, produce less smoke, make it easier to cook, clean etc. but still they need to rely on firewood or charcoal which only helps in delaying the problem of deforestation and resulting in unsustainable use of biomass resources. Traditional firewood as a cooking fuel is also not considered uniform and reliable fuel source by international organizations like United Nations and developing countries governments. In the rainy season or in case of scarcity of wood as it is observed now due to deforestation in countries like Tanzania, people face problems even with advanced cook-stoves. After all of these efforts, traditional firewood cooking still exists for about three billion people in the world.

It can be strongly argued that one of the biggest reasons for the persistence of this problem is that there is no focus on securing a reliable and renewable energy fuel source which can be used in advanced cook-stoves. Conventional cooking fuel source alternatives like LPG/kerosene/electricity are riddled with other problems such as cost, safety, transportation and lack of infrastructure in rural and remote areas. Therefore, it is essential to introduce sustainable fuel supply made from locally available renewable resources with high fuel use efficiency and as competitive in terms of harmful emissions as of LPG. One of the potential renewable resources can be the manufacturing of pellets by sustainably available local biomass resources which could represent a reliable and uniform cooking fuel. The use of pellets in efficient gasifying stoves with micro-gasification technology converts solid biomass into gas for clean burning. However, these stoves use along with pellets is very limited in developing countries at present and there is a need of awareness to develop scalable and financially sustainable business models which provides wider acceptance of efficient biomass stoves and pellets as a cooking fuel. In this report, based on presently available limited business models of selling pellets and gasifying stoves, hypothetical business models will be designed which will be accessed for selected variables.

This research report will investigate the potential business models for cost effective pellets production as a sustainable cooking fuel supply in developing countries. It is a key to sell advanced cook-stoves and long term solution to the problems faced in traditional cooking practices.

ABBREVIATIONS

ABM	Appropriate Business Models
ACS	Advanced Cook-stoves
BC	Black Carbon
BMC	Base Model Companies
BP	British Petroleum
CDM	Clean Development Mechanism
CO_2	Carbon di-oxide
CO	Carbon Monoxide
EU	European Union
FA	Fan Assisted
FE	First Energy
GHG	Green House Gases
GDP	Gross Domestic Product
IAP	Indoor Air Pollution
ICS	Improved Cook-stoves
IEA	International Energy Agency
JGVK	Joygopalpur Gram Vikas Kendra
KCJ	Kenya Ceramic Jiko
KJS	Kampala Jellitone Suppliers
kWh	Kilo Watt Hour
LPG	Liquefied Petroleum Gas
Mt	Million tones
MJ	Mega Joules
MPU	Micro-Pelletizer Unit
ND	Natural Draft
NGO	Non Governmental Organization
NISP	National Improved Stove Program
NPIC	National Program on Improved Chulhas
OECD	Organization for Economic Cooperation and Development
PTD	Participatory Technology Development
SIDA	Swedish International Development Co-operation Agency
TCS	Traditional Cook-stoves
TLUD	Top-Lit Up-Draft
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
VLE	Village Level Entrepreneurs
WHO	World Health Organization

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1. INTRODUCTION

Biomass has been used as an energy source since the beginning of human civilization. Biomass supplies 14% to the world's energy consumption and is still considered a key renewable energy resource of the future. It is the fourth largest source of energy used in the world [Hall and House, 1995]. The sources of biomass are available in various forms such as plants, animal residues, crops, etc. Apart from providing food, biomass is also used for building materials, paper, heating and cooking as one of the energy uses. It can be argued that the biomass fuels could potentially provide much more extensive source of energy if it is used in a sustainable way with efficient technologies. Besides the efficiency improvements of available energy systems, there is a need to consider biomass residues[1] which are left over from agricultural, forestry or industrial activities as a substantial biomass fuel, compared to disposing it by dumping or burning it openly in the present scenario of developing countries.

There are possible technologies to use biomass resources as carbon neutral or carbon negative, compared to carbon positive in case of fossil fuels. One of the examples could be the usage of biomass in gasifying stoves which produces carbon rich biochar[2] in a carbon negative process. Biomass energy is mainly used in open fires by burning wood and charcoal for cooking in developing countries. However, millions are suffering every day due to smoke and indoor air pollution from open fires.

1.1 Background and Need

Cooking in the modern kitchen is an amusing activity using electricity or gas stove, about three billion people in the developing countries[3] (figure 1.1) still cook their food over open fires using traditional fuels like wood, charcoal, crop residues, coal and animal dung – the way it has been practiced for thousands of years [WHO, 2006]. For instance in Tanzania, more than 90% of rural households rely on biomass for traditional 3-stone cooking practices [MEM, 2003].

Biomass use is closely related to poverty. As household income increases, people tend to switch their cooking fuel to whichever is seen as more convenient such as LPG/Electricity from biomass usage in developing countries [Victor and Victor, 2002]. Therefore, growth in income is one of the obvious solutions to biomass energy problems for cooking. However, doubling typical incomes would only reduce biomass fuel usage for 16% of the population in a country [IEA, 2009], which indicates that the use of biomass as a fuel will continue for many years among developing countries. Traditional biomass fuels will be used by 100 million more people by 2030 compared to today [IEA, 2010]. Even access to electricity or Liquid Petroleum Gas (LPG) primarily in urban regions, the traditional fuel use will continue due to cultural factors and cost.

The energy efficiency issues of open fires has been known since early 1950s but it was publicized as *"other energy crisis"* in 1970s [Eckholm, 1975]. It is argued that biomass fuels used in traditional ways contribute to Green House Gases (GHG) [Venkataraman et al., 2010] and increases Black Carbon (BC) in the atmosphere [Ramanathan and Carmichael, 2008]. Much research has been done for household energy issues in developing countries during 1980s and 1990s. Cooking problem at that time was observed as fuel substitution or biomass inefficient usage based on deforestation and fuel scarcity issues [World Bank, 1996]. According to World

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[1] Biomass residues are the by-products of biomass, waste streams and residues from agriculture, forestry and related industries [UNFCCC, 2005].

[2] Biochar is black carbon produced from combustion of plant-derived fuel in zero or low oxygen ambiance at high temperatures. In comparison to coal as a fossil fuel, biochar can be used as soil amendment [Lehmann and Joseph, 2009].

[3] Developing countries are defined as the countries with relatively lower Gross Domestic Product (GDP) and less industrialization compared to other countries [Farlex, 2012].

Bank review of lending programs in 2000 to 2008, less than 1% of this finance was contributed for clean cooking [Barnes et al., 2010]. One of the major difficulties is that household energy problem includes multiple disciplines ranging from energy, forestry, climate change, gender and health.

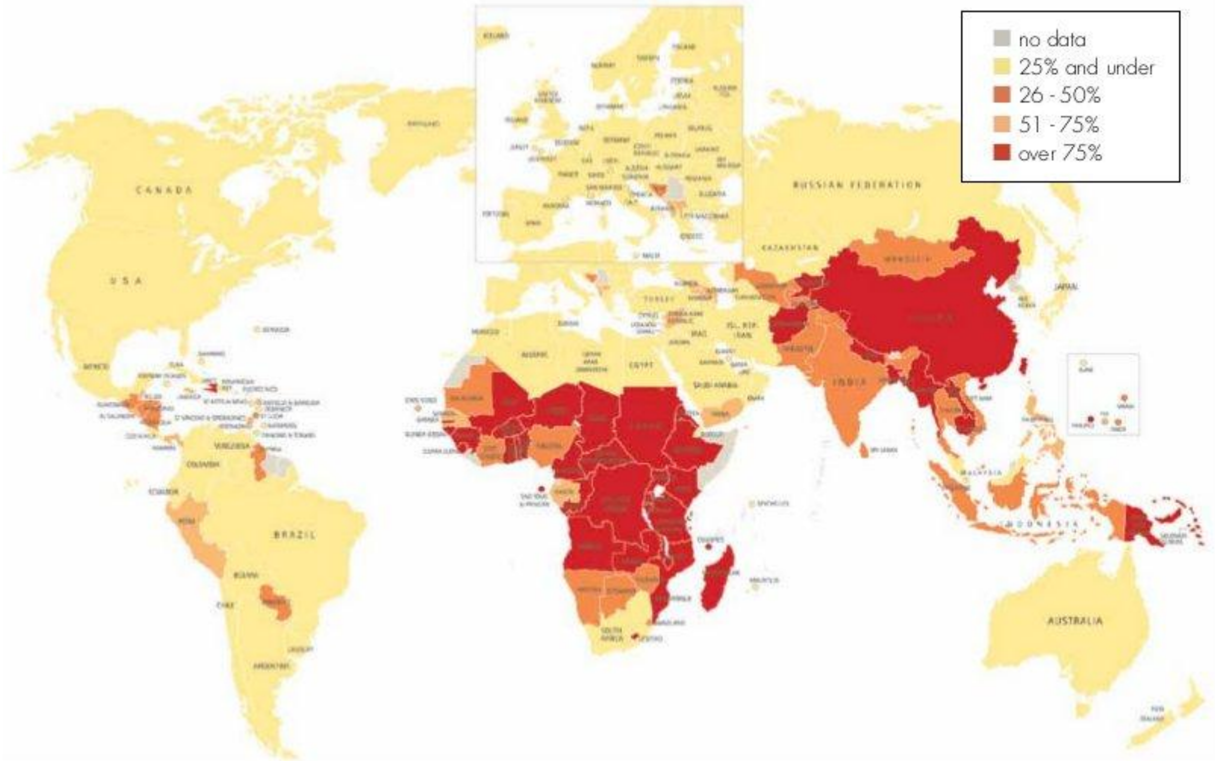

Figure 1.1: Traditional Fuels Usage Percentage (WHO, 2006)

Health Impacts

One of the world's biggest but less known problems is daily exposure to toxic smoke from open fires. In the beginning of 1990s, there was more focus on Indoor Air Pollution (IAP) and its effects on health due to traditional cooking. Growing scientific evidence over last 15 years has shown that IAP contributes not only to respiratory illness but also include cataracts, child pneumonia, heart disease, cancer and low child birth weights to pregnant mothers [Smith et al., 2004]. Furthermore, thousands more fall sick with illnesses which could be avoided by adoption of clean burning fuels in efficient cook-stoves [Smith et al., 2004].

According to WHO estimate, smoke exposure from traditional cooking practices is fifth worst risk factor in developing countries for diseases, causing around two million deaths every year which exceeds deaths from tuberculosis or malaria (figure 1.2) [Ezzati et al., 2002].

Toxic smoke exposure is high for women and young children who spend most of their time near open fires or school-children may try to study by weak light of cooking flame. Open fires and typical wood-fired cook-stoves emit Carbon Monoxide (CO) and other noxious fumes which are up to 100 times higher than WHO recommended limits [WHO, 2011]. About half of all pneumonia deaths under the age of five in developing countries happen due to smoke exposure [Smith et al., 2004]. Research has shown that even without improving combustion efficiency of the cook-stoves, addition of chimney to stoves can help direct smoke exposure reduction but it provides no environmental benefits and limited health impacts [Smith, 2009].

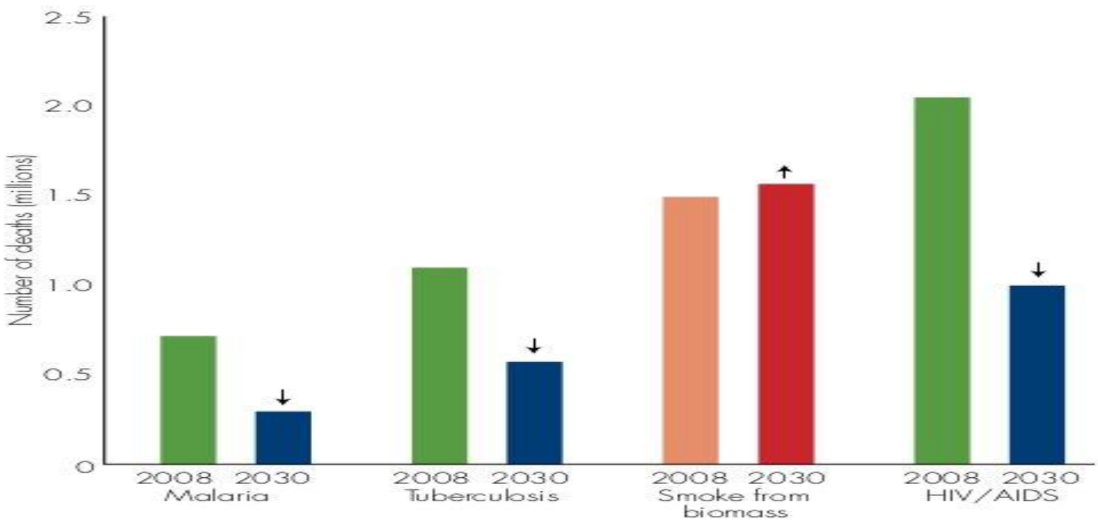

Figure 1.2: Annual Deaths from Selected Diseases[4] (IEA, 2011)

Open fires from cook-stoves has another risk of burns faced by poor households depending on kerosene, clay cook-stoves or unstable metal usage which contributes an estimate of 300,000 burn deaths/year [Peck et al., n.d.].

Environmental and Livelihood Impacts

Dependency on inefficient cook-stoves and polluting traditional fuels result in variety of environmental problems. Most of the native forests have been cut down in many countries for charcoal production [Rose et al., 2009] or reliance on wood fuel in other countries can lead to more pressure on natural resources and local forests [Smith, 1994]. Unsustainable use of wood for charcoal production can lead to watershed losses, mud-slides and desertification which indirectly impacts regional agricultural productivity and food security [Wood and Baldwin, 1985]. Increasing loss of forest canopy due to charcoal production was observed in Democratic Republic of Congo, Togo, Cambodia and Guatemala impacting the habitat of endangered species [Jeremie et al., 2011].

Extensive network is used to transport charcoal after production; it is $10 billion[5] industry in sub-Saharan Africa which causes vast destruction of forests felled to provide cooking fuel [Nicholls, 2011]. The cycle of destruction is growing at alarming rate every year along with population growth and increasing movement of refugee camps place pressure on natural resources resulting in desperate fuel search for women further and further away from home. Furthermore, many countries face strife due to competition between local population and refugee communities for fuel resources [Martin, 2005]. Rural women will be affected most due to global conflicts for natural resources and world population growth [Cecelski, 2000].

Outdoor air pollution from Traditional Cook-Stoves (TCS) also contributes to deadly emissions around the world impacting both with and without clean-cooking energy resources [Ruiz-Mercado, 2011]. In India, household fuels burning for cooking are causing half of health-damaging air pollution [Smith, 1986]. China also experiences air quality impacts due to biomass-fired and coal-fired stoves for household cooking and heating [Zhang and Smith, 2007]. TCS smoke is due to inefficient operation which is contributing significantly to global climate change. Open fires emit the gases such as CO, methane, nitrous oxides and particles impacting climate in short-term [Smith, 2009]. Cooking-stoves, mainly from residential sources, represent more than 25% of black carbon emissions in global inventory [Bond et al., 2007]. As methane has life span

[4] Smoke from biomass does not include coal-fueled cook stoves deaths – 1.96 million total 2008 deaths from cook stove smoke inhalation

[5] Price mentioned in USA dollars

of a decade, climate mitigation can be achieved more rapidly by its reduction compared to carbon di-oxide (CO_2) alone [Bond et al., 2004].

Traditional fuels usage also has economic burden on families who need to pay as much as one-third of their income simply to purchase cooking fuel for daily meal. The financial impact is especially higher on very poor, whose income of less than $1/day is stretched to cover daily necessities such as food, fuel and medical care. If cooking fuel is purchased rather than collected, initial cost of more efficient cook-stoves can be recovered within few months due to fuel savings and these savings can be used for betterment of livelihood. Furthermore, studies has shown that women reinvest 90% of their income in their families and related activities compared to men with only 30-40% [DAC, 2008], which means that saving from cooking fuel can impact entire community.

Advanced Cook-stoves

Traditional cook-stoves (figure 1.3) can be considered ranging from three-stone fires to brick models. Defining an improved-stove depends on several factors but generally depends on design improvements aim and type of TCS considered. For example, an improved-stove can be designed by reducing smoke, increasing efficiency or lessen cooking time. In previous cook-stove programs, there were many improved-stoves designed at about $5 or less to serve even poorest households. Considering that many cook-stoves are used in different parts of developing countries, improvements can vary according to the region or country. Therefore, the term *"Improved Cook-stoves"* (ICS) is an umbrella to represent diversity of improvement to traditional cook-stoves[6].

Figure 1.3: Traditional Cook-stoves

There is no definition of *ICS* which is accepted universally according to technical or performance standards. It is difficult to use various precise measures to distinguish wider set of an "improved-stove" compared to "advanced-stove". Therefore, throughout this report, *TCS* is referred to open-fires or stoves made by local artisans who have poor combustion features and are not energy efficient. *ICS* represents the stoves used in legacy programs containing either chimney or firebox which can limit IAP but outdoor air quality is not controlled. On the other hand *Advanced Cook Stoves (ACS)* is referred to designs based on higher level of research and development with most recent manufacturing. These stoves are also not yet well-defined for safety, emissions, durability and efficiency but are considered comparatively more expensive. They might be designed for dedicated fuels like pellets, charcoal, wood or residues using a specific technology. This report will focus only on micro-gasification based stoves (considered as ACS) as explained in Appendix A.

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6 The term cook stove and stove is used interchangeably in this report.

Considering solid biomass fuels, micro-gasifiers are cleanest-burning option presently available [GTZ, 2011]. It has lowest emissions based on the available results in 2009 (figure 1.4).

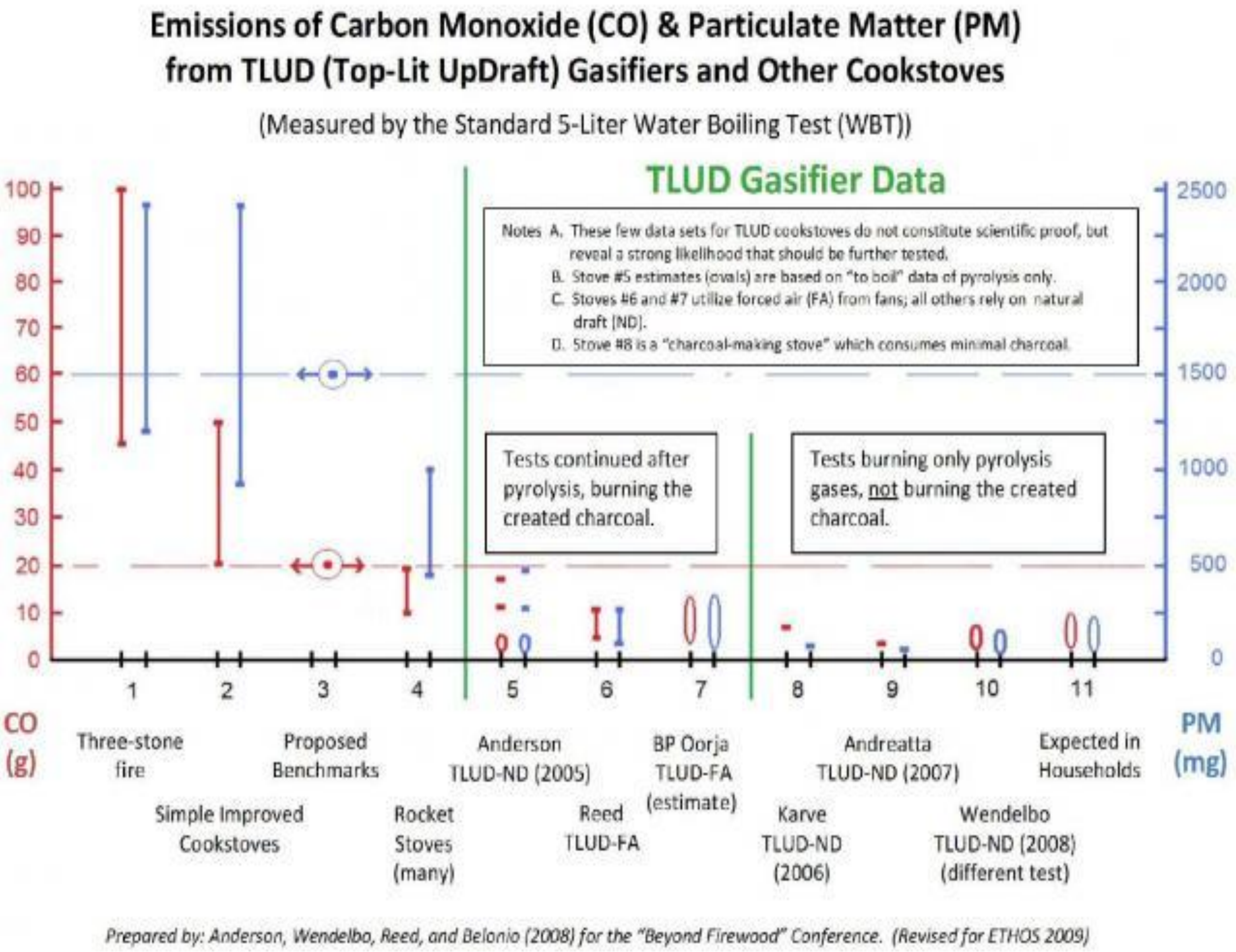

Figure 1.4: Stoves Comparison (www.bioenergylists.org/andersontludcopm)

The strength and weakness of micro-gasifiers used for household purposes are listed below:

Table 1.1: Micro-gasifiers Summary

Strengths:	**Weakness:**
→Complete burning and clean cooking from variety of solid biomass →Higher fuel efficiency due to complete combustion →Ready to use just after lighting →Less tending of fire for batch-loading →Can handle wide range of biomass which can be cleanly burned in other ICS →Stable combustion process for long time (more than 2hours) without human intervention	→Firepower regulation can be difficult →Once started, it is difficult to stop the gas generation unless fuel is consumed →Cannot be refueled during the time of operation →Need of material (such as kerosene) to start the fire

Opportunities:	Risks:
→Can be attached to presently existing stove structures for using range of fuels →Can create char as a by-product →Carbon-negative cooking is possible if char is used as biochar	→Un-burnt thick smoke leaves the gasifier, if flame is extinguished and wood-gas is still produced. It is important to learn that how people will avoid this risk

1.2 Learning from Past Programs

Chinese National Improved Stove Program (NISP) has undertaken biggest ICS distribution in the world by installing 177 million stoves covering about 76% of the rural households [Junfeng et al., 2000]. It is the only cook-stove dissemination effort which has achieved success on large scale as most of it was used for long period of time (figure 1.5). On the other hand, India's National Program on Improved Chulhas (NPIC) has also installed 33.8 million ICS by 2001 [MNES 2002]. It is also unclear that how much of distributed ICS are in actual practice regularly [WHO, 2009]. NPIC faced criticism for stove design, low uptake risks, high program cost due to heavily subsidizing stoves and ignoring already existing local markets of stoves [Barnes et al., 1993].

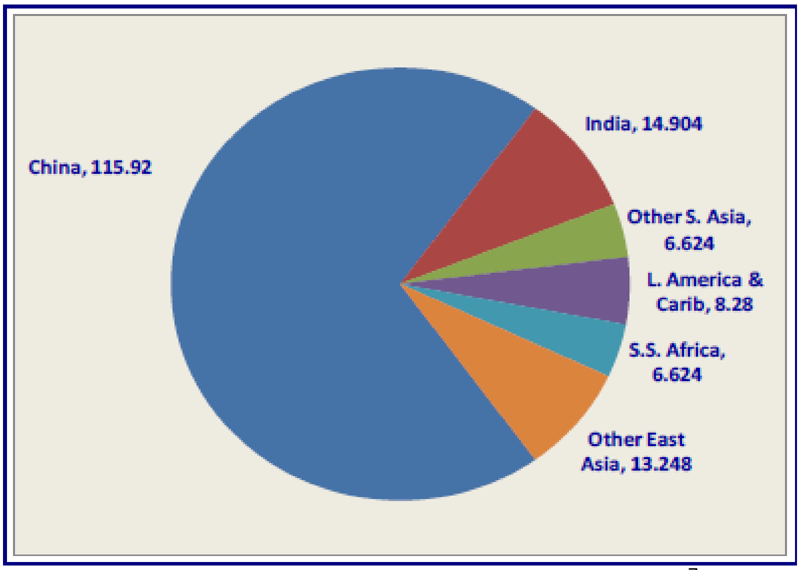

Figure 1.5: Distribution of Improved-stoves (in million)[7] (WHO and UNDP, 2009)

Many companies like Phillips have recently started focusing on selling ACS commercially in Africa, Asia Pacific and Latin America region. However, there are limited examples which show self-sustainability for commercial distribution of ICS or ACS. It is crucial to design the approach to reach consumers which impact performance of any cook-stove program irrespective of commercial or non-commercial venture. ICS had slow adoption, may be due to less prioritized benefits seen by user or people are unaware of the benefits [Howells et al., 2010]. Stove design should drive from understanding valued benefits for the users so that customers can be approached according to the appropriate benefits [Karnani, 2007]. Location based promotion; partnerships with locally based organizations for sustainability, cooperative promotion can be used to reach rural customers [Velayudhan, 2007].

Carbon finance is emerging as new kind of financing that can be applied for consumer, distributor or for an enterprise level. It provides credits from GHG emissions reduction due to efficient cook-stove usage in developing countries to the developed world buyers [GTZ, 2010]. Applying for carbon financing is becoming popular in cook-stove programs and different carbon offset

[7] Data are collected from most recent national households surveys which included questions on usage of household stove type. *ICS* are considered with chimneys and firebox, which should not be confused with ACS in this report.

mechanisms are used such as Kyoto Protocol's Clean Development Mechanism [CDM, 2008] and voluntary offsets [DNV, 2007].

1.3 Research Motivation

Selling ACS have some crucial characteristics which may make it challenging to reach the poor [Slaski and Thurber, 2009]. For instance, typical price of $20–90 are comparatively expensive considering the population earning less than $2/day, or 2.6 billion people relying on biomass for cooking globally [World Development Report, 2007/08]. There is consumer affordability issues in purchasing efficient cook-stoves compared to other health and welfare products for low income populations (table 1.2) below.

Table 1.2: Low-Income Population Technologies Comparison

Product	Sample Price per unit (US $)	Comments
Solar home light	$12-$200	About $12 for the basic model from D-Light
Point-of-use water treatment	$9/3-year supply	WaterGuard, sells 250ml of 1% sodium-hypochlorite for about 25 cents (which can be used for a month)
Insecticidal net	$10	Price includes distribution, awareness for usage and monitoring
Efficient cook-stove	$20-$90	Cost varies according to the material used, location of production, technology sophistication, distribution, etc.

Apart from economical issues, it has been observed that it is difficult to switch from traditional settings to cooking technologies and new fuels due to cultural and societal cooking preferences [Eberhard, 1993].

One of the most important factors is that many of the ICS users do not value spending extra money for benefits of time savings and health impacts. These benefits seem to be attractive for an outside viewer but it may not be on high priority for users [Howells et al., 2010].

Commercial efforts may have an advantage to match the product features according to the user needs as there is profit involved by selling stoves. The complication in stove design considerations is that women are main beneficiary who may value health benefits due to clean stove usage but financial decisions are usually taken by man in the household and priorities are therefore usually not high for efficient stoves [Ramani and Heijndermans, 2003]. Designer has to decide trade-off between cost, low emissions, efficiency, durability with fuel type, stove material and draft mechanics [Bryden et al., 2010].

The literature also shows an important criterion for designers about the stove usage in rural or urban areas. Rural customers usually collect biomass and their income is also lower compared to their counterparts in urban areas which are more likely to buy cooking fuel [Barnes et al., 2005]. Companies can also shift their focus to restaurants or hotels rather than household customers to enhance financial sustainability. Focus on customer segment of commercial scale and households who are in financially stable situation typically ignores household customers with low purchasing power and in result may be left out from business [Zerriffi, 2010]. Therefore, considering the complexity of customer income segments, organizations need to find out various strategies to sell product to variety of segments.

Research Question

One of the biggest reasons for existence of traditional cooking problems is that there has been no focus on reliable and renewable energy fuel which can be used in efficient cook-stoves. It is essential to introduce cost effective sustainable fuel supply made from locally available renewable resources with high fuel use efficiency and as competitive in terms of harmful emissions as LPG. Pellets have potential to become reliable cooking fuel which can be used along with gasifying ACS for challenges to overcome traditional cooking practices. However, presently the uses of pellets along with ACS are limited and there is a need for financially sustainable and scalable business models. This research report aims to investigate various business models for pellet production as a sustainable cooking fuel supply.

Based on above mentioned literature and lack of focus in sustainable cooking fuel using local biomass resources, a research question and two sub-questions are formed as mentioned below.

RESEARCH QUESTION

How business models can promote pellets as a sustainable cooking fuel along with ACS in developing countries?

SUB-QUESTIONS

What kind of biomass densification products can be considered as cooking fuel?

How most important variables can impact the realization of successful business models?

Availability of sustainable biomass resources can be used to manufacturer pellets in developing countries. However, there are challenges and lack of awareness to manufacture cost effective pellets in developing countries. There can be multiple ways to promote pellet industry in developing countries. This research highlights the solution in terms of financial sustainability and scalability achieved by business models.

The sub-questions will help to investigate solutions for research question. First sub-question will indentify about the possibility of biomass densification fuels and their present use. It will also provide learning from previous biomass densification fuels usage for cooking. Second sub-question investigates the impact of most important business model variables on the appropriate business models. The variables are considered according to their importance for cost-effective pellets production and distribution along with ACS. Chapter 3 and 4 will be answering the first and second sub-questions respectively.

1.4 Research De-limitation

Due to limited resources and wish to investigate as a practitioner in specific area of the problem, this project is limited for following factors to provide broader picture:

- This study provides a general overview for developing countries. It is not geographically focused to provide detailed case analysis. There will be certain changes required in this research finding to apply for a particular place.

- Pellets are extensively produced and used in developed countries. However, this study does not follow the knowledge from small scale pellet production in developed countries as well as pellet usage for heating and other energy generation facilities in developing countries.

- The biomass resources used for pellet production should be available in sustainable manner. However, assessment for biomass sustainability and other uses (in housing, animal feeding) is not considered in this report.

- The improvement by targeting government policies, marketing strategy (TV, radio, etc.), financing mechanism (CDM, UNFCCC), etc is not focused in this report. Furthermore, the organization implementing or managing the business models can be an enterprise, NGO or government institution which is also not highlighted.

- Lack of pellet production experts in developing country was a challenge to gather data. This was the reason for weak quantity of survey questionnaire data.

- Pellet burning in biomass gasifying based ACS are considered. It is not considered for other wood based efficient stoves. Other types of biomass based fuels (such as liquid fuels) are also not considered in efficient cook stoves.

2. METHODOLOGY

2.1 Theoretical Framework

The theoretical framework applied in this report uses two different literatures:

1. **Business Model**

The existing literature targets solutions to overcome the obstacles for stoves or other related products to be sold commercially. Financial sustainability and scalable operations depends on business model generation for selling pellets as a cooking fuel along with ACS.

"A business model describes the rationale of how an organization creates, delivers, and captures value" [Osterwalder and Pigneur, 2010].

Business model is a strategy which an organization implements through its processes, structures and systems. Customers, offer, infrastructure and financial viability represents four main areas of business which are further classified in several blocks. Some of these several basic blocks for business defined by Osterwalder and Pigneur (2010) are:

- Customers segmentation
- Value propositions offered
- Distribution and sales channels strategy
- Revenue streams
- Key resources

Segmentation of customers is the target group which is aimed to reach and serve by a company. Value proposition defines the number of products and services created for a specific customer segment. Channel strategy of a company is defined by the way communication occurs with its customer segments for providing services. Revenue streams are the money raised by the company from each customer segments. Key resources represent most important assets needed for a working business model [Osterwalder and Pigneur, 2010].

Unsuccessful records of Indian government and strictly charitable large scale efforts have lead to increase focus on commercial solutions. In case of Kenya Ceramic Jiko (KCJ) distributing ICS (for charcoal) had a wide success on commercial basis with 2 million stoves sold by 2002 [Ministry of Energy, 2002]. KCJ had started with NGO funding in early 1980s but along time it has shifted to commercial sustainability [Kamman, 2001]. Focusing on commercially available sustainable solutions also shows wide shift in conventional wisdom on improving the livelihood of poor with donors catalyzing the markets instead of providing endless support [Bailis et al., 2009]. It can be strongly argued that business operations offer more potential in theory for being scalable and sustainable compared to completely subsidized efforts. Enterprise develops customer-feedback business models and value supply-chains instead of relying on centralized distribution system and funding support.

Scaling issues of NGOs mainly due to lack of scalability and financial sustainability are documented [Uvin et al., 2000]. Subsided supply-chain distinguishes between charitable and commercial operations. Targeting rural poor for selling products can bring obstacles like support and distribution networks, lowering down cost, poor infrastructure, etc. [WLPG, 2005]. Different strategies are used by companies to overcome these challenges such as Hindustan Lever Limited and Indian Tobacco Corporation are successfully expanding their operations in rural India by combing involvement of local communities and information technology [Simanis and Hart, 2009].

Business model financing strategy is critical for sustainability of the program [Zerriffi, 2011]. Financing can be done in many ways such as by retail outlets, stove company itself, through commercial banks, micro-finance [Rao et al., 2009], etc. Financing can also be done by a local entrepreneur who wants to become a stove distributor. These kinds of enterprises can help to reduce overall cost of stove for the manufacturer [Gompers and Lerner, 2004]. There are various ways to reach the end user ranging from purely commercial venture financing options to purely non-commercial grant giving option. The intermediate step between these two approaches are from social venture capital which are supposed to benefit investors by providing returns to customers for solving the environmental and social issues [Nyssens, 2006]. However, investors also expect return of invested amount while achieving social goals.

The partnership with NGOs to reach women's group through rural distribution network may increase the reach of the firm. However, there is a need of feedback mechanism to control the reach for providing better after-sales support which will be difficult from a third party involvement like NGO especially considering ACS.

2. **Appropriate Technology**

Appropriate technology refers to the solution which is considered most suitable for developing countries. A technology designed for appropriate need of particular problem in developing countries which is different compared to the technology used in developed countries for same problem [Hadjor, 1993]. Developed countries have industrialized solutions which are more capital intensive and less labor orientated whereas in developing countries it is opposite. Therefore, economic efficiency can be achieved by labor-intensive technology in developing countries. However for some kinds of production, there will be no practical choice to go for labor-intensive technologies such as refining petroleum. It is also argued that if an industrialized solution is applied in developing countries, it will limit jobs resulting in unemployment and poverty. Appropriate technology is also referred to an opportunity for creating employment. However, appropriate technology literature also contains other factors such as local culture, institutions which are not included for this research due to general study of developing countries.

Previous stove programs also experienced appropriate technology for stoves dissemination. For instance, the stove designer may need to make trade-off between features (efficiency, material) and cost reduction as mentioned in previous chapter. In this report, the appropriate technology concept is also used for pellet production and distribution apart from ACS and pellets technologies. The pellet production cost can be reduced by using more labor-intensive process and reducing the scale of production for developing countries. It is worth to note that appropriate technology concepts are also used in business models for reducing the cost of transport and distribution of pellets to the customers.

2.2 Analytical Framework

About 730 million tons of biomass burning occurs every year in developing countries [WHO, 2007]. Considering the sustainable part of biomass use in developing countries, pellets can become a solution for providing cooking energy in which biomass residues can also be utilized. Pellets production should be financially self-sustainable as it is required to provide fuel as long as ACS is used. However, if fuel prices are out of reach from many customers, then ACS dissemination scale will be limited. Presently, the organizations providing pellets as a cooking fuel are limited (or at early stage of development).

Based on business model understanding of First Energy (FE) in India and Inyenyeri in Rwanda studied in previous projects by author (which is highlighted in Chapter 4), new business models are designed. These companies model are referred to as “Base Model Companies” (BMC) in this report which is the base to design new business models referred as “Appropriate Business

In case of providing cooking fuel, ACS sales depend on distribution system and reliability of the fuel apart from its cost. To achieve financial sustainability, the business model should be designed to be self-sustaining or become sustainable due to trend of the business after certain interval of time.

This research report is examining business solutions as a platform for pellets and ACS dissemination. However, there is need for an investigation of how different variables can impact on successful adaptation of pellets as a cooking fuel along with ACS. Based on the literature study mentioned in previous chapter [Shrimali et al., 2011; Bailis et al., 2009; Slaski and Thurber, 2009] and past projects experience and interviews conducted by the author, most important variables are selected to characterize ABM for obtaining financially sustainable and scalable business operations (table 2.1). These selected variables are also derived on their importance and challenges faced by businesses of BMC.

Table 2.1: Business Model Variables

S.No.	Sector	Variable	Comments
1	Pellets Production Management	Biomass resources	Type of raw material, source (virgin, industrial, agricultural, etc.), price (paid, marginal, free)
2	Pellets Production Management	Biomass drying	Biomass drying mechanism used or dried at source
3	Pellets Production Management	Electricity	Source of electricity (Grid, diesel, solar), cost of electricity
4	Pellets Production Management	Packaging	One time use bags or refilling of bags for pellets
5	Pellets Distribution Management	Channel strategy	Collection and selling points (home delivery, crowdsourcing), distribution network (own, franchise, partnership, third party, etc), customers support
6	Pellets Distribution Management	Transportation	Distance traveled, transporting biomass (raw, hammered, pellets), mode of transportation, price of fuel
7	Pellets Distribution Management	Target customers	Segment (commercial, household), area (rural, urban, regional, national), competition (LPG, kerosene, charcoal, firewood)
8	ACS Management	Stove design	Cost, efficiency, ease of use, manufacturer location, mass production, flame control

An ABM assessment based on these chosen variables will be done from personal meetings and interviews of experts in densified biomass based fuel supply. Variables 1-4 drives cost of pellets within production unit. Variables 5-7 will determine cost to reach customers to deliver the products and services. These variables (1-7) can govern overall pellets production cost and further cost for consumers purchase price and revenue streams with the aim to cover large segments of populations to provide quality pellets. For instance, business model can segment customers on the basis of income for distribution of ACS. However, the performance and cost of stove in which pellets are used can drive the customers decision to use pellets as a fuel. Variable 8 provides the impact of stove design choices such as ease of use, health benefits, time savings, cost planning etc. However, it is worth to note that there are other variables impacting overall performance of the program such as use of micro-finance, types of organization (social enterprise, NGO, government, etc), marketing strategy (TV, radio, etc.) which are not focused in this report as the aim is limited to address the challenges for pellets production and supply-chain of raw biomass/pellets. Another reason for this de-limitation is due to general studies of developing countries rather than case study for a particular place.

Based on variables assessment for a particular business model, it will provide findings for research question about business solutions to promote pellets and ACS use in developing countries (figure 2.1).

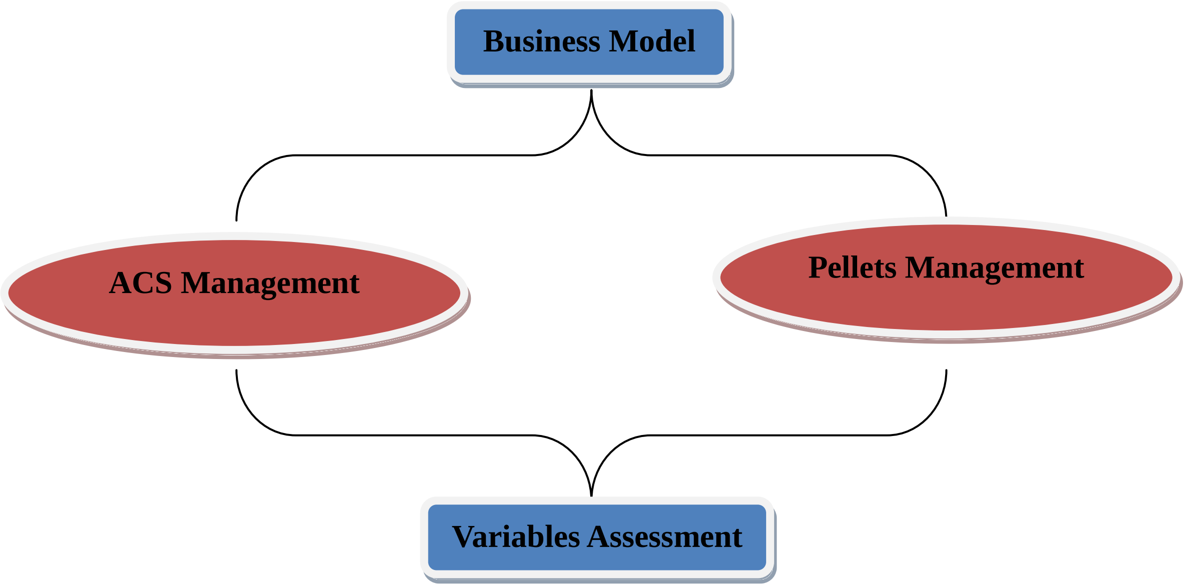

Figure 2.1: Research Method

Data Gathering

The data gathering methods used in this report are listed below:

- Phone conversations
- Personal meetings
- E-mail Interviews
- Survey
- Field Visits observations
- Workshops

List of people communicated by interviews and surveys is attached in Appendix D. Multi-sector organizations including academic institution experts, enterprises, village representatives and NGOs are contacted to gather data for accessing the variables. As it is experienced from previous cook-stoves programs, various sectors play crucial role to deal with this multi-discipline problem of traditional cooking practices and fuel usage. It is essential to gather data from multiple-sector organizations and individuals for this study to design ABM. Updated data was also gathered from BMC to understand their present challenges based on local situations, so that it can be taken care in ABM for better implementation. There is lack of particular researchers for pellets use along with ACS in developing countries; ABM presented in this report will also act as basis along with BMC to promote the use of pellets as a cooking fuel for upcoming businesses in developing countries.

The survey (Appendix C) used to contact present pellet manufacturers for data gathering on selected variables in developing countries was designed under the guidance of field survey experts from University of California, Berkeley. However, the quantity of survey replies is limited as many companies representatives do not replied. Majority of interviews are conducted by meeting in person or by phone. In some cases, communication started by email surveys and resulted in interview/bi-lateral feedback on designing the ABM and impact of variables for a particular ABM. It is worth to mention the data gathering from field visits. The author visited following field locations during the research period (details are provided in Appendix B):

- **Kitwe, Zambia (December, 2011)**

This location was selected to examine the ACS and pellets pilot program by Vagga till Vagga, Sweden.

- **Coastal Orissa, India (February, 2012)**

Availability of wide variety of biomass residues, focus on rural customers and poverty in the region was the reasons for this field visit.

- **River Islands, Sundarbans, West Bengal, India (April, 2012)**

Isolated islands, high population densities in urban areas and deforestation problems due to cooking fuel were the reasons for selection of this area.

2.3 Report Structure

The structure of report as mentioned below (figure 2.2) shows that how different chapters are related to research question.

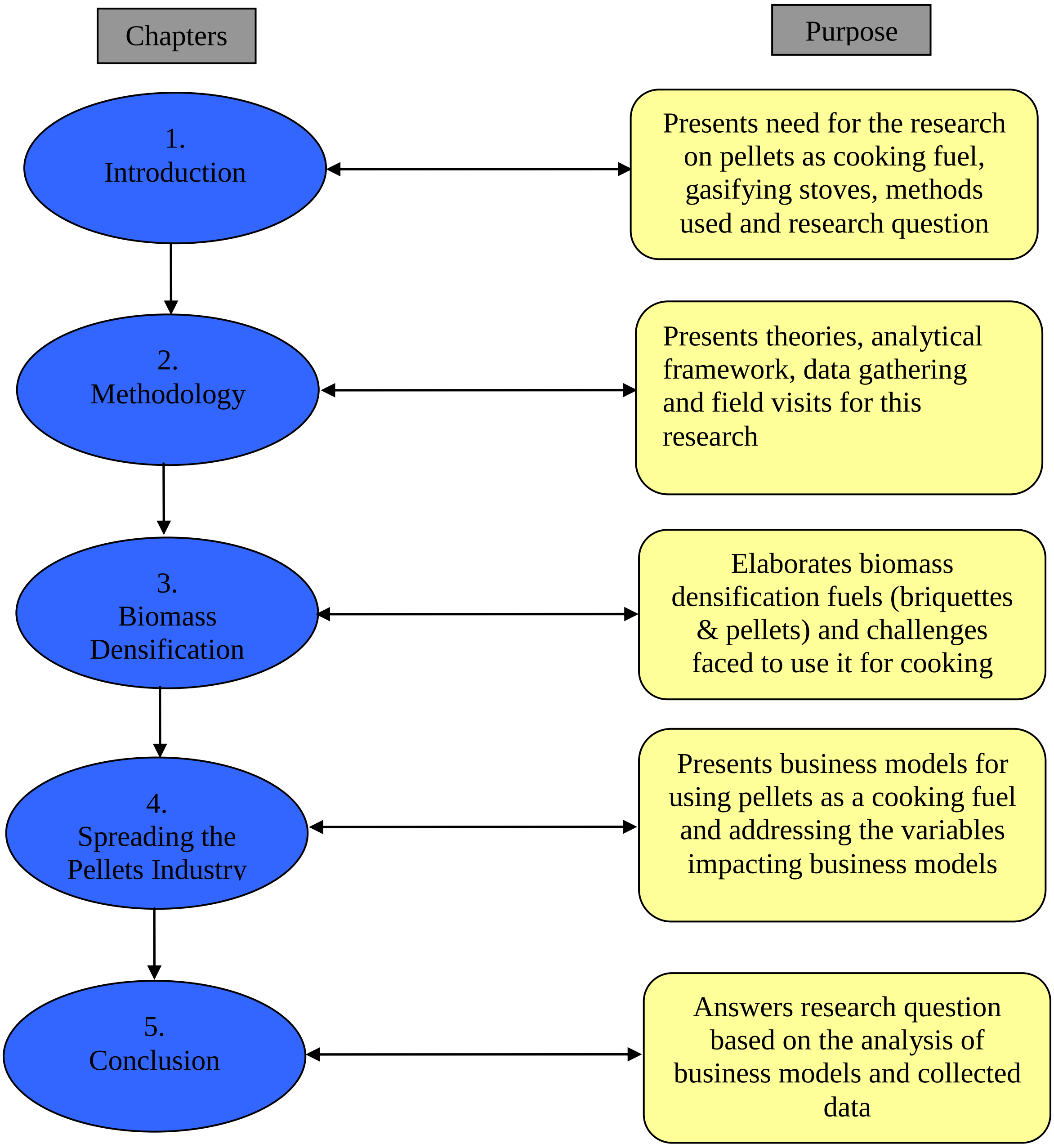

Figure 2.2: Report Structure

3. Biomass Densification

Wood has been commonly used for heating and cooking purposes for thousands of years. The energy ladder (figure 3.1) shows step-by-step incremental change in fuel followed by low and middle income households in developing countries. Increasing prosperity tends to shift fuel usage for more convenient, efficient and cleaner operation. Considering the vast use of firewood and biomass residues, there is a need to use biomass resources in a more efficient manner.

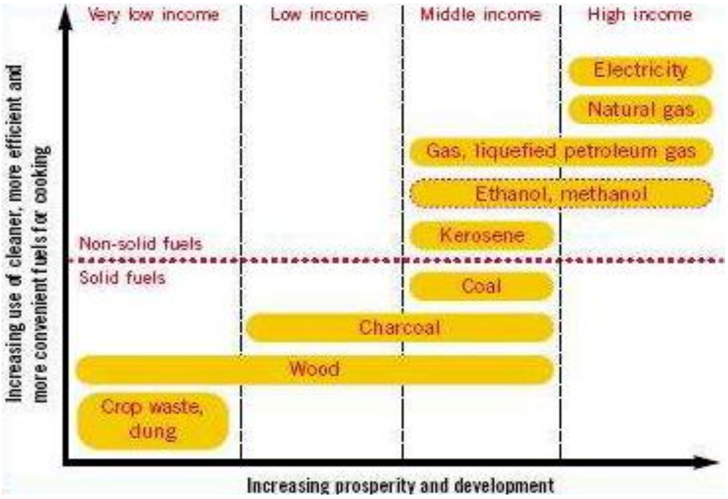

Figure 3.1: Household Energy Ladder (WHO, 2009)

Biomass is considered a carbon neutral renewable energy source. However, the low density of woody biomass limits its use for energy generation purposes [Battacharya, n.d.]. Firewood and biomass residues have a low heat content, uneven distribution in shape, moisture, size, etc. and are often troublesome to use for cooking purposes. Biomass densification can be used by increasing raw material bulk densities as high as 10 times, provides uniform shape and moisture content which helps to reduce the associated technical problems such as storage, transportation and handling [Tumuluru et. al., 2010]. Densification has an interest in many countries worldwide due to availability of technique and benefits obtained as an energy resource. Densifyed biomass is classified in *briquettes* and *pellets* as explained in next sections.

3.1 Present Biomass Use

Biomass is the basis of cooking and heating in rural households of developing countries and it is also used as fuel for various industrial processes. A study has shown 70-98% of total biomass is consumed in domestic activities for developing countries (table 3.1) [Bhattacharya and Salam, 2002].

Biomass fuel saving by efficiency improvements in these countries can reach 326 Mt/year by considering all biomass types (table 3.2).

Table 3.1: Biomass Consumption

Country	Base year	Domestic sector		Industrial/Commercial sector	
		Amount, Million tons (Mt)	Percentage	Amount (Mt)	Percentage
China	1993	458	94	29.4	6
India	1991	231.5	78	65.9	22
Nepal	1993	15.1	98	0.3	2
Pakistan	1991	48.5	78	14	22
Philippines	1995	18.6	70	8.1	30
Sri Lanka	1993	10	87	1.5	13
Vietnam	1991	29.1	91	2.9	9

Source: Bhattacharya and Salam (2002)

Table 3.2: Estimated Biomass Saving Potential

Country	Base Year	Biomass Type		
		Firewood (Mt)	Agricultural-Residues (Mt)	Animal Dung/Charcoal (Mt)
China	1993	51.6	77.2	2.9
India	1991	69.5	20.8	32.8
Nepal	1993	3.1	1.2	0.8
Pakistan	1991	17.5	7.3	8.3
Philippines	1995	7.6	2.3	0.3
Sri Lanka	1993	2.6	0.5	-
Vietnam	1991	15.8	3.9	0.1
Total		**167.7**	**113.2**	**45.2**

Source: Bhattacharya et al. (1999)

Cost Analysis

Economic feasibility of biomass energy technologies mainly depend on the cost of biomass fuels and it further depends on location as well as type of biomass collected. Sustainable plantation grown biomass cost varies according to the place and cost difference is observed within developing countries [Bhattacharya et al., 1999]. Therefore, it will give different cost for biomass fuels throughout the world.

Final energy obtained from biomass depends on associated fuel costs like plantation, harvesting, transportation, etc. along with maintenance and capital costs. According to cooking fuel comparison research in India by Gupta and Ravindranath (1997), firewood with ICS (Astra-stove) was most cost-effective solution as firewood was collected without any cost in rural areas, and biogas was most expensive option. If there is a supply of kerosene, the subsidized rates of kerosene by Indian government were found to be cheaper in typical kerosene stove. In urban situation, kerosene subsidy was cost-effective fuel option. However, if biomass is purchased and used in TCS with efficiency of 10%, actual energy delivered to cooking pot will be substantially low and overall cost will increase compared to LPG/kerosene.

Energy cost for traditional thermal applications like cooking varies widely. In most of rural areas, households collect their own biomass fuel to be used in stoves or some of them use it in ICS. Energy obtained in these cases is practically free if time spent to collect fuel is not considered.

3.2 Briquettes

Briquetting is a method to convert loose biomass residues like sawdust, straw or rice husk into high density blocks which can be used as fuel. It is made of relatively large size typically 5-10cm diameter and length of 30-40cm (figure 3.2).

Figure 3.2: Briquettes

Briquettes are mostly produced in developing counties as a form of densifyed biomass which are used to substitute firewood or fossil fuels for industrial and cooking processes. It is a clean fuel with easy handling and reduces GHG emissions. The briquetting plant with high pressure can produce more than 200 tons/day. Saw-dust and other woody residues are considered as best materials for briquetting as it has high proportion of lignin[8]. However, other dry residues like grass can also be used if it is grained into coarse powder. Bagasse, peanut shells, rice husks, pine needles and corn cobs are examples of the raw material for briquetting. Briquette densification technology is explained in Appendix E.

The densifyed biomass is not considered cheap compared to firewood in developing countries. For instance in Nepal, the briquettes price/kg is around 3 times of firewood [Shakya, 2001]. Even with higher price of briquettes, it has found acceptance in special situations due to following reasons:

1) **Reliability:** Briquettes manufacturer and supplier agreement/understanding with the user can establish a niche market for this industry. For example, these types of connection are practiced in tourist destinations of Nepal and tea stalls in Bangladesh.

2) **Consistency:** Alternatives of briquettes are firewood which is uneven in shape and size. Moisture content of wood also varies widely according to the type of wood and season in which it is used. Users need to make an estimate to use firewood in batch task which is difficult and combustion quality is also unpredictable.

3) **Environment-friendly:** Briquettes have eco-friendly image as it can also be manufactured from wood industry or agricultural waste compared to deforestation caused by firewood.

4) **Calorific Value**: Briquettes are of superior quality and has higher calorific value than

[8] Organic substance which act as a binder for the cellulose fibres in wood and certain plants.

comparable size of firewood and charcoal resulting in longer flame time. Firewood usage may need preparation like drying and sizing before the usage compared to direct use of briquettes.

5) **Lower Price:** If raw material is available at comparatively marginal cost or free and low-cost briquetting technique is used, the briquettes can be manufactured in cheaper price compared to charcoal and coal.

Food-vendors preferred briquetted charcoal obtained from sawdust briquettes carbonization in Thailand compared to charcoal made from wood due to its superior properties like lasting fire and consistent quality [Bhattacharya and Shrestha, 1990]. Briquettes are used in Uganda and India in furnaces/stoves that were using firewood [Fulford and Wheldon, 2012; Nishant Bioenergy, 2012].

3.3 Pellets

Pellets are renewable fuel in compressed and cylindrical shape used for clean burning purpose in various applications such as households heating, large-scale power generation. It is made by densifying the biomass resources such as recycled wood waste, sawdust, etc. In developed countries, pellet production is most commonly used densification technology; practiced for automatic feed in heating stoves and power generation applications (figure 3.3) which has much larger capacity than briquettes machines. It has reduced emission particles compared to coal and is commonly manufactured in Europe and America [Pellets Fuels Institute, 2012]. Use of pellets is insignificant in developing countries.

Figure 3.3: Pellets Stove and Small Scale Boiler

If raw material is mixed with contaminated material such as soil, it will increase the ash content and may lower the melting temperature of ash resulting in combustion equipment problems. Therefore, pellets should be manufactured clean after removing all the additives [Forest, 2012]. Pellets represent an economic alternative to traditional wood logs, coal, electricity and even gas (figure 3.4). Savings also become high for demand of high heat loads. A large farmhouse with requirement of 75,000 kWh/year using oil heating might pay back the cost of installation and converting it to pellet boiler in four to eight years based on the present prices [IDA, 2010]. It provides new methods to divert efficient use of wood industry waste, which may end in land fill without pellet production.

Figure 3.4: Fuel Comparison for Space Heating

Pellets Properties

Physical properties make difference between fresh wood and pellets; however chemical properties, energy content and the composition are same. Density and quality of pellets (table 3.3) are mainly defined by the sieve used for hammering before palletizing, moisture content of biomass and by the rollers pressure.

Table 3.3: Pellets Characteristics

Length	10-50 mm
Diameter	6-10 mm
Density	1150-1400 kg/ m^3
Moisture content	8-10%
Calorific value	4700-5000 kCal/kg
Ashes content	0.3-0.6%
Fine particle	5%

Source: Forest, 2012

Main advantage of pellets are uniformity and high bulk density which gives economical transport along with high calorific value, low moisture-content facilitating high energy-content combustion performance [Forest, 2012]. However, there is a need of electricity to manufacturer pellets which limits its off-grid production in developing countries.

Global Pellets Market

Pellets production started in Europe and North America as a response to oil crisis in 1973. It was considered as potential alternative to oil [Pellet Club, 2004]. Now-a-days, the global pellets market is experiencing an increase by last four years as it is first wood based fuel to transport overseas profitably [Egger et al., 2003]. In 2007, the global production was 8 million tons/year and increased to 13 million tons in 2009. North America is highest producer of pellets with almost 5 million tons were exported to Europe out of 7 million tons in 2009. The countries consuming most of the pellets are Sweden, Austria and Finland whereas Germany, France and Italy have highest market growth rate in production and consumption of pellets. It is estimated that Europe pellets consumption will reach 50 million tons/year by 2020 compared to 8 million tons in 2009. Apart from Canada and Germany as main supplier of pellets, USA increased its production capacity more than 200% from 2002 to 2006. USA also has advantages of better prices, steady availability due to sustainable plantation, enhanced production capacity and faster shipping compared to traditional Canadian supplier providing long-term supply agreement [Pirraglia et al., n.d.].

The pellets market for Africa, Asia and South America combined production is only 0.3 million tons/year in 2009 [Pirraglia et al., n.d.]. The countries in these continents are unable to have relatively large share in the pellets market due to challenges such as initial investment cost, land required for sustainable wood cutting and storage of pellets, supply chain of biomass, etc for large scale pellets production.

Pellets price mainly depends on transportation costs in USA and it is shipped in bags on pallets by retailers which add around $20/ton. Pellets can vary in price from as low as $176/ton to as high as $600/ton in Northern USA. However, USA companies intend to export the pellets, the freight price of $35-$45/ton is to be considered and it can change anytime. Pellets commodity market can be developed by agreements with oil, lumber and other products. Transportation in Europe is done in bulk cargo, so the prices are more stable at $304/ton [Pirraglia et al., n.d.].

Various multinational companies such as Weyerhaeuser and Mitsubishi invest in pellets facilities, research and development to explore the feasibility of pellets production in USA [Pirraglia et al., n.d.]. The processing of pelletization is a well-established industry. Main consideration for pellets making is for spices of wood and moisture content used. These two parameters will provide the findings of right recipe for production conditions. Labor and infrastructure requirement is relatively low for pellet plants. There could be some issues by increasing the size of the facilities like self-heating of pellets during storing and cooling of mass volume. Use of local wood species in pellets recipe with different properties may affect the output and production parameters. Crumbling of pellets resulting in fine particle must be managed by quality consideration while transportation.

In some developing countries like Brazil, large-capacity production can be considered in future where sustainable wood or industrial wood residues collection is possible [Pirraglia et al., n.d.]. In India, Abellon CleanEnergy started pellets production by using agricultural residues and sawdust. It is used to replace coal from the factory boilers and in cook-stoves. It is expected that small/medium scale pellets manufactures will increase for exporting the pellets mainly to European Union (EU) as well as to provide energy generation for local usage. Considering deforestation due to firewood collection for cooking and other industrial burning processes and present use of non-renewable energy such as coal and kerosene, it can be argued that the use of pellets as fuel will increase in developing countries.

Pellets industry appears to be sustainable for decades to come in both developed and developing countries. However, more innovation is required to increase awareness of pellets production and usage in developing countries whereas volatile price of pellets is to be addressed in countries like USA.

3.4 Biomass Densification Challenges

Biomass energy technologies face barriers in technical specifications for commercializing them. The low price of oil on the international market has affected financial sustainability of renewable energies in the last four decades. The situation intensified further by subsidies given to fossil fuels in many countries. In India, $1.5 billion annually is spent by government for subsidizing kerosene in 1990s [Forsyth, 1998]. For instance, it gives diesel generators biased advantage compared to gasifier engine. The biomass energy had following major barriers:

- Lack of understanding to use biomass as an energy source
- Risk for sustainable fuel supply and energy conversion technologies
- Cost of energy production is higher than fossil fuels
- Only farming/forestry communities were trying to create a market
- No support from the government policies for biomass as a renewable energy

In developing countries, improvements in efficiency and environmental impact for domestic applications will enhance future biomass energy usage. Environmental concerns such as climate change will result in developments of cheap biomass utilization from agriculture and wood residues which could be a potential fuel source for cooking. Increase in fossil fuels prices can also accelerate the use of biomass resources in an efficient manner. Plantation of biomass in degraded land can provide additional supply of firewood where agricultural residues are not available.

Raw material for biomass densification like agricultural residues and wood industry waste are generated in large quantities each year but most of it remains unused or burned and in some cases it is disposed at a cost. Therefore, briquettes and pellets appear to be the waste utilization product. In Bangladesh, it is estimated that biomass residues can potentially support 18,000 briquetting machines compared to 1000 machines actually operating. Lack of technology awareness, operation, maintenance, trained technicians, stable supply and price of raw materials were highlighted as barriers to biomass briquetting in Bangladesh [Moral, 2001]. Lack of proper financing mechanism for business development is also included as barrier in case of Myanmar. Briquetting industry in India shows that frequent failures of power supply may also act as barrier to non-stop and profitable operation in some developing countries. All these barriers appear in other cases of developing countries [Clancy, 2002]. Briquetting as well as pellet technology is comparatively new in many countries resulting investment risks for establishing it. Densification industry is facing various barriers in developing countries, which must be removed for wider acceptance and promotion of its technology.

4. SPREADING THE PELLETS INDUSTRY

4.1 Base Model Companies

In the following, BMC's business operations are explained to investigate the impacts on variables for pellets production in developing countries.

First Energy, India

Background: First Energy (FE) started in 2006 as partnership between British Petroleum (BP) and Indian Institute of Science, Bangalore to design a stove based on strong understanding of consumer energy needs [Smith, 2007]. The company conducted pilot program in Tamil-Nadu and Maharashtra. In 2009, FE branched out from BP to become a separate entity [IFMR, 2011]. FE value preposition offered are Oorja stoves and pellets. The stove is marketed as low-cost and low-smoke ACS which uses pellets as a fuel. FE pellets are made from processed agricultural residues such as bagasse. Oorja stove uses a fan (powered by rechargeable batteries) to force air into the fuel chamber for better fuel combustion.

Business Model: FE has dependence on local NGOs and large NGOs for distribution and marketing of the stove as their channel strategy. FE also had tie-ups with dealer networks in the rural areas such as Sakthi Retail, Villgro stores, Adharam energy [IFMR, 2011]. FE partnerships with larger NGOs have retail stores in rural areas and with decentralized/smaller NGOs were helpful in dissemination of products in different locations.

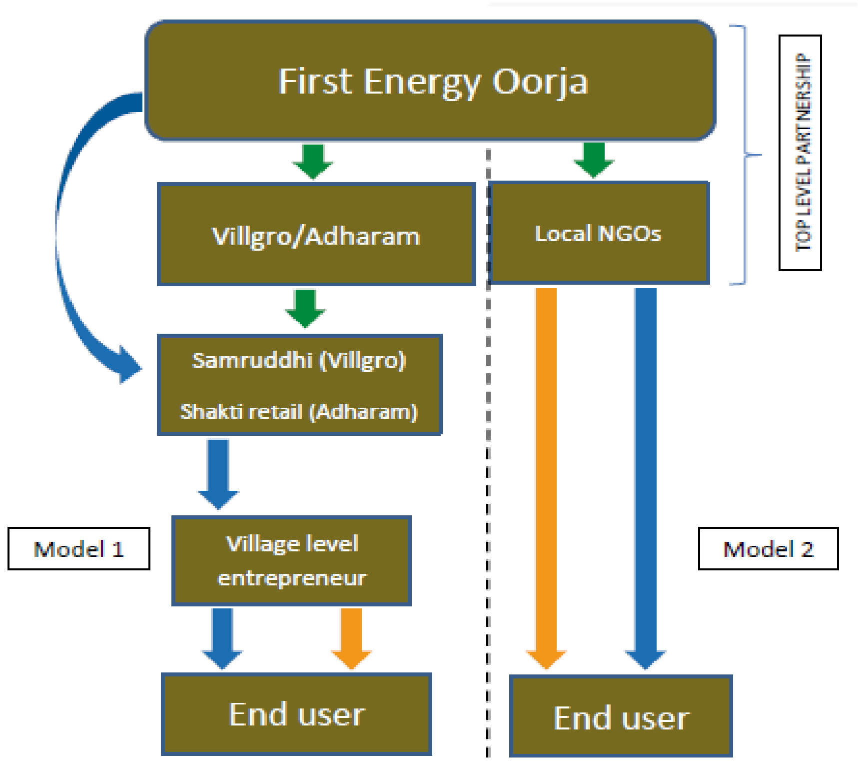

Figure 4.1: FE Business Model (IFMR, 2011)

The retail outlet helps to build brand for the company in rural locations. Some of the partner organization to FE employs Village Level Entrepreneurs (VLE) for providing affordable and innovative solutions to the villages. FE involves local community to understand the requirements of target segment by consistent interaction with local people.

Model1 shows combination of NGO and retail stores distribution channel which increases product visibility and reach across rural areas. The importance of partnership with established NGOs to give the product push in the market is practiced in this model. Villgro stores are used as warehouse for oorja stoves and pellets. The store has VLE as their partners who sell and transport product in villages. This model ensures the availability of product to the rural locations and existing NGO brand is used. On the other hand, Model2 has local NGO partnership which reaches customers directly in rural areas. In this case, well known FE parent company BP brand name is used to sell products. The company bears the training and packaging cost to local NGOs [IFMR, 2011].

Inyenyeri, Rwanda

Background: Inyenyeri started in 2011 by an American entrepreneur. Inyenyeri's value preposition is to provide pellets as a cooking fuel made from agricultural and forestry residues. These pellets are used in ACS (manufactured by various companies), which are also distributed by Inyenyeri. The company envisions expanding the operations beyond Rwanda and becoming the largest household cooking fuel provider in Sub-saharan Africa.

Business Model: In Rwanda, 97.7% of rural households use firewood, forestry and agricultural residues for cooking [NISR, 2006] and Inyenyeri is expecting to collect these residues for pellet production. This approach is considered as crowdsourcing by Inyenyeri. The households providing collected biomass will get free pellets along with first free ACS. This biomass-pellets exchange between customers and Inyenyeri will be maintained by signed agreement. Households without biomass need to buy the pellets and ACS according to the agreement signed and the sales of pellets to these customers will generate revenue stream for the company. This kind of approach (figure 4.2) expects to cover all the households which will use pellets as cooking fuel in rural and urban areas.

Crowdsourcing to collect biomass intends to drive down the pellets cost compared to FE, enabling to challenge charcoal prices in cities by 25% and saving $80 for households in first year and more in subsequently years [Inyenyeri, 2011]. However, Inyenyeri also aims to reduce pellets cost further by mass production as experienced in case of FE.

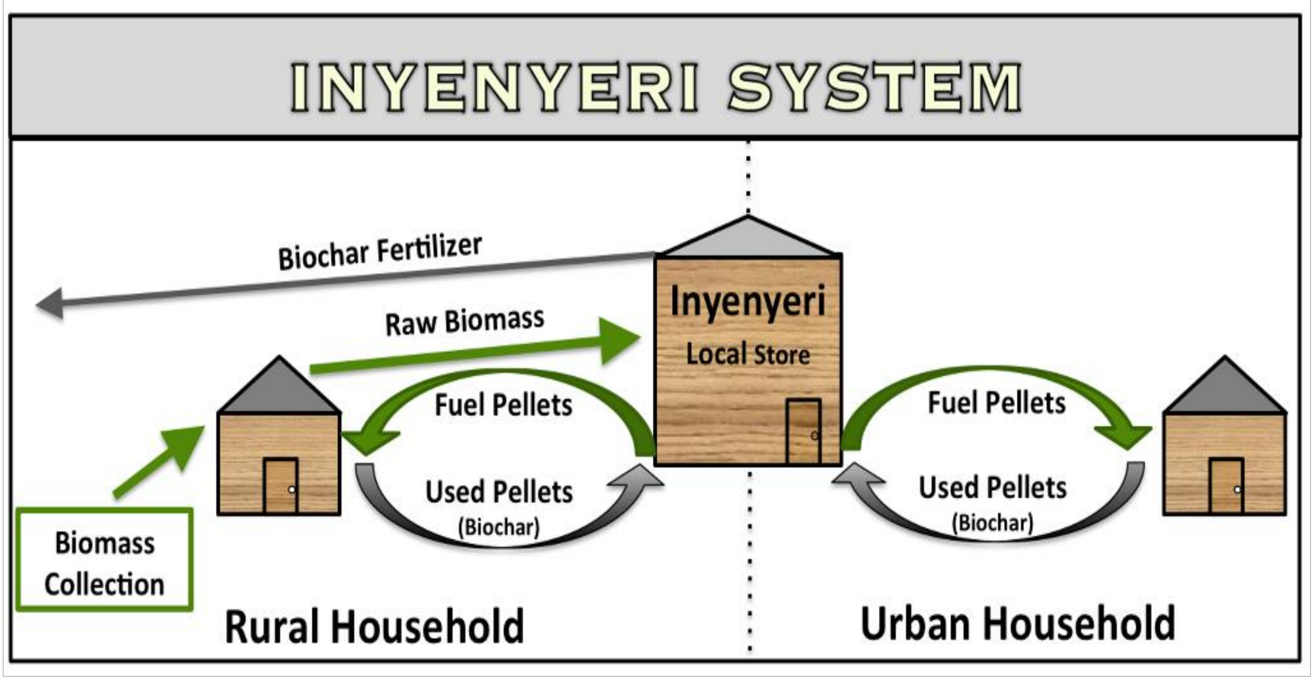

Figure 4.2: Inyenyeri Business Model (Inyenyeri, 2011)

According to company, all the customers need to sign the agreement which will also be signed by local government officials as company's key resource. Any kind of problems occurred between customers and company due to conditions of the agreement can be sorted by local officials. Inyenyeri also claims to be flexible for designing new agreements for a particular customer segment. The company claims to capture all the customer segments irrespective of their financial situation after learning from their initial years operations. The company aims to collect the biomass residues by setting up extensive physical infrastructure for biomass collection as their channel strategy. Biomass residues will be hammered in each collection center, so that efficient transportation can be practiced. The hammered biomass will be transported to centralized pellet production plants (12-15 for Rwanda) with a capacity of 25 tons/hour. It is worth to note that there will be a need of electricity at every biomass collection center to run hammer mill [Inyenyeri, 2011].

Inyenyeri states that pellets will be made from same biomass resources which are collected by households presently, so that it does not offer challenges for residues collection. Furthermore to stop deforestation, Inyenyeri do not accept wood sticks wider than 2cm according to company officials. The company also claims to monitor the change in time spent for fuel collection and cooking meals, so that further improvements can be done. Presently, the company has proven its crowdsourcing model for biomass collection in two villages and generated revenue from non-biomass providers.

4.2 Appropriate Business Models

Based on the above mentioned business models, appropriate business models are considered as follows based on the impact of variables mentioned in methodology.

Circular Mapping Model

This business model is designed to map whole area with the aim to reduce distance between biomass resources and pellets production. Households and farmers will crowdsource to provide biomass resources resulting in lower price of pellet production. By this way, transportation cost will be comparatively limited for rural customers and it increases gradually for the customers located far from the production site. The organization will set-up an appropriate Micro-Pelletizer Unit (MPU) in each village with certain number of households which can provide biomass residues (agricultural and forestry). The capacity of MPU in particular region will depend on amount of biomass residues sustainably available. MPU will produce pellets for local village households as well as for nearby villages or part of urban region (figure 4.3). If a city is surrounded by various villages with available biomass resources, surplus pellets production from each MPU can be sold to nearby city region generating revenue stream for the company. However, if crowdsourcing for biomass collection does not work, the company may need to buy the biomass residues and pellets price can also increase.

Households and farmers need to dry the biomass residues, if required so that drying infrastructure and cost can be removed/reduced. It is expected that dried biomass will be collected from households as it is relatively easier to dry small quality compared to large quality biomass for company. Households collecting the biomass residues will be paid in the form of pellets (1/4 of crowdsourced biomass). The farmers providing agricultural residues will have an option to be paid in pellets or in cash according to the agreement. Availability of extra pellets due to periodic supply of agricultural waste can ensure storage of pellets for rainy seasons or bulk supply to industrial boilers/furnaces. A hammer mill will be used to pre-process the raw-material for MPU at each production site. There will be several MPU in order to cover relatively large region. All these MPU can be maintained and managed by company resulting in decentralized production with centralized administration.

Customers Segments: Rural poor and urban households buying charcoal/firewood.

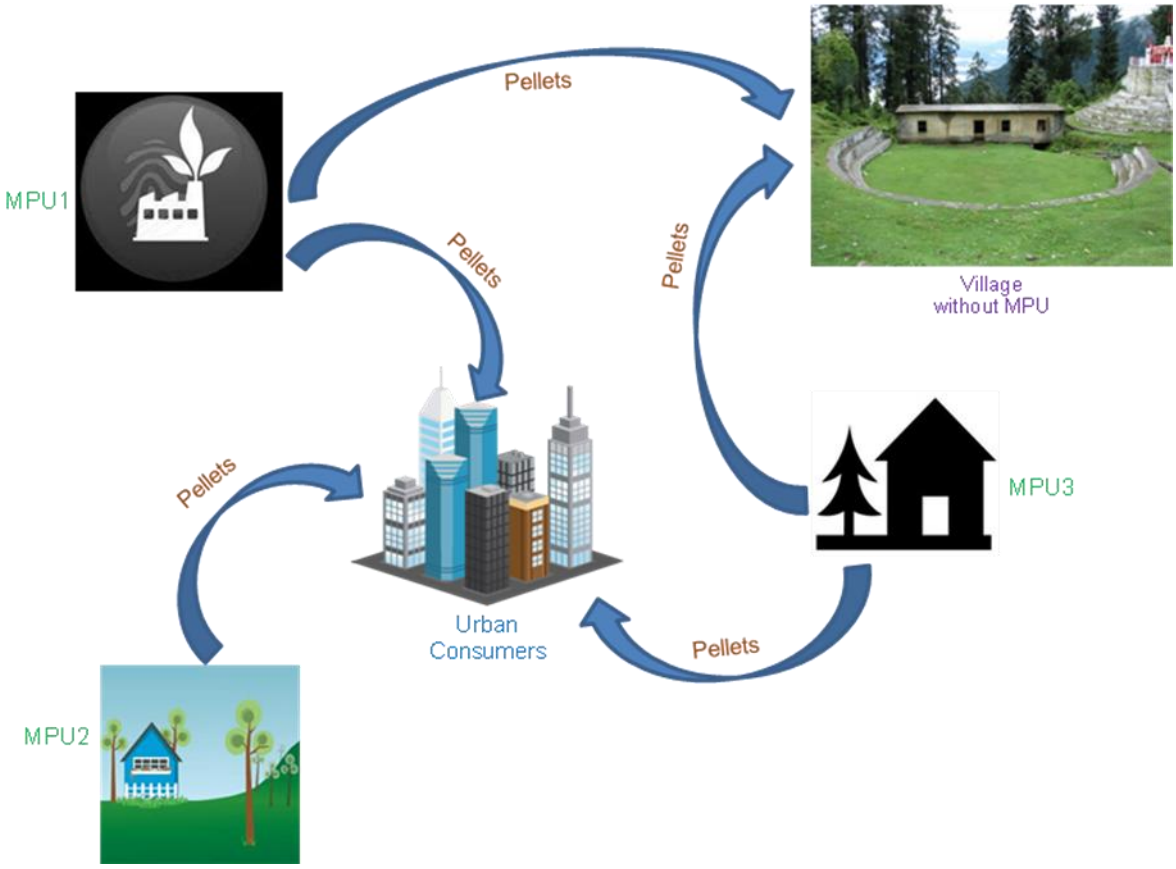

Figure 4.3: Circular Mapping Model

A pellet industry consultant from Canada, Martin Bokesch commented on MPU compared to large-scale production.

"Small-scale Pelletizers require smaller electrical connections. Tonnage per kilowatt is not the issue; the issue is electrical infrastructure for higher demand loads and larger than 220V supply. As well, transport costs are generally very high, and transport of biomass feed stocks is rather bulking when not preprocessed. Field processing requires more machinery, localized processing requires far less transportation, in some case, delivery by manual cartage, rather than Trucks. Small units are more affordable to a Co-Operative group and the maintenance and repair are also more manageable……As always, each area, and individual area would have to be carefully reviewed. If large and reasonably priced infrastructure is in place, large makes sense, but my personal experience leads to believe that smaller, more labor-intensive units would be prudent choice"

Dan Phipps, co-founder of Alithia Energy Inc., USA commented:

"The source will have an impact on processing methods tend to drive whether centralized or decentralized is the way to go. e.g. using grass vs. short-rotation trees vs. old-growth trees. In biomass selection, long-term impact on soil fertility must be taken into consideration (e.g. using "waste" biomass which otherwise would compost and build soil fertility will, over time, reduce the availability of biomass in any tropical or sub-tropical zone)"

Advantages:

- Efficient transportation due to densification compared to BMC
- Revenue generation by continuous supply of extra pellets to near-by area
- Covering urban market along with rural
- In case of machine failure, the fuel can be supplied from nearby MPU
- Local employment generation

- Low-capacity electricity demand compared to large-scale plants
- Customer support and ACS distribution using extensive network of MPU, which also resolves biomass supply chain issues

Disadvantages:

- Electricity requirement (at-least 25horse-power), if no grid electricity is available. It provides opportunity to generate electricity from solar panels or gasifiers
- Maintenance cost increases due to the presence of several MPU for whole region

Island Model

This model is based on centralized pellets production near to the untapped biomass residues source irrespective of rural or urban location. For instance, consider a saw-mill which is facing difficulty to dispose sawdust, which is potential source to make pellets (figure 4.4). Pellet plant capacity will depend on the amount of residues available and the rate at which residues are added sustainably. Revenue can be generated by selling pellets and ACS to nearby rural/urban areas. Isolated production and product usage is practiced in this type of business model.

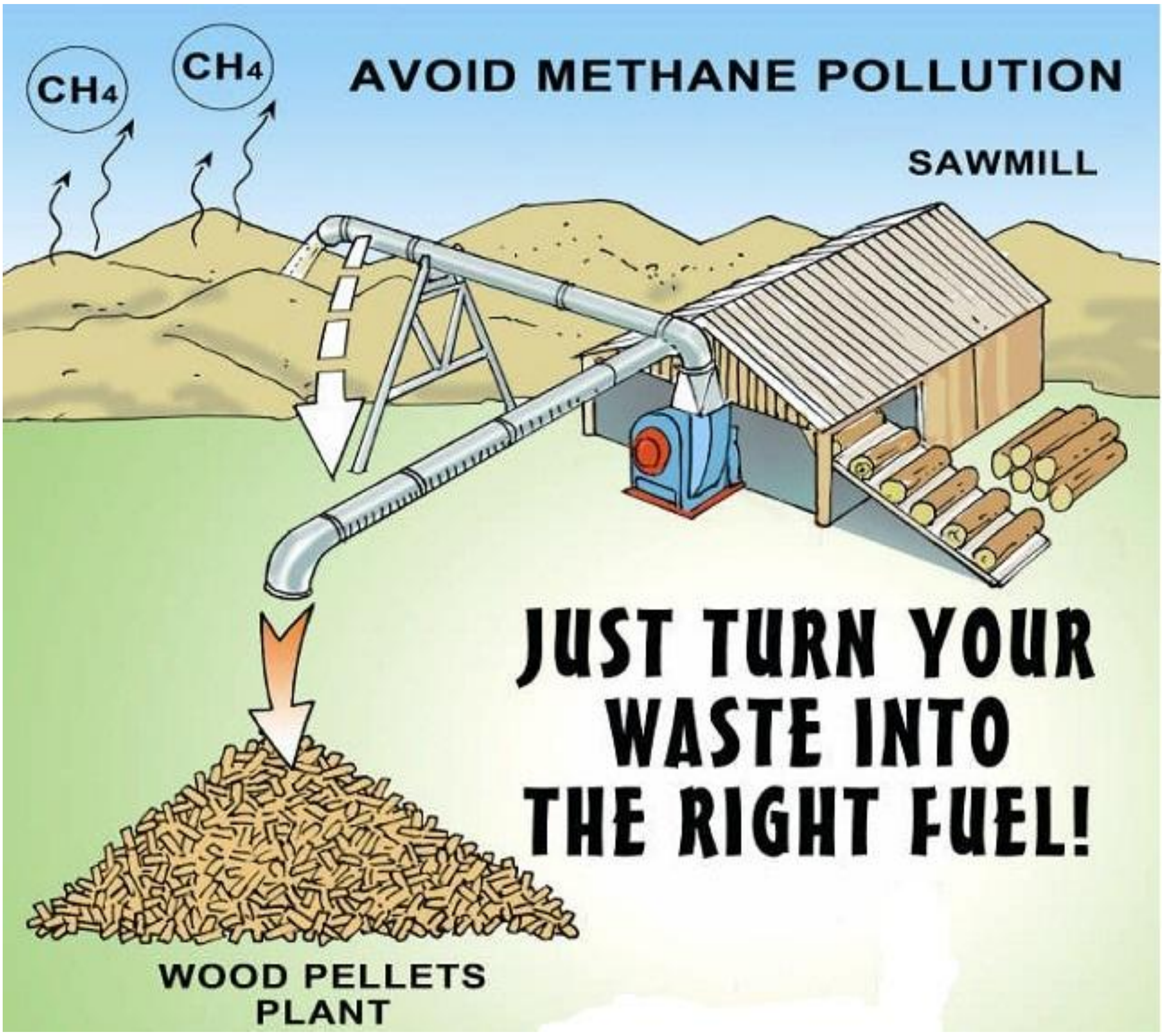

Figure 4.4: Island Model

There will be a need to pre-process the residues using hammer mill. Pellet production plant can also be set-up at the same location of saw-mill (for instance) in collaboration with them. Crowdsourcing to collect the biomass will not be required in this model. For distribution of pellets, the company will rely on third party organization such as NGO, retail stores or VLE partnerships for reaching the customers in case own distribution chain is not built. An interview comment was:

"If the Plant were placed close to an existing mill of some type, using Zambia as a model, near a Plantation forest, residues would be far easier to come by…..as well as transport and mechanical skills and knowledge would be more readily available. This model cannot work everywhere, However, where it can work, cost saving are high"

--Martin Bokesch

Customers segments: Commercial cooking, concentrated urban population, near-by rural areas

Advantages:

- Mass production reduces pellets cost
- Transportation required only for distribution of densified pellets
- Concentrated population near the plant can be served
- Local employment generation

Disadvantages:

- Dependency on several partners for pellets and ACS distribution
- Machine failure need to be addressed urgently due to centralized production
- Customer segments can be limited to near-by production site
- External drying may be required in case of wet saw-dust

4.3 Addressing the Variables

Impact of the most important variables on ABM is investigated in this section.

Biomass Resources

An enterprise manufacturing pellets by buying the biomass residues depends on the price of raw material. In case of dependency on particular biomass residues for pellets recipe, it is most likely that the market price will be volatile. The company should try to diversify its dependency on various biomass residues like ground nut husk to stabilize the pellet price [Shrimali et al., 2011].

In both the ABM, constant price of pellets can be achieved by partnerships with raw material providers as a key resource for the company. To low cost and avoid competition with other biomass uses, residues should be preferred to manufacture pellets as a value preposition for the company. However, the user can also try to burn firewood collected from near-by area along with pellets which should be taken care by stove design as another value proposition.

Biomass Drying

"Given the variety of feedstock, and the moistures of the same, the ability of arid areas to utilize solar drying and rainfall areas to have to dry, it may be prudent to go with small decentralized units"

--Martin Bokesch

Use of external dryer will require additional electricity cost and also infrastructure cost. To design an appropriate model, there is a need to dry the biomass by labor-intensive way at the source end rather than at manufacturing site, it will also result in efficient transportation as well as pellets can be manufactured without using a dryer. Circular mapping model expects households to dry the biomass before providing to factory. This approach reduces the storage and key resources required. Drying price impacts revenue stream for the organization as it is easier to dry relatively small quantities of biomass rather than collected large quantities. However, it cannot be assured that households will perform as expected and pilot studies are required to observe the response of the targeted segment.

Electricity

Reliable electricity is one of the key resources for any pellets manufacturing plant. Availability of grid electricity in developing countries for small-scale plants can be a challenge to manufacture pellets. However, solar panels and gasifier-based electricity can be an option to handle MPU load. As mentioned in previous comments by experts, heavy electricity load for large scale plants can be an issue in developing countries. Island model has a requirement for reliable electricity source due to centralized production for delivering value preposition to its targeted customer segments.

Packaging

Packaging becomes an important issue and key resource as mentioned in this comment.

"Of particular concern is the moisture absorption after production. Unless the pellets are hermetically sealed in reusable containers, you will be creating or exacerbating plastic waste issue"

--Dan Phipps

There is a need to use reusable containers to avoid plastic waste and moisture absorption. Reusable containers can be practiced in both the ABM and it helps in reducing the running cost of the company. If plastic bags are used with the aim of one-time use, it will impact on revenue streams and further price of pellets to the consumer. This method will also increase the plastic waste which needs to be managed resulting in environmental degradation.

Channel Strategy

Developing wider infrastructure for company providing fuel pellets can have multiple customer segments such as industrial furnaces, commercial and household stoves. Increasing awareness of the product is one way to obtain initial customers but sustainable business can only be created if well developed distribution and sales channel strategy exists. This will allow the company to provide value prepositions directly and become financially sustainable. The companies achieving volume sale have focused on scalable supply channel and involved actively to manage it. However, building a strong supply chain to reach consumers is considered as the biggest challenge for a fuel manufacturing company. For instance, a fuel company selling ACS to a particular customer segment at a discount rate of $10 so that profit can be earned on pellets sales at $0.13/kg. But due to challenges of supply chain management of fuel, the company has doubled the price of stove and raised fuel prices by 60% [Shrimali et al., 2011]. This example shows the importance of channel strategy as a valuable key resource for a company.

Many organizations do not focus on development of product supply chain and more research is required to identify its impact on operational scale of value prepositions offered for ACS and pellets. As it is explained in earlier chapters, after-sales support for stoves is one of the important reasons for determining the success of the program. There could be a case where organizations have back-end plan for customer support to deal with complaints of ICS and ACS but it cannot be practiced in current situation due to lack of funding and the focus is to have more sales. The advantage of a company supplying fuel as its value preposition by a strong supply chain could be that this channel strategy can also be used for providing customer support as there is continuous contact through fuel sales to generate revenue streams. The approach of crowdsourcing for biomass collection as a key resource can be used to build strong network which will provide after sales services along with value prepositions offered. However, pilot studies and research is required to examine if a strong channel strategy network is useful for households.

Transportation

Transportation of raw biomass increases overall cost significantly as low density residues need to be transported in case of centralized pellet production. However, island model centralized production is trying to reduce the transportation cost by setting up the site near to biomass source. It is worth to note that both the ABM was designed to reduce transportation of raw biomass significantly so that cost can be lowered and efficient transportation can be practiced by transporting pellets. Interview comment mentioned above also support the argument of transporting pellets instead of raw biomass. If a company needs to transport raw biomass for relatively long distances, it will impact the revenue streams.

Target Customers

Selection of customers can be done based on particular segment such as region (rural or urban), biomass availability or according to their education level to initiate the stove program and reducing the risk of failure due to other variables. A research done by Shrimali (2011) on 12 stove programs in India shows that none of the organization completely focuses on individuals earning less than $2/day. Normally, the stoves are more likely purchased by urban households and higher-income households rather than biomass collecting the biomass which is target for ICS manufactures [Barnes et al., 2005]. However, circular mapping model has customer segments of rural poor as well as urban households together compared to past stove programs customer segments.

The choice of customers segment is internally related to stove technology and design selected. In case of expensive or unavailability of competitive fuels such as LPG or electricity compared to market price of pellets, customers using these convenient systems are also likely to use pellets as a cooking fuel. It can be strongly argued that it is safer to earn profits on targeting commercial stoves as a customer segment. These types of consumers have relatively high income which can be approached easily with skillful marketing.

Stove Design

Overall price value of stove presented to consumer is influenced by stove design and technology. Stove manufactures tries to increase heat transfer to pot by modifying it as well as the focus is also on modern looking attractive design product. However, irrespective of the efforts made by designer, ACS can also show problems in the field. For instance, customers can complain about the battery performance in battery-operated stoves as well as corrosion in the inner chamber of stove [Shrimali et al., 2011].

The strategy to manufacture stoves also depends on design of the stoves. Most ACS manufacturers such as Phillips prefer to have mass-production instead of artisan made-stove. Mass-production approach allows controlling the quality and costing which is required for a stove using pellets. However some organizations prefer to make the stove by artisans specially women near to location of stove use [Shrimali et al., 2011]. The use of fuel pellets can also give better understanding of stoves use as it can be tracked by pellets distribution channel strategy network.

Apart from these variables focusing on running cost of pellets production, there are one-time investment costs which need to be considered for each model:

- Equipment purchasing cost
- Distribution network infrastructure

5. CONCLUSION

Modern biomass densification technologies interest is growing worldwide in recent years. The present market price of fossil fuels like coal is high compared to biomass fuels if environmental impact is considered due to these fuels. Considering the fair price of energy and environmental impact, biomass based energy should become more widely available in many situations and the technology usage will accelerate in future. Even-though densification (in the form of briquettes) has a great deal of interest but actual production is still very low compared to its technical capacity. The interest in pellet production is more likely to grow in future. Biomass residues are significantly available in many countries which are not required for agriculture. However, biomass densification has variety of challenges such as initial investment, lack of reliable electricity and awareness, etc. which must be removed to accelerate the production. Climate change concerns of the globe are likely to improve the policies and prospects of densification technologies in near future. As the cost of fossil fuels increases, use of briquettes and pellets is expected to grow.

Future prospects of densified biomass will increase for domestic consumption in developing countries as well as export market consumption for developed countries. Densifying market will also develop where competition of firewood or charcoal price for cooking is increasing rapidly. Many previous stove programs from Government and NGOs have failed to scale efficient cook-stove which changes the traditional cooking patterns. However, pellets use in ACS can increase the stove dissemination by providing reliable fuel supply. Various business models can help to provide a platform and increase awareness for financially sustainable and scalable operations of pellets as a cooking fuel. Several factors impact the business to generate revenue streams from pellets used in ACS as observed in this research. Raw biomass resources and pellets supply-chain management along with reliable electricity supply was observed as biggest challenge for pellets distribution and production.

Business approach to solve the problems related to cooking can increase the awareness of using pellets as a cooking fuel along with ACS. ABM considered in this report has a potential to become financial sustainable and scalable businesses by overcoming the weakness in BMC. Experts have also shown interest in decentralized production of pellets to reduce the transportation cost. However, maintenance of several small-scale pellets MPUs in circular mapping model could be an issue for running cost and availability of spare parts in rural areas, which was not considered in this report and can act as a potential variable to impact business. Lack of electricity in many areas of developing countries can also limit the pellet production irrespective of sustainable biomass availability. More research is required to design micro-pelletzing mills which can be used without electricity. Existing briquettes facility in developing countries also offers learning for biomass densification and business opportunities for targeting commercial customer segments. Field observations and result analysis have shown that there is no single business model which can be applied in all regions of developing countries with biomass availability for solving cooking energy problems. If any of the ABM is used for a particular place, changes may be required according to the local situation and considering other business variables such as customer relationships, key activities, key partnerships and cost structures.

Growing concerns with the household cooking energy development community demands for better quality stoves with increased fuel efficiency, improved air quality and user acceptance over long time. Combustion of solid biomass fuel is complex process due to variations in size, moisture, heat content compared to liquid or gas fuels. Use of pellets as a cooking fuel can remove these barriers. However, there is a need for an efficient stove to burn pellets.

Now-a-days, there are new generations of ACS entirely manufactured in workshops and factories with better insulation, technological designs, forced air flow or natural air flow, providing clean-burning while paying more attention to combustion efficiencies. Systematic research of combustion efficiency and heat transfer in the laboratory shows that which technology works best and ensures that significant improvement over TCS is achieved by designing these ACS. Besides addressing the drawbacks of TCS, modern wood firing advanced cooking facilities should also address flame control rate and quick start-up/stop of the fire.

Micro-Gasification

Biomass gasifier is a device used to turn solid biomass into gas which can be burnt subsequently in controlled manner. It is different from open fire as gas-generation is separated in space and time from gas-combustion (figure A.1). Most of the TCS and open-fires are regulated by fuel supply whereas gasifiers are controlled by air supply [GTZ, 2011].

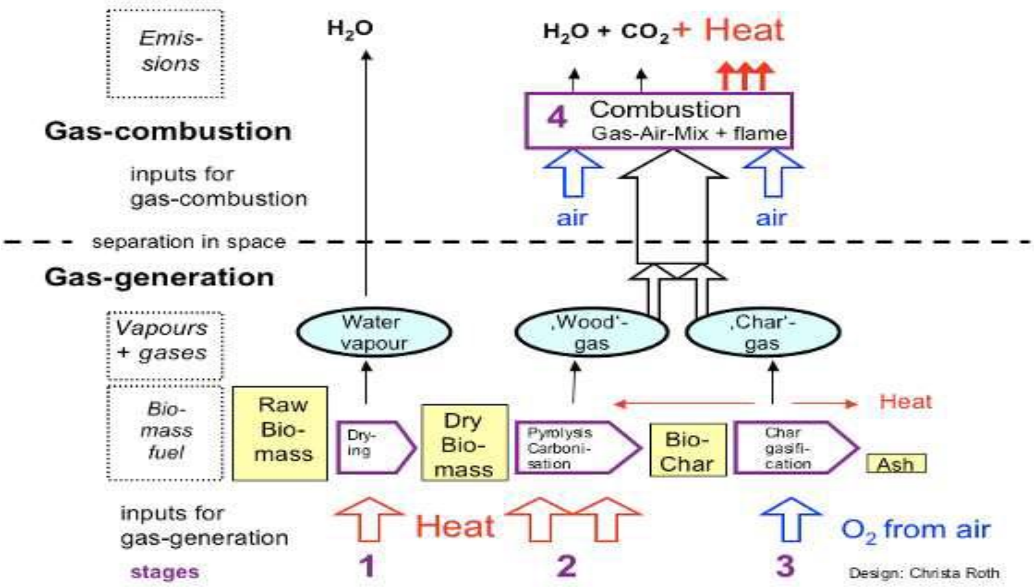

Figure A.1: Gasifier Operation (GTZ, 2011)

Gasifiers have potential to optimize flame-conditions of conversion steps. Clean combustion of biomass can be achieved by controlling the inputs of air and heat. However, gasifiers had a challenge to get right amount of air at right places. The process of heat creation from solid biomass follows in stages:

- Wood-gasification turns wood to gases (also known as wood gas) and char (controlled by heat input).
- Char-gasification turns char to gases and ashes (controlled by oxygen input).

As gasifiers need to transfer the heat into cold biomass, it is a challenge to use biomass gasification for small scale operation such as domestic cooking. The gasifiers were commercially used in large industries and also in transportation for long time. More than one million vehicles were using gasification of biomass (mainly charcoal) during World war-2 [GTZ, 2011]. There was no application of household stove at that time but downdraft gasifiers were used to supply town gas for street-lamps, in which the gases generation and combustion was in different chamber. Obtaining household cooking energy using micro-gasification is relatively young development.

Micro-gasification is a gasifier with convenient height to fit under the cooking pot. Top-Lit Up-Draft (TLUD) micro-gasifier process was designed in laboratory prototype stages in 1985 by Dr. Thomas B. Reed in USA. It was also independently developed in 1990s by Norwegian Paal Wendelbo in refugee camps of Uganda. The properties of TLUD for cooking purposes are classified as:

- **Top-lit:** Micro-gasifiers usually use lit at the top of fuel-bed. It is a way to keep the heat under the cooking pot. Most of the micro-gasifiers are batch-loaded with the fuel, which means that the container can be filled once for single operation.

- **Up-draft:** The air and combustible wood gases flow upward while the flaming front moves down-ward. Up-draft design is preferred as hot gases rise naturally if they are lighter than ambient air. This is classified as natural draft (ND) through the fuel-bed. However, depending on the density and fuel type, forced draft can be achieved by fan assisted (FA) to the fuel-bed for adjusting the flow of oxygen. For instance, pellets will work well in forced draft stoves due to their high density.

- **Close-coupled combustion:** Hot wood gases are combusted directly above the gas-generation zone. The heat can be directed easily to cooking pot and scrubbing, cooling and piping of the gases is not required [GTZ, 2011].

TLUD devices were considered as biomass burning cook-stoves and in 2003 first micro-gasifier was commercially launched by Dr. Reed as a camp-stove for outdoor camping niche market [GTZ, 2011]. There is a growing interest now-a-days for commercially available models as they are still scare.

Micro-gasifiers designed by Dr. Reed and Paal Wendelbo are pyrolytic TLUDs with controlled supply of primary air (figure A.2). Pyrolysis is the process of carbonization of biomass in the absence or limited presence of oxygen with the regulating factor of heat. TLUD design principle is not protected by copyrights and patents; it is ‘open source’. Simplest TLUD can also be designed by single tin-can, using different entry holes for primary and secondary air. The fuel does not move in TLUD except volume shrinkage when pyrolyzed. After igniting TLUD from the top, hot flaming front moves downward along the mass of solid fuel forming char from biomass. Wood gases travel upwards to the combustion zone and the char resides above the front [GTZ, 2011]. As rate of heat generation is related to amount of oxygen available, the progress of pyrolysis can be controlled by primary airflow. Further, increasing the airflow using fan (forced draft) will result in faster progress of flaming front down the biomass and increase in temperature.

A typical TLUD pyrolysis front moves 5-20mm/minute downward depending on the primary air availability and nature of fuel. The pyrolytic gases are tarry and long-chain hydrocarbons which form thick smoke, if not burned.

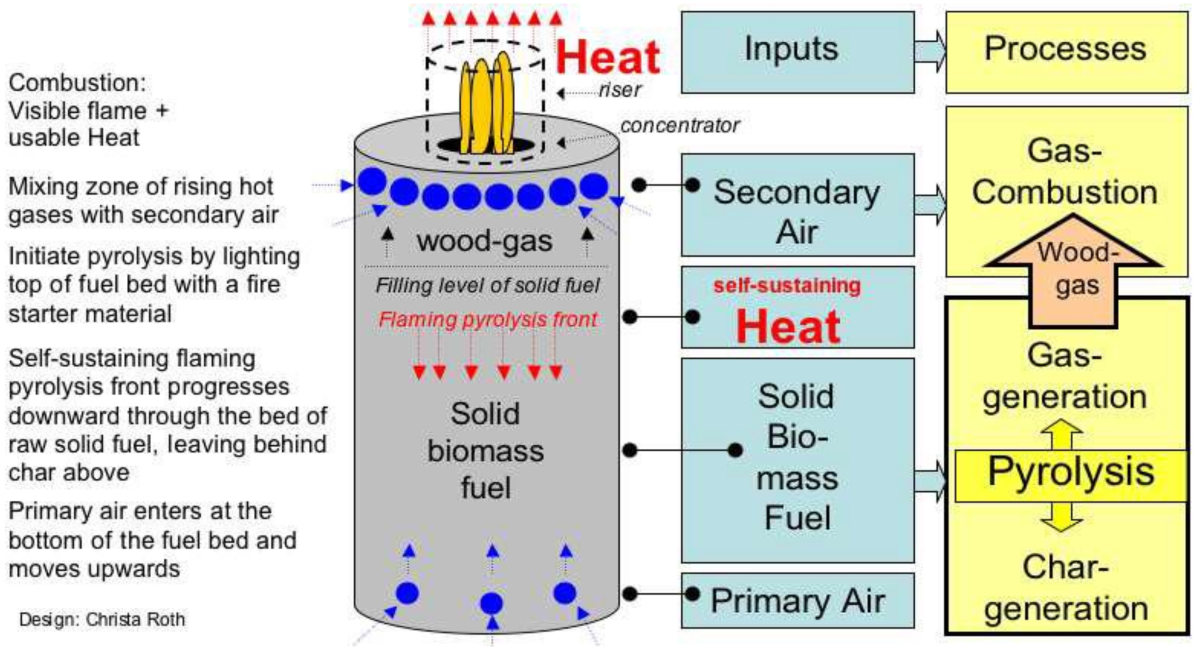

Figure A.2: TLUD Design (GTZ, 2011)

The environmental factors which are not related to user but can impact the performance of ACS are:

Location: Wind causes cooling effects and is not favorable. Wind can enter the combustion zone and it can extinguish the flame until it is lighted again. Best way to use micro-gasifiers is in ventilated location.

Altitude: There will be a need to enhance the air flow by fan or by an additional riser at high altitude (more than 1500meters) with lower atmospheric pressure.

Ambient Temperature: Overall energy yield at lower temperature has negative influence and the speeds of chemical reactions are also slowed down. Complete combustion is favored by higher temperature.

Humidity: High humidity conditions have negative influence on the overall performance of the micro-gasifiers [GTZ, 2011].

The design of ACS must be able to handle worst situations of these variables for a particular place.

Particle diameter of feedstock for TLUD should be at least 3mm and less than 20mm depending on biomass characteristics [Caregnato, n.d.]. TLUDs operation works in batch mode and all of the wood-gasification occur before the char-gasification. This transition can be recognized by flame color, yellow-orange flame represents tarry gases combustion and smaller bluish flame means CO is burning [GTZ, 2011].

Kitwe, Zambia (December, 2011)

Pekope stoves were introduced to the rural households in Kitwe region for pilot program by Vagga till Vagga, Sweden. The observations and recommendations provided to the pilot program are given below. Tests were conducted on saw-dust pine pellets from Zambia and eucalyptus pellets imported from Rwanda and the results are as follows:

Pellets load: 1 kg
Water Used: 2L
Ambient temperature: 29 degree C

Zambia Pellets:
Total burn time: 58 minutes
Time taken to reach Boiling point: 19 minutes (without using lid for the pot)

Rwanda Pellets:
Total burn time: 52 minutes
Time taken to reach Boiling point: 18 minutes (without using lid for the pot)

Observations:

- After 5 minutes, little blue flame is observed in the beginning and after 10 minutes the flame becomes relatively strong.
- Smoke observed in the beginning but there was almost no/limited smoke during the operation and in the end of process.
- The amount of smoke depends on type of recipe and moisture content used to make pellets.

Figure B.1: Pekope Testing and Biochar produced

Advantages of Pekope Stove

1. It burns hot.
2. No smoke in the end.
3. No Un-burnt pellets in the end.
4. Less sensitive to wind compared to other micro-gasifier stoves. The hole in the top plate is bigger providing large surface area for flame. So, if there is wind, the flame blows all around the pot resulting in wastage of heat, but the stove does not go off. Strong wind can stop the stove.

Disadvantages of Pekope Stove

1. Ground becomes hot where the stove was placed because there are holes in the bottom plate of inner canister.
2. Produces more ash.

3. When fire is reducing in the end, it becomes low (height of the flame), so effectively there is comparatively less heat transferred for last 3-4 minutes.
4. Stove body becomes hot from bottom to top. It needs wooden handle to move the stove.
5. There is smoke in the beginning. The inner canister is bigger in diameter and shorter in length, so it takes a while to give stable flame and by this time there is a smoke.
6. It produces soot in the bottom and sides of the pot.

Stressing the Pekope Stove

This experiment was carried to check the maximum load handled by the stove. The goal was to observe maximum burn time.

Results:
Pellets Used: Greveria (from Rwanda)
Load: 2480 grams
Total burn time: 136 minutes
Empty space from the top: 90 mm (Total length of stove is 225 mm)
Biochar: 919 grams (37%)
Rate of Burn: 54 minutes/kg

For the first time, we got to know that this stove lasts more than 2 hours and 15 minutes. 13 workers also cooked there food using the stove in just 1 hour of burn time.

However, I can say from my experience **that the stove should not be loaded more than 2.5 kg** (message for rural households in pilot program) as it will be difficult and time consuming to achieve the initial gasification phase (there should be more than 90 mm space from top).

Recommendation: *Mark the stove inner cylinder at 100 mm from the top.*

In another experiment to stress the stove, combination of two recipes was tried to burn in the stove.
First in the bottom, Greveria (Rwanda): 1500 grams
On the top, Eucalyptus (Rwanda): 1000 grams
Total load: 2500 grams (but pellets were not shaken to avoid mixing of two recipes)

2L water Boiling time: 12 minutes (with the top lid on pot)

After **57 minutes of burn time the stove went off.** There could be multiple reasons for this but the reason I understood is that the eucalyptus burned completely and then it was difficult to switch to greveria pellets. It cannot be concluded in one experiment that combination of recipes cannot be used.

Recommendation: *More testing of combined known recipes is required. Care should be taken while packing and distribution of the different recipes.*

Stove Testing

a) Biomass Used: Eucalyptus pellets (Rwanda)
Load: 1000 grams
Total burn time: 50 minutes
Biochar: 33.5%
Rate of burn: 50 minutes/kg

b) Biomass Used: Corn Cobs
Load: 850 grams (The stove was 80 mm remaining from the top)
Total burn time: 45 minutes
Biochar: 8%

Water Boiling Time (1L): 8 minutes (without the top lid on pot)
Rate of burn: 53 minutes/kg

c) Biomass Used: Pine and peanut recipe pellets
Load: 1000 grams
Total burn time: 61 minutes
Biochar: 30%
Rate of burn: 61 minutes/kg

d) Biomass Used: Pine and peanut recipe pellets
Load: 1000 grams
Total burn time: 67 minutes
Biochar: 23.5%
Water Boiling Time (1L): 19 minutes (without the top lid on pot)
Rate of burn: 67 minutes/kg

Biomass Hammering

There are different size and types of biomass available to be hammered. There are many possibilities for errors and impact the motor performance.

Recommendations:

- The speed of input feedstock by the user should match the speed of output as hammered biomass. That means the feed in should be slow and consistent compared to full feed in.
- It should be preferred to hammer the biomass using 3 mm sieve first and then 1mm sieve (in two stages) to avoid pressure on the motor. However, if biomass is in saw dust form, it is still required to use 1 mm sieve directly.
- The hammer mill (with 5 - 8 HP) should not run more than 4 hours a day to be on safe side. Time tracking is required.
- The hammer mill should be stopped immediately if there is any substance other than biomass in input, operator is feeling uncomfortable in breathing, eyes irritation due to particles or something is obstructing the belts of the motor.
- While purchasing the hammer mill and motor, after sales services like guarantee, technical issues should be made clear to avoid future delays during production of pellets.

Pellets Production

Most challenging part to run a pellet machine is to find correct recipe to manufacture pellets. It was observed that after adjusting the settings of rollers by +/- 45 degrees in the machine, recipe mixture and moisture content are the most affecting variables for the pellet production.

Observations:

1) Majority of eucalyptus (80-90%) and rest peanut shells is blocking the machine.
2) Usually, by adding 100-150 ml of water to 2 kg of recipe turns moisture from 10% (if it is around 10%) to 14-15%. It also depends on the recipe material and initial moisture content.

Recommendations:

- All the recipe combinations should be measured and recorded for future learning experience.
- Input feed should not be too less and not too much. The best way to determine input feed speed is by identifying the correct working voice of pellets making.
- The holes in the die plate should be clean before starting pellets machine.

Post Production

Once formula to make the quality pellets recipe is found, it can be replicated but still quality check is required.

Recommendations:

- The pellets produced should be cooled down in shaded hall to increase the binding.
- After cooling, pellets produced should be examined to remove small particles (which do not have high calorific value).
- There is a need to sun-dry all the pellets produced for 2 days (in summer) before packaging.
- Randomly samples should be taken (of 1 kg and 2 kg) for the stove burn test including water boiling test.
- Mixing of different recipes in one bag should be avoided.
- The bag with less calorific value/low intensity flame should not be dispatched.
- After filling the bag with pellets, it should be sealed as soon as possible and the households should be motivated to keep the bag closed if it is not used. Also, if the pellets does not catch fire for long time, the households should sun-dry it for minimum 5-6 hours.

Island model can work in Kitwe, Zambia as observed by author during field visit where several pine trees processing saw-mills are facing difficulty to dispose saw-dust waste. Centralized pellet production is possible by collecting saw-dust from several saw-mills according to conditions of agreement. Similar business model was also mentioned in an interview by Rural Renewable company (in India) collecting pine needles for briquettes manufacturing in foothills of Himalayas. The company pays to local women for collecting the needles from forest. The company also claims that this practice also reduces forest fires.

Coastal Orissa, India (February, 2012)

This area was selected to continue the work for rural household survey carried by the author in March, 2011 during 2nd semester project from Aalborg University. The results of survey concluded that there is an availability of biomass residues and there is an urgent need to deal with cooking energy problems for reducing deforestation. Previous working experience on other projects and close ties with local NGOs in this reason also helped to provide assistance during the field observations in February, 2012. The aim of field visit/analysis was to consider a solution for a pilot program in a particular area by Youth Development Foundation (YDF). This NGO was willing to upscale the project and also agreed for initial investment in partnership with companies for the pilot project. To test a micro-gasifier stove in the rural areas of Orissa, Pekope stove was designed by a local black-smith artisan according to specifications from Paal Wendelbo for $10.

As the project was also expecting to manufacturer briquettes or pellets fuel to use with the stove, it was necessary to test a micro-gasifier as an initial phase of the project. The gasifying stove was made successfully after 5 hours of work by black-smith artisan and a wood sticks was chopped to small pieces to use it as a fuel. Initial observations of the stove are as follows:

- There is a need to ignite the fire using kerosene as it was required for pellets.
- Top plate of the stove should be kept when fire is stable. It can be observed in approximately 3-4 minutes after starting the fire.
- There was no difference observed in flame for pellets and wood sticks. However, it is essential to use dry wood sticks.
- The flame lasts for lesser time in case of wood sticks usage compared to pellets (due to pellets relatively high density), considering same volume of stove was filled by both the fuels.
- Biochar was obtained in the end of combustion process in less quantity compared to pellets.
- Smoke was observed in the beginning of ignition. There were little puffs of smoke during

operation of the stove as well.

Figure B.2: Orissa Field Visit

Overall, the stove performance was satisfactory and number of people watching demo fire keeps on increasing in the workshop (figure B.2). Two different local NGO representatives believed in the micro-gasifying stove and commented that this stove can be up-scaled to masses in Orissa considering its simple and rigid design which requires comparatively low maintenance. Orissa's urban areas are highly populated and urban poor generally use firewood to cook food due to proximity of biomass resources in near-by area. If Pekope stove is up-scaled to masses, it can be used by rural and urban households due to its low-cost of production and efficient combustion.

The representatives of NGO were suggesting using local technical workshop centers to have a decentralized production of stoves for several villages and they were willing to provide initial investment. However, as a part of whole project, there was a need to manufacture low-cost densified biomass fuel which can be used in stoves. After using the stove for 3-4 days, the author observed that use of biomass residues only does not provide enough heat to cook food. The users will always prefer to cut the wood logs in pieces and use it in the absence of densified biomass. In the present scenario, forestry and agricultural residues like coconut shells, saal leaves, etc. are also used in major quantity along with firewood. Pellets can be manufactured from these residues but in the absence of pellets, it is most likely that firewood will be used in Pekope stove. It is also expected that biomass residues will be used separately in three-stone stoves as it is practiced traditionally. By promoting and manufacturing the Pekope stove, firewood consumption may increase in the absence of pellets. However, due to efficiency of the stove, the consumption can also be reduced or remain same for an individual household. More analysis is required to decide for the production of the Pekope stove in Orissa. Presently, it was advised to stop further manufacturing of Pekope stove and test the stove for various biomass resources available in the area by NGOs.

To introduce a business model about manufacturing densified biomass, circular mapping model concepts can be used. There will be a need of more field analysis for a particular place in order to modify the business model. It can be prominent solution for several villages with grid electricity connection. Reliable supply of electricity in many parts of coastal Orissa is also supporting this decision. The link between availability of biomass resources in rural areas and mass populations in cities can be created by decentralized pellets production. Presence of technical centers for small-scale electrical and carpenter trainings in Orissa can be considered to partner for biomass/pellets supply chain management.

River Islands, Sundarban, West Bengal, India (April, 2012)

This field visit was selected due to following reasons/thoughts:

- Large population densities of urban areas can provide more sales of pellets, if available
- Deforestation due to population pressure to obtain biomass resources
- Present impact on biomass residues for cooking
- Interest and field study support by Joygopalpur Gram Vikas Kendra (JGVK) working as local NGO in Sundarban
- Decentralized production of pellets fuel in isolated islands

Purulia, an urban city in West Bengal was visited in this field visit before going to river islands. The author observed complexity and non-uniform cooking fuel use pattern in this city. Due to city's proximity with coal mines, urban poor households and commercial cooking was done using coal as a cooking fuel. In the interviews with coal suppliers and consumers, it was pointed out that coal price is not stable and it increases every year starting from INR 2.5/kg in 2007 to INR 8.5/kg in 2012. Urban poor households and commercial customers do not want to use coal due to its increased price and dirty cooking, but there is no other inexpensive cooking fuel choice for them. Firewood, cow dung and saw-dust were also commonly used by urban poor and near-by rural areas. It was observed that by using firewood with INR 4/kg presently, on average same price is to be paid compared to coal to cook a meal. There are about 20 saw-millers inside the Purulia town whose saw-dust waste is sold. Urban poor people queue up every morning at 06.00 hours to buy the residues at Rs 2-3/kg. It was also observed that some saw-millers give preference to sell the residues only to women. In general, all kind of biomass resources including wastes are consumed in the urban areas due to high population density.

Near-by rural areas to the town also had problems for cooking. Rural households stated that every year, they need to walk more to reach the forest as it is decreasing due to firewood collection which is sold in cities. Due to lack of water and agricultural productivity, most of the farmers grow crops only in one season. Therefore, agricultural residues are not a reliable option to use for cooking in rural households considering other uses such as animal feeding, house construction, etc. Neither island model nor circular mapping model can be used in these kinds of areas where biomass resources availability is uncertain.

Figure B.3: West Bengal Field Visit

The field observation was different in JGVK operational area of Sundarban (figure B.3), south of West Bengal. JGVK was started in 1998 in Joygopalpur village (60 kilometers from Canning, nearest train station) by Biswajit Mahakur. He is working on improving the livelihoods of Sundarban people since early 1980s. Sundarban is the world's biggest mangrove forest and it is of special interest to the Indian government and international organizations such as WWF. Severe illegal deforestation has occurred due wood collection for different purposes including cooking. Presently, Indian government is strict for deforestation in whole area. This also impacted the rural households using firewood and forestry residues for cooking. Paddy, Green chili, potato and pumpkins etc. are major crops of the region. The land is productive but high tide and thunderstorms results in limited agricultural activities compared to whole year production. The pressure is also high on biomass resources due to high population density and limited resources.

A private company running 500 KW gaisifier plant since 1997 in Gosaba Island was also visited to understand the biomass resources supply for the electricity production. The plant officials claimed 50% diesel and 50% biomass use to run the plant. The plant uses 15-100 grams weight pieces of tree branches. These tree branches are sourced from the same island. However, wood logs were also observed in the plant site. There were many economic activities such as textiles shops, mobile operators started in the Island due to the introduction of electricity (about 1500 connections). However, local people also claimed that forest in the Island has reduced due to electricity production and economic activities. Local households generally use own land agricultural residues and firewood for cooking. In this scenario, any of the ABM cannot be applied due to continuously reducing biomass resources and lack of reliable electricity. However in the neighboring islands to Gosaba, there were abundant forestry residues available but lack of electricity in the region limits the pellets production. There is a need to introduce mechanical production of densified biomass as it is observed in case of briquettes. Considering the same concern, Milinda (trust) have started a pilot project to sell ICS from Envirofit which reduces the wood consumption by 40%. Milinda also considered the pellets production along with ACS. The proposal for pellets production was rejected by the management due to enough biomass unavailability and reliable electric supply.

Overall, West Bengal has most complex and non-uniform use of cooking fuel (from cow-dung, firewood, coal, LPG, saw-dust, other residues) in a single place as observed by author compared to other states which challenges to set-up particular business model in that area. High population density offers a market to be served by business solutions but it also limit the availability of biomass resources. Multiple solutions from businesses as well as policies are required to manufacturer densified biomass.

Grants for the field visits

- The author is thankful to Vagga till Vagga, Sweden for sponsoring (includes travel, accommodation and food) and providing opportunity to contribute in their project for pellets production as a cooking fuel in Zambia.

- The author also thanks to International office, Aalborg University for granting DKK 4500 to visit India for field observations as a part of research.

Appendix C: Survey for pellet manufacturers in developing countries

Date:

Name:
Designation:
Contact Number/Email:
Organization Name:
Private ( ) NGO ( ) Research Institution ( ) Government ( )

1. Is your organization buying or planning to buy the biomass to make pellets?

Yes, we buy it ( ) No, we get it for free ( )

2. How does your organization obtain the biomass? (Mark more than one if applicable)

Virgin material/Energy Plants ( ) Agricultural residues ( )
Saw-millers waste ( ) Forest residues ( )
Other industrial waste apart from saw-millers ( ) Others:_________________________

3. What are the challenges your organization faces in manufacturing pellets? (Mark more than one if applicable)

Supply chain of biomass collection ( )
Economic sustainability for selling pellets ( )
Transportation of biomass ( )
Availability of Electricity & its cost ( )
Mechanical problems in pellet machines ( )
Pellet recipe ( )
Moisture in raw biomass ( )
Others:____

4. Who are the intended recipients of your pellet production market? (Mark more than one if applicable)

Households ( )
If yes, Heating ( ) Cooking ( )
Small and medium size enterprises **( )**
If yes, Heating ( ) Cooking ( ) Electricity ( )
Industry **( )**
If yes, Furnaces ( ) Kilns ( ) Electricity ( )
Others:____

5. As a pellet manufacturer, do you think that enough raw biomass residues are available, if all the households in your area start using pellets for cooking (ex: 2 kg/day/household)?
   Yes ( ) No ( )
   If yes, are there any challenges/side-effects of using all the biomass residues for cooking?

____

6. In near future, will pellets export to Europe/USA represent major source of income for your organization?

____

7. For household cooking purposes, which business model can be used in order to optimize the supply chain of biomass in the villages while being economically sustainable?

Large centralized pellet plant ( ) Distributed micro-pelletization ( ) Mobile pellet mill ( )
Why?____

Appendix D: Interviews, Surveys and Workshops

S. No.	Interviewee	Purpose	Phone Interview	E-mail Interview	Personal Meeting
1	Dan Phipps, Co-founder of Alithia Energy Inc., USA	To understand distributed pellet production/challenges		X	
2	Emiliano Maletta, Director at Bioenergy Crops, Researcher and consultant at CIEMAT, Madrid	Overview of South American Pellet Market	X	X	
3	Cassie, Amisy Pellet Mill, China	Pellet industry survey		X	
4	Bjarne Laustsen, Director, Kiwia & Laustsen Limited, Tanzania	Pellet industry survey		X	
5	Ram Kumar, Ram Exports, India	Briquettes/pellets equipment enquiry and pellet industry survey	X	X	
6	Divya Prakash, CEO, Sun Tradings, India	Manufacturing challenges and pellet industry survey	X	X	
7	Karsten Bechtel Creec, Head of Bio-energy, Dodoma University, Tanzania	Pellet industry survey		X	
8	Guangqing Liu, Executive Secretary-General of China Alliance for Clean Stoves, China	Pellet industry survey		X	
9	Chandrakumar, MD, Sri Sakathi, India	Pellet industry survey		X	
10	A.K.Singh, Business Development Manager, Rural Renewable Urja Solutions P. Ltd., India	Briquetting Challenges and to discuss impact on variables pellet industry survey	X	X	X
11	Vishal Srivastava, Sales Manager, SLT Energy Ltd, India	Pellet Industry Survey		X	
12	Jerry Brown, Great Lakes Renewable Energy, USA	To understand small-scale pellet units and pellet industry survey		X	
13	Jennifer Edwards, Researcher, University of Colorado, USA	To know about the awareness of fuel supply	X	X	
14	Martin Bokesch, Owner, MAB Consulting, Canada	Decentralized pellet production details		X	
15	Brijesh Rawat, Owner, Rural Renewable Urja Solutions P. Ltd., India	Briquette making process		X	
16	Job Mutyaba, Renewable Energy Officer, WWF, Uganda	Pellet industry survey		X	

17	Jean Kim Chaix, Founder, The Charcoal Project, USA	To understand the market of briquetted charcoal	X	X	
18	Mattias Ohlson, Vagga till Vagga, Sweden	Zambia pellet production model	X	X	X
19	Per Lofberg, Vagga till Vagga, Sweden	Raw material for Zambia pellet plant	X	X	X
20	Kayje Booker, Carbon financing head, Darfur Stove, USA	To know about the on-going Darfur stove project challenges in Sudan	X	X	
21	Adam Rausch, Researcher, Darfur Stove, University of California, Berkeley, USA	To know about the on-going Darfur stove project challenges in Sudan	X	X	X
22	Andree Sosler, Director, Darfur Stove, USA	To know about the on-going Darfur stove project challenges in Sudan	X	X	X
23	Dr. Ashok Gadgil, Inventor, Darfur Stove, Lawrence Berkeley Lab, USA	To interview about the future prospects of Darfur project			X
24	Trans O'brian, Climate scientist, Lawrence Berkeley Lab, USA	To propose a project in Lawrence Berkeley Lab about micro-pelletezing		X	X
25	Manoj Vyas, Assistant Manager, Renew Wind Power P. Ltd., Gurgoan, India	To understand pellet production in India	X		
26	Tushar, Owner, Govind Soods P. Ltd, India	Pellet industry survey	X	X	
27	Daniel M. Kammen, Chief Technical Specialist for Renewable Energy, The World Bank, USA	To understand the importance of cooking fuel in World Bank			X
28	Ranjit Deshmukh, Researcher, University of California, Berkeley, USA	To under electricity production by gasification		X	X
29	Kirk Smith, Director, Global Health and Environment Program, University of California, Berkeley, USA	To know about the pilot project of Philipps stove in India		X	X
30	Biswajit Mahakur, Secretary, Joygopalpur Gram Vikash Kendra, Sundarban, India	To conduct interviews and understand challenges for biomass supply chain in sundarban			X
31	Vijay Bhaskar, Program Manager, Milinda, Kolkata, India	To know about the cook-stove project in sundarban area	X		X
32	Tridibesh Bandyopadhyay, Director and CEO, Inskills, Kolkata, India	To understand rural marketing			X
33	Saw-mill owners, Sundarban, India	To understand the			X

		quantity of saw-mill waste			
34	Rural households, Sundarban, India	To know their preference			X
35	Gasifier Plant, Gosaba rural energy development Co-operative society, India	To know about the functionality of gasifier plant			X
36	Azzurra Massimino, Senior Associate, CleanStar Ventures LLC, New York, USA	To understand liquid fuel clean cook-stove project in Mozambquik	X		
37	Clare Talwalker, Professor, University of California, Berkeley, USA	To design the pellet industry survey			X
38	Gobinda Dalai, Founder, Youth Development Foundation, Orissa, India	To understand biomass resources and urban market	X		
39	Vinit Kumar, Founder, Educate to Empower, Orissa, India	To understand school functionality	X	X	X
40	Anand Jain, Co-founder, Educate to Empower, Orissa, India	To know about the local area and field visit			X
41	Gour Gobinda Das, Principal, Mayurbganj Public School, Orissa, India	Overall idea of the school			X
42	Wolfgang Stelte, Research Assistant, DTU Chemical Engineering, Denmark	To understand biomass resources and pellets production in developing countries		X	

Key Findings of Survey

The survey was sent to 39 pellets/briquettes manufacturers in Africa, Asia and Latin America and out of those 11 people replied. The survey was kept short, so that it takes 5-10 minutes to fill it and addresses main challenges for densified biomass production. Overall, the quantity of survey results is low to show graphs but some of the key findings which were common in majority of the replies are:

- All of them are listed as company in their respective countries.
- All of them are buying the biomass. Agricultural residues and sawdust from saw-millers industry are the most commonly used biomass resources.
- Reliable electricity and raw material supply chain management was identified as biggest barriers. However, transporting the biomass was also highlighted as a barrier considering small-scale production.
- Household cooking and industrial furnaces are indentified as a key end use of densified biomass. However, the companies are also struggling to become financially sustainable.
- Large scale and centralized production was shown as their first preference to run a business.

Workshops Attended

- Rural Marketing, InSkills, Bhubaneswar, Orissa, India (9 February, 2012)
- *StartingBloc Social Innovation Fellowship* in Los Angeles, USA (16-20 February, 2012)
- Cooperation & Development Center (CODEV), International UNESCO Chair Conference on *Technologies for Sustainable Development: A Way to Reduce Poverty?* In EPFL, Lausanne, Switzerland (29-31 May, 2012)

Appendix E: Briquette Densification Technologies

Briquetting requires the raw material to be hammered to coarse power like sawdust prior to densification. High pressure briquettes are typically produced at pressure of about 1500 bar using power driven press. The compression heats up the biomass at about 120 degree C resulting in melt down of lignin in the woody material. The press allows the controlled force on the hot material through a die. The lignin cools down and solidifies again to bind the biomass powder into uniform shape briquettes as the pressure decreases [Fulford and Wheldon, 2012]. Briquette density is higher than the raw material obtained from saw dust and cutter shavings resulting in transportation cost reduction. The combustion equipment using briquette as a fuel must be flexible to handle shavings and saw-dust since the briquettes can break up before entering the combustion chamber. Therefore, the briquettes are not suitable for small scale applications for single family house but there is a market for applications of large boilers.

There is a need of electricity and mechanical power for high pressure briquetting. The energy input is typically between 40-60 Kwh/tonne depending on the type of biomass used and the quality of briquette produced [Fulford and Wheldon, 2012]. Wood briquettes are different in physical properties compared to fresh wood but not in composition or chemical properties. The mechanical durability of the briquettes is mainly determined by:

- Wide particle size will result in a weak product
- Moisture content in the solid feed material prior to the press
- Low pressure in the compression process resulting in lower durability [Forest, 2012]

The moving components and dies in the machines need to be made from hardened steel because of the continuous use of the biomass at high pressure. After die wear out, there is a need of replacement. Lower pressure press can also be used, but in this case the die needs to be heated which requires additional heating energy [Fulford and Wheldon, 2012]. The high pressure machines are available for wide range of sizes such as 30 kg/hour to 1300 kg/hour. The briquette presses that are used in developing countries are of two types (figure E.1):

- Heated-die screw press, which uses tapered screw producing long and hollow briquettes
- Piston press, which uses oscillating piston to compact the biomass producing cylindrical briquettes of 50 to 100 mm diameter.

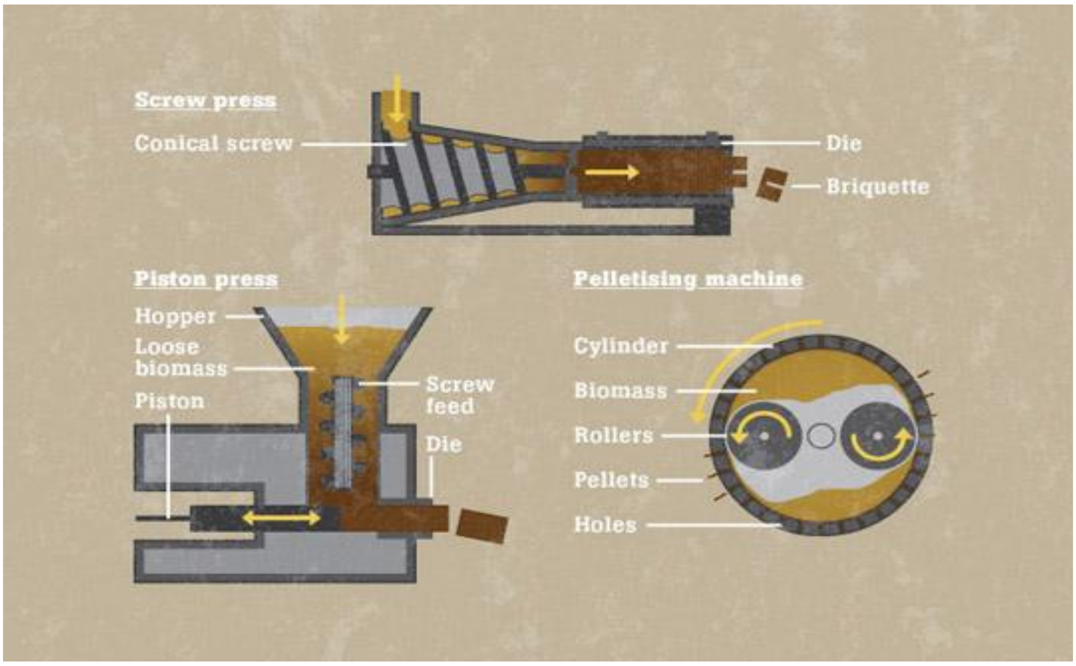

Figure E.1: Briquette and Pellet making machines

The heated-die screw press technology was invented in Japan in mid-1940s which has spread in most of the Asian countries like Bangladesh, Philippines, Thailand, Malaysia, Vietnam, Taiwan, Korea, China etc. The design of the screw press machine was adopted according to the local conditions in different countries. The piston press technology is mainly used in Brazil, India and Africa. These machines are locally made in India and Brazil whereas in Africa it is mostly imported. The screw press technology has less capacity compared to piston-press but it produces high density and strong briquettes. For producing carbonized charcoal briquettes, screw press technology is more suitable due to high density output [Battacharya, n.d.].

Commonly used materials for heated-die screw press briquetting are rice husks and saw dust. Coffee husk, coir pith, tobacco stems, spice waste and tamarind seeds can also be used. Sawdust is the only raw material which is carbonized after making briquettes. It is readily available in Malaysia, Korea, Thailand and Philippines whereas in Bangladesh only rice husk is available as a raw material. The piston press briquetting machines are used widely with variety of pulverized raw materials. For instance, in India coffee husk, sugar cane bagasse, sun flower stalks, cotton stalks, ground nut shell, saw dust, etc. In Africa, cotton stalk and peanut shell appear to be most important raw materials.

Low pressure Briquetting

Apart from high pressure briquetting, low pressure conventional briquetting can also be done for raw materials with low lignin such as charcoal dust and paper. The process to form briquettes in most cases is followed after carbonization process; the resulting charcoal is converted into briquettes using suitable binder [Battacharya, n.d.]. The suitable binder could be starch or clay and water with a mixture of powdered biomass along with it. The other way to achieve briquettes is using low-pressure binder-less by mixing of decomposed, pulverized and chopped biomass with water into a pulp. A perforated pipe of around 4-inch diameter is used to press the pulp to get cakes which is further sun-dried to get briquettes [Stanley, 2002]. The basic press can be made on the site for forming lower density briquettes compared to conventional briquettes. Lagacy Foundation, a non-profit organization, is involved in providing the dissemination of the technology. The briquettes which are made by mixing pulverized coal, slaked lime and biomass has been introduced by Japan in two Asian countries, Indonesia and China. These coal-biomass briquettes are produced by using a roll-press. The use of desulfurizing agent as slaked lime results in less ash and cleaner combustion of briquettes in stoves compared to coal briquettes or only coal [Kobayashi, 2002].

A low pressure machine can also be hand operated (figure E.2) using a lever which further drives the piston to compress the paste. In Eastern Africa, briquettes are made traditionally from the left over dust of charcoal production. The charcoal dust is mixed with clay as a binder and rolled into balls for sun drying. Using molasses from bagasse as a binder for briquetting has been reported to have limited success in Sudan.

Figure E.2: ARTI hand operated briquette press

A company in India named ARTI made a portable kiln to produce char using sugar-cane leaves which are normally burned directly in the field. A hand operated press by ARTI can be used to make briquetted from loose char. Similarly, it has been done for nut shells and coconut husks [Grover and Mishra, 1996].

Kampala Jellitone Suppliers (KJS) has biomass briquetting unit in Uganda. KJS delivers briquettes to customers, which were using wood in furnaces/stoves earlier. The customers vary from public institutions like schools, university halls to businesses like bakers and coffee roasters [Fulford and Wheldon, 2012]. In another case, Nishant Bioenergy has developed a commercial stove which uses briquettes as a cooking fuel to cook for hundreds of school children in India. The aim of Nishant Bioenergy is to compete with increasingly expensive commercial supply of LPG [Nishant Bioenergy, 2012] (figure E.3).

Figure E.3: KJS Briquettes and Nishant Bioenergy Cook-stove

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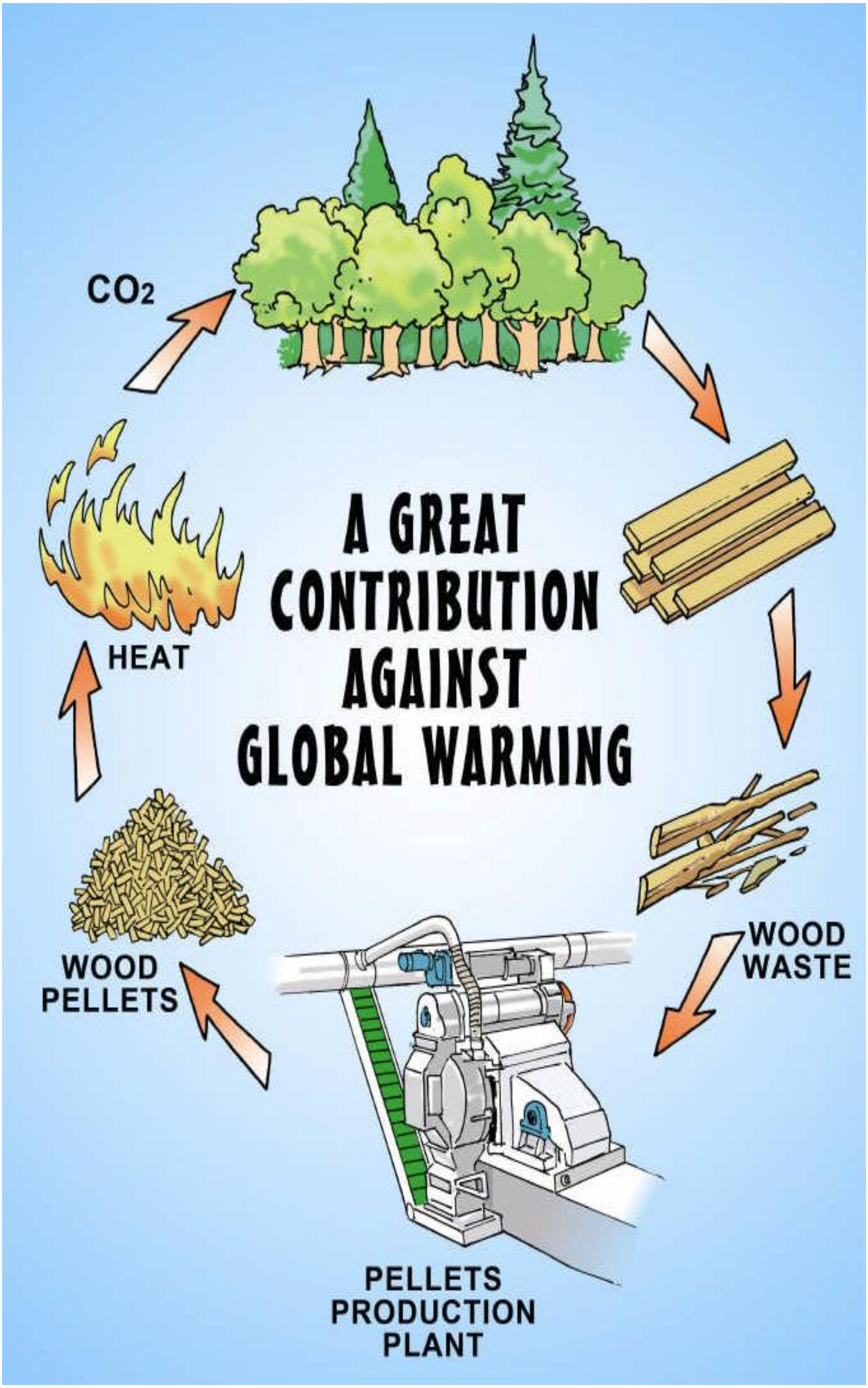
CO2
A GREAT CONTRIBUTION AGAINST GLOBAL WARMING
HEAT
WOOD PELLETS
WOOD WASTE
PELLETS PRODUCTION PLANT