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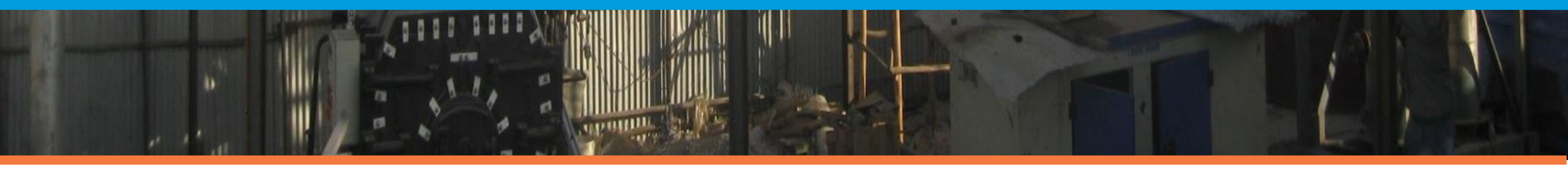
Guidebook on Ethanol Microdistilleries for Clean Cooking



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COORDINATION: Jossy Thomas, Industrial Development Officer; Kolade Esan, Project Coordinator; Limi Kalapurackal, Ana Garavito, Project Associates, Division of Energy and Climate Action, UNIDO.

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LIST OF ABBREVIATIONS AND ACRONYMS

ASEAN	Association of Southeast Asian Nations
ASTM	American Society for Testing and Materials
BOD	Biological Oxygen Demand
CECC	Council on Ethanol Clean Cooking (UNIDO)
CHP	Combined Heat and Power
CMC	Carboxymethyl Cellulose
COD	Chemical Oxygen Demand
DDG	Distillers Dried Grains
EMD	Ethanol Microdistillery
ENA	Extra Neutral Alcohol
GHG	Greenhouse Gas
HAP	Household Air Pollution
IFES	Integrated Food Energy Systems
IRENA	Industrial Renewable Energy Agency
IRR	Internal Rate of Return
Kcal	Kilocalories
kJ	Kilojoule (energy unit)
LHV	Lower Heating Value
LPD	Litres Per Day
LPG	Liquefied Petroleum Gas
MJ	MegaJoule
MSW	Municipal Solid Waste
MTBE	Methyl Tertiary-Butyl Ether
MT	Metric Tonnes
NGO	Non-governmental Organization
NPV	Net Present Value
P, N, K, Ca	Phosphorous, Nitrogen, Potassium, Calcium
PM2.5	Particulate Matter 2.5 microns or less in width
RCN	Raw Cashew Nut
REN	Rectified Extra Neutral
ROI	Return On Investment
SAT	Semi-arid Tropical
SDG	Sustainable Development Goal
SME	Small and Medium Enterprise
SS	Suspended Solids
SSA	Sub-Saharan Africa
TA	Technical Alcohol
tCO_2	Total Carbon Dioxide
TSS	Total Suspended Solids
U.S.	United States
v/v	Volume per volume
WHO	World Health Organization
w/w	Weight by weight


ALPINA

FOREWORD

The global search for clean and sustainable energy solutions has never been more urgent, especially in the context of achieving the United Nations' Sustainable Development Goals (SDGs). Access to affordable, reliable, sustainable, and modern energy (SDG 7) is intrinsically linked to the reduction of poverty (SDG 1) and hunger (SDG 2), particularly in developing regions. Ethanol microdistilleries, as highlighted in this guidebook, present a promising pathway to achieving these objectives through the promotion of localized renewable energy production and clean cooking solutions.

This publication on ethanol microdistilleries (EMDs), serves as a critical resource for stakeholders aiming to transform agricultural residues and local feedstocks into clean fuel. It addresses several global challenges: reducing reliance on fossil fuels, enhancing energy security, and improving health outcomes by mitigating indoor air pollution caused by traditional cooking methods. The guidebook goes beyond theoretical benefits, providing practical guidance to farmers, entrepreneurs, and policymakers on how to establish and operate small-scale distilleries. These microdistilleries are adaptable, scalable, and aligned with the available resources and agricultural outputs of smallholder farmers, particularly in rural areas. As we explore the significant benefits and potential of ethanol microdistilleries, we recognize their capacity to create low-carbon liquid fuels that are accessible to many communities, particularly in rural areas where such initiatives are often most needed.

As we move toward the 2030 Agenda for Sustainable Development, this publication emphasizes not only environmental sustainability but also the empowerment of rural communities (SDG 8). By equipping smallholder farmers with the knowledge and tools to harness local resources for ethanol production, microdistilleries can become a vital part of local economies, creating jobs and enhancing livelihoods. Moreover, the use of ethanol as a clean fuel directly contributes to climate action (SDG 13) by reducing greenhouse gas emissions.

This guidebook will serve as a valuable tool for fostering innovation in renewable energy and clean cooking, contributing to a future where communities can thrive with sustainable and modern energy solutions. The lessons shared here will not only inspire but also empower local stakeholders to adopt ethanol microdistilleries, paving the way for cleaner, healthier, and more sustainable cooking practices globally.

PREFACE

Ethanol has gained recent interest in being used as a fuel given the rising pressures caused by environmental, societal, and economic reasons. In rural areas, large-scale production of ethanol may be limited due to finances, infrastructure, and other resources. As this publication explains, ethanol microdistilleries can provide an opportunity for ethanol production well-suited to the quantity of feedstocks that small farms can produce and consistently supply.

Ethanol microdistilleries are a potentially sustainable solution where typical industrial-scale ethanol production is not feasible. The benefits of ethanol microdistilleries are such that they offer an opportunity for local natural and agricultural resources to be used for renewable energy production. This is further beneficial considering that they can be adapted to the scale of feedstock availability.

Despite the opportunities they offer, it is often overlooked and faces several barriers to being fully replicated, such as the lack of availability of information about microdistilleries.

This guidebook aims to share knowledge about ethanol microdistilleries, providing the know-how for local implementers and encouraging stakeholders to consider ethanol production at a microscale as a potential window of opportunity. Thus, it covers topics including the chemical and physical processes involved, the energy required, common feedstocks, waste management, the infrastructure, the ethanol standards for fuel use and a financial analysis.

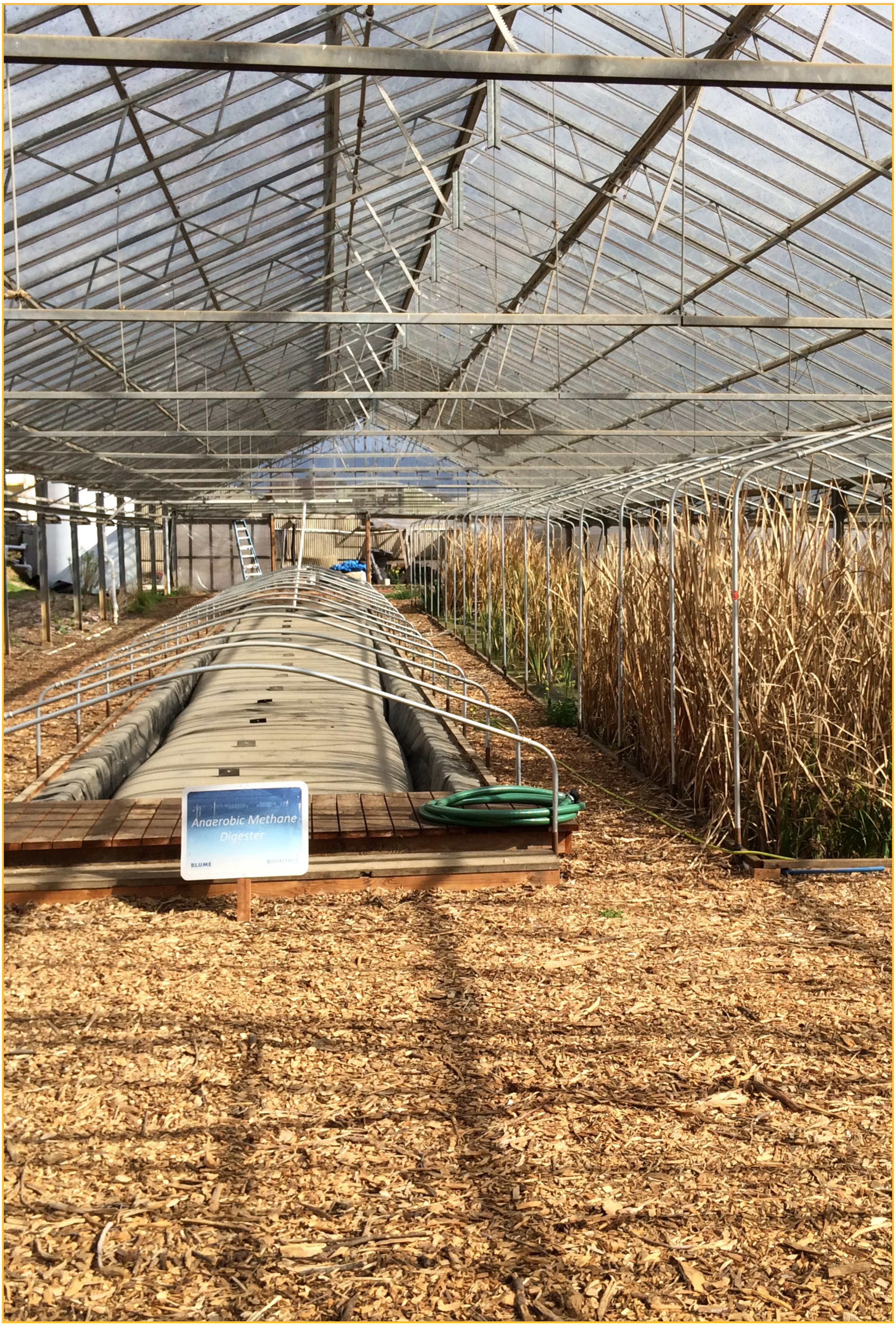
INTRODUCTION

Ethanol production is a widely known, age-old technology. Its production and use in many developing countries are unfortunately captive to the alcoholic beverage market, a legacy, in part, of past economic and trade priorities. In recent decades there has been a growing interest in the use of ethanol for fuel, due to rising oil prices, the burden of energy imports and, more recently, commitments to reducing greenhouse gas (GHG) emissions. Production of ethanol in Sub-Saharan Africa (SSA) is mostly done in relatively large distilleries—small compared to United States (U.S.) and Brazilian distilleries—that rely on large, mechanized farms for feedstock supply. These are mostly sugarcane plantations supporting sugar mills, with ethanol as a by-product. While large operations like sugar mills and sugarcane plantations can be an efficient way to produce ethanol, what we call microscale ethanol distilleries for ethanol fuel production can be a good fit for local owners. In rural, smallholder settings, the infrastructure and financial capacity to support large operations are limited and farm production volumes are lacking or difficult to aggregate. Microscale ethanol production, defined as a few thousand litres of production per day, is well-suited to the quantity of feedstocks that small farms can produce and consistently supply. Distilleries are dependent upon the feedstocks that are supplied to them. To be successful and profitable, a distillery must have a consistent, reliable supply of feedstock. Thus, distilleries can and should be sized to the farms that produce feedstocks for them.

In the context of smallholder African agriculture, microdistilleries may thus be best suited to the available quantity of feedstocks. These microdistilleries will transform feedstocks into a value-added commodity for local fuel markets, or markets in nearby towns. Cash markets for fuel already exist and are ready to pay, given the shortage and cost of fuels. What small-scale African farmers often need most is access to markets. Experience in Brazil and other countries has shown the feasibility of producing ethanol efficiently and profitably in properly designed microdistilleries that rely on production from small farms in the local community.

An ethanol microdistillery (EMD) is a complete distillation plant designed to process starch or sugar feedstocks such as sugarcane juice, sugarcane molasses, cocoa sweatings, fruits or fruit wastes, such as mangos, pineapples, guavas, litchee nuts and cashew apples, and starchy materials such as cassava, sweet potato, other tubers, corn, sorghum, broken rice, etc. EMDs can be sized to meet different levels of feedstock supply and different scales of demand. Somewhat arbitrarily, ethanol microdistilleries can be defined as producing up to 5,000 litres per day (LPD). When this quantity is exceeded, process simplification and manual operation become difficult, the quantity of feedstock and land area from which it is drawn become more demanding, and outputs, particularly the wastes, become more challenging to handle and use appropriately. Thus, for this guidebook, we are defining a microdistillery as producing up to 5,000 LPD. For the lower limit, we recommend a quantity that is still industrial in scale (i.e., 1,000 LPD), rather than artisanal, and that can take advantage of the modern technologies of alcohol distillation.

Few farmers, entrepreneurs, development experts, civil society actors, bank and government officials, whether in developing or developed countries, are familiar with EMDs and the opportunities they offer. This guidebook will introduce ethanol and microscale ethanol production to stakeholders and their investors and facilitators who may not be familiar with the microscale approach. •



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THE MICRODISTILLERY OPPORTUNITY

Microdistilleries are the opportunity to unlock natural and agricultural resources for renewable energy production—the production of low-carbon liquid fuel—on a scale that is achievable for many more people than have the ability to do so today. In unlocking these resources, the potential is created to manage them better, more renewably and sustainably. Livelihoods and income are created, especially in rural communities where they are much needed.

During Brazil's Programa Nacional do Álcool or Proálcool program in the 1970s, ethanol micro-distilleries were constructed in Brazil to produce fuel, mostly for on-farm use. Over the years, many hundreds if not thousands were built. Similar developments occurred in the U.S. with the rise of on-farm distilleries, spurred by the 1973 Oil Embargo. These on-farm distilleries laid the groundwork for ethanol fuel production in the U.S. and Brazil, which took off in Brazil in the mid-1970s and in the U.S. after 2002, when tetraethyl lead, an anti-knock agent, and Methyl Tertiary-Butyl Ether (MTBE), a synthetic oxygenate, were banned from gasoline in favour of ethanol. Microdistilleries were built in many African and Asian countries. Fuel blending programs began in Zimbabwe and Malawi and continue to this day. While the ethanol fuel production industry rapidly consolidated to large and very large-scale production, especially in the West, because that was where investment capital and government policies took the industry, nevertheless, small and microscale producers persisted, and their plants have been constantly improved and modernized along with the big ones.

A defining feature of ethanol production is that it can be run efficiently at almost any scale. Thus, microplants exist today as a ready option for ethanol production, particularly in settings where large-scale plants are neither feasible nor desirable. Ethanol production in Africa, in any event, does not exist on the scale that it does in Europe, the U.S. and Brazil. It is characterized mostly by plants producing a few tens of thousands of LPD, rather than plants producing many hundreds of thousands of LPD. The size of plants is inevitably determined by their supply of feedstock. They are also predicated on finance and the guarantee of a reliable, predictable market. Many smaller sugar factories in Africa that have enough molasses available for the production of a few thousand litres of ethanol per day do not have distilleries. Africa could produce more ethanol if its plants were sized more to scale with its producers. If this were so, many more farmers, growers and processors could be involved, including owners of their distilleries.

Many studies have shown, and this guidebook will demonstrate, that microdistilleries can be built for a similar capital cost per unit output as a large or even a mega distillery and that while production costs may be higher, the trade-offs are such that these higher costs can be more than made up for with benefits of the microscale approach. Although it has always been assumed that economies of scale are required, this is not true for ethanol production, which can operate efficiently and economically at microscale. Thus, EMDs are a sustainable approach to ethanol production in settings where typical industrial-scale solutions are not feasible. With the emerging market for ethanol cooking fuel, microdistilleries can produce for the cooking fuel market. At the same time, bigger producers stay focused on their markets, which traditionally have been the production of rectified ethanol (ENA) for the liquor industry with small amounts going to the industrial (paints, solvents, chemicals) and institutional (medical, medicinal, laboratory) markets. The cooking fuel market has struggled because the big producers have shown little interest in diverting from their traditional market. This is largely because of their capacity constraints. They have limited ability and have not been zealous in addressing a new market.

Replication of ethanol microdistilleries from Brazil, India, the U.S., or other locations to Africa has been slow for several reasons:

- limited availability of information about microdistilleries.
- lack of capacity in countries that could benefit from them.
- lack of supportive government policy for alcohol fuels.
- existence of barriers to importing ethanol and machinery and equipment for ethanol production.
- failure of the government to distinguish between ethanol fuel and ethanol for beverage, the latter of which is controlled by excise and other taxes.
- dominance of petroleum fuels in the market, and also traditional fuels, especially charcoal, with a fierce resistance to change put forth by these two powerful stakeholders.

As a result, there are not many examples of modern ethanol microdistilleries to point to in Sub-Saharan Africa. Potential developers have been slow to receive support from banks, lenders, donors or development agencies. But this could change. Modern EMDs have recently been built in Ethiopia, Nigeria, Ghana, Zambia, South Africa, and Madagascar and as the ethanol cooking fuel market develops in Africa, many more will likely be built. Global South countries have favourable climates, land and biomass resources and existing agricultural capacity to support the microscale production of ethanol. Given that most developing nations wisely base their economic development strategy on their agricultural productivity, EMDs represent an opportunity for them to play to their strength.

Much recent work has been done with microdistilleries in Thailand, Vietnam, and the Association of Southeast Asian Nations (ASEAN) countries using cassava. This work has been supported by UNIDO. These efforts have arisen out of interest in cassava as a cash crop for farmers and, likewise, an interest by those nations in automotive fuel-blending. Advances are also being made in the cassava-to-ethanol process. This work is already benefiting African countries. As more work is done to develop cassava as an industrial cash crop for farmers, this feedstock will become important for ethanol production in Africa. There are cassava distilleries planned in Kenya and Zambia and operating in Nigeria, Ghana, and Sierra Leone, with more planned. These are good examples that can be pointed to as new EMD projects take shape.

Because the scale of investment and technical requirements are manageable for small businesses, including equipment fabricators, EMDs are replicable. As capacity is built, they can be fabricated locally. A network of small, standardized, ecological distilleries, integrated for support, could create a profitable, scalable energy program for a nation. Since the cooking fuel market is ubiquitous and local, it provides an ideal market for EMDs. The market is as close as the neighbouring village or town. The ethanol stove is simple to use and substitutes easily for firewood, charcoal, kerosene, and liquefied petroleum gas (LPG). A litre of ethanol—a typical daily consumption for a family of five—displaces 8 to 12 kg of fuelwood or 3 to 4 kg of charcoal. It slightly exceeds the cooking capacity provided by a litre of kerosene. It displaces LPG litre for litre, or one litre of ethanol per 0.5 kg of LPG. A 1,000 litre-per-day distillery will support the cooking needs of 1,000 families. A 2,500 litre-per-day distillery will support 2,500 families.

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THE OPPORTUNITY TO PRODUCE COOKING FUEL

EMDs for fuel production can deliver important benefits for countries that encourage them. Most developing countries struggle to meet the cooking needs of their people, either with biomass, electricity or imported fuels. The heavy reliance on fuelwood and charcoal is one of the two leading causes of deforestation and forest degradation in Africa. Electrification continues to lag, with peak power heavily dependent on imported diesel. Electricity production and supply are dependent on dams, thermal power plants, high voltage lines and other large, costly infrastructure, with their associated environmental costs. Heat for cooking places a heavy demand on the power supply, which might better be used for industry, commerce, lighting, cooling and communications. Generally, the most efficient way to deliver heat for cooking is through the efficient combustion of a fuel. By and large, liquid fuels have better energy density and handling characteristics than solid and gaseous fuels. Alcohol fuels are unique in that they are easy to combust efficiently.

Reliance on imported fuels for cooking only increases the dependency that countries already have on gasoline, diesel, kerosene and fuel oil for transportation and electricity generation. The enormous cost of importing fuels affects the balance of trade and the strength of the currency. Ethanol produced domestically keeps wealth at home. Unlike the exploitation of forests for fuel, EMDs rely on agricultural production from farms. Farms are managed systems, much more highly managed than forests and woodlands. Smallholder farming has been practiced sustainably for many centuries. There is much science and practice behind sustainable farming. To return a living, the land must be carefully managed by the farmer. But to operate profitably, the farmer needs markets. An EMD producing ethanol for the local cooking fuel market provides a reliable cash market to the farmer. The cooking fuel market, unlike the fuel blending market, is an easy, relatively “low-tech” market to create. It can be scaled incrementally from hundreds of stoves to thousands of stoves, and from one distillery to many. Demand already exists. It is a matter of matching stoves to the supply of fuel.

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While ethanol fuel production delivers important benefits to the economy, ethanol cooking delivers important benefits to the consumer. Ethanol is a modern fuel that can be used conveniently and safely in properly designed appliances.

Cooking with ethanol reduces the time spent preparing meals and collecting, buying, and managing fuel. It reduces or eliminates exposure to pollutants, which include carbon monoxide, nitrous oxides, and carcinogenic compounds, including smoke and soot (very fine particulates often referred to as particulate matter 2.5 microns or less in width or PM2.5). Cooking with ethanol can save money as well as time. Reduced exposure to harmful emissions from cooking means less time lost to sickness, more time for productive work and better all-around health. In the community, ethanol production creates jobs on the farm, at the distillery and up and down the supply chain. Money is earned and spent in the community, rather than sent off to pay for imported fuels. Farmers are good stewards of their land, especially when they can earn a living from it. With a good market for their ethanol, they take care of their soils, grow a variety of crops, manage the plant and animal nutrients on their farm, and rely less heavily on their woodlands for fuel.

ETHANOL: THE DEMOCRATIC FUEL

We have always been taught that economies of scale are essential in industry: bigger farms, more industrial-scale processing, bigger factories. But as we confront the limitations now made clear to us by global climate change, we are reassessing what it means to live, produce and consume sustainably. It is increasingly understood that smallholder farms can be profitable and operate sustainably. Why not then reconsider the scale of the industry that serves farmers to add value to what they grow? Indeed, EMDs have significant advantages over large-scale distilleries. They have design and operational flexibility to use a variety of feedstocks depending on what grows best locally and is available seasonally. An EMD can be installed adjacent to its feedstock source, removing the need for costly feedstock transportation. Some EMDs even have been built to be moved around. The by-products and wastes from the distillery do not overwhelm the farms from which the materials come, allowing the farmers to safely recycle the minerals and nutrients. All products from the distillery can be turned into valuable co-products. Much of the equipment for the distillery can be built in good workshops locally or in the regional or national industrial hub, provided there is training and capacity building to ensure the equipment is built to the required design standard. Happily, virtually all distillery technology is in the public domain. Most of the labour required to operate the distillery is unskilled. One or two skilled people are required to run the plant. These can be recruited from the many thousands of young women and men engineers graduating each year from university with knowledge and skills that need to be used. The size of the capital and operating costs of microdistilleries are within the reach of many new investors, and if capital is lent to build the distillery, it can be repaid within three to four years, with a satisfactory return on investment (ROI) starting in year two.

These attributes of an EMD industry describe the opportunity to produce a fuel in which the community is a principal stakeholder. The ethanol production takes place in the community and is owned locally. Many stakeholders are involved in its production. In this sense, then, ethanol could be described as a democratic fuel. Any business, large or small, with access to modest amounts of capital, and associated with the farmers who will grow the feedstocks, can produce it. It can be produced almost anywhere where sugar and starch crops are grown.

There is already a wide experience in most developing countries in how to produce and use ethanol as a fuel. Today, the cost of locally-produced ethanol is competitive with other modern cooking fuels and also with charcoal. Despite this, the opportunity of ethanol fuel for cooking is usually overlooked or discounted by development agencies and energy experts alike and, therefore, by funders. In addition to the reasons already discussed, there is another fundamental reason for this, the unremitting hostility of the oil industry over generations to the development of ethanol as fuel. We have been told that ethanol is not a good choice—that using it has many disadvantages. Remarkably, microscale ethanol production is especially effective in addressing all of these concerns raised over ethanol—indirect land use change, food vs. fuel, sustainability, etc. It will take time and experience to undo this institutional bias. If governments lead with policies conducive to the development of ethanol as fuel, and if biofuel champions provide help with funds, this process will be hastened. Over more than a century, oil-rich nations and the powerful businesses that grew from oil built the oil paradigm. In the past 50 years, nations like Brazil, India, and China, not rich in oil, have helped to chip away at it. Now, as we face the realities of climate change, nations in SSA, powerful in small-scale agriculture, rich in sugar and starch biomass, and with a rapidly growing, indeed urgent need for fuel, can break the paradigm.

ABOUT THIS GUIDEBOOK

The purpose of this guidebook is to help increase knowledge about small and microscale ethanol distilleries to produce fuel, provide the know-how to local implementers, encourage agencies and government to support their endeavours and open the minds of facilitators and financiers to consider what ethanol as a fuel, produced at a small scale, has to offer. It is hoped that the availability of technical and financial information about this solution will help to bring it about.

You are encouraged to read all the chapters to gain a comprehensive understanding of ethanol production in microdistilleries. The guidebook is not a step-by-step technical manual for building and operating a distillery but rather a guide to getting started, planning the EMD project, making the right fundamental decisions and then setting about to do it. It provides the know-how to determine project feasibility, plan the project, cost the project, choose the right process, identify the help needed, and then get started. Implementers will need experts to help them build their distillery—but this expertise is readily available.

- The first chapter introduces the reader to ethanol, ethanol production technology and the chemical and physical processes involved. It provides information on what is required to analyse an EMD investment.

- The second chapter provides a guide to conducting an energy and materials balance for an EMD. This provides insight into the energy required to produce ethanol and the quantity and quality of feedstock needed, depending on the feedstock type. This is the most technical chapter of the guidebook. You can return to it later for help.

- The third chapter reviews commonly used feedstocks for ethanol production and alternative feedstocks. This is one of the most important chapters of the guidebook since making plans for ethanol production begins with determining the availability and desirability of a feedstock and the reliability of its supply. A viable feedstock should complement, rather than compete with, local food production. This alternative feedstock is therefore to be considered if it can be used to support and enhance the farming operation, as it will contribute to the feasibility of the project.

- The fourth chapter discusses EMD wastes and treatment technologies that can be applied to treat wastes and turn them into products of value. Environmental-safe and properly treated wastes can bring value to the operation. Implementers are urged to look closely at the requirements for treatment, discharge and use of all material flows before deciding to embark on a project.

- The fifth chapter details the equipment and infrastructure required to build an EMD. The information in this chapter should help investors understand the type of equipment the project will need and give them information to consider if sourcing from a local, cost-efficient manufacturer is possible or not.

- The sixth chapter discusses ethanol standards for fuel use and will help you understand the requirements the EMD must achieve to make a good product. Meeting a quality standard for ethanol is important if the fuel is to combust cleanly and satisfy the customer. This chapter discusses the reasons for these specifications. To produce quality fuel, the implementer must select the right equipment. Ethanol for cooking will serve its purpose when the fuel is of sufficient strength and purity to burn with high flame temperature and no discernible soot production.

- The seventh chapter aids the reader in conducting a dynamic financial analysis of the EMD investment based on a case study on a 2,500 litre-per-day EMD. To this end, the reader fills in and uses a ready-to-be-used Microsoft Excel financial model which can be printed to complete a set of financial statements to be included in a business plan.

- The eighth and final chapter provides a case study on an ethanol microdistillery implemented in Addis Ababa (Ethiopia) to foster ethanol cooking technology among households.

There is a glossary of terms at the end of the guidebook to help readers with technical terms.

Finally, there are three annexes to the guidebook as follows:

Annex I: Ethanol Microdistillery Financial Module. This annex provides an introduction to the dynamic financial model in Microsoft Excel that is available to users of this guidebook, by visiting https://projectgaia.com/our-approach/resources/ or scanning the QR Code.

Annex II: Further Reading: Technical Guides to Building Farm-Based Ethanol Microdistilleries. This annex provides a list of publications on EMDs for further reading that will take the reader on a "deeper dive" into building a distillery. Some of these are practical "how to" books of historical and technical interest, as they show some of the historic work and ideas involved in the microdistilleries built in the 1980s.

Annex III: Microdistillery Effluent Handling Strategy – Biogas Production. This annex explores the opportunity of treating microdistillery effluent and producing valuable co-products by using low-cost polyethylene bag digesters. ■

1. ETHANOL TECHNOLOGY

1.1. ETHANOL

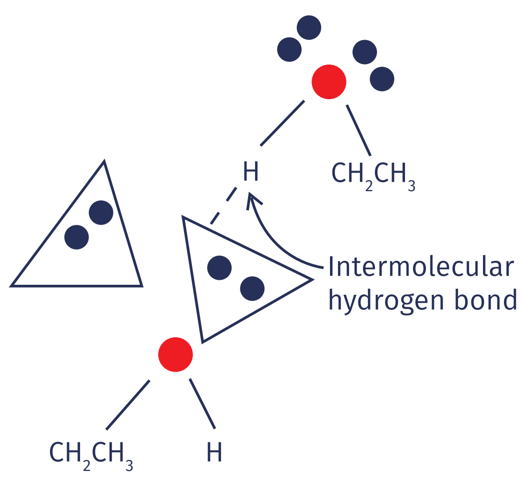
Bioethanol or ethanol (also called ethyl alcohol, abbreviated as EtOH) is an organic chemical compound. Ethanol and its closely associated alcohol, methanol (MeOH), are the simplest members of a class of compounds for which the general formula is CnH2n+1OH. The chemical formula of ethanol, an ethyl group (two carbon atoms) linked to a hydroxyl group (O-H), is CH_3CH_2OH, also written as C_2H_5OH or C_2H_6O. Ethanol is a volatile, flammable, colourless liquid with a slight characteristic odour. The physical properties of ethanol come primarily from the presence of its hydroxyl group and the shortness of its carbon chain. Ethanol's hydroxyl group participates in hydrogen bonding, rendering it slightly more viscous and less volatile than less polar organic compounds of similar molecular weight, such as propane (Nomenclature of Organic Chemistry, 2014).

Ethanol is miscible (completely soluble) with water. Mixtures of ethanol and water form an azeotrope (a constant boiling point mixture) at a mixture of 95.6 per cent ethanol by mass (or around 97 per cent alcohol by volume) at atmospheric pressure, which boils at 78°C. This makes it difficult to remove all water from ethanol through distillation. Hydrogen bonding causes pure ethanol to be hygroscopic, to the extent that it readily absorbs water from the air. The polar nature of the hydroxyl group causes ethanol to dissolve many ionic compounds, such as sodium and potassium hydroxides, magnesium chloride and calcium chloride (Lide, 2012). In general, the hydroxyl group makes the alcohol molecule polar. Hydroxyl groups form hydrogen bonds to one another and other compounds. This hydrogen bonding means that alcohols can be used as solvents.

Two opposing solubility trends in alcohols are the tendency of the polar OH to promote solubility in water, and the tendency of the carbon chain to resist it. Ethanol is miscible in water because the hydroxyl group wins out over the short carbon chain.

Figure 1

Guidebook on Ethanol Microdistilleries



Note. Britannica (n.d.)

However, higher alcohols of five or more carbons (pentanol and higher) are effectively insoluble in water because of the dominance of the carbon chain over the hydroxyl group. Simple alcohols are highly soluble in water and organic solvents but poorly soluble in fats and oils (Britannica; Chemical Book, n.d.).

Because of hydrogen bonding, alcohols tend to have higher boiling points than comparable hydrocarbons and ethers. The hydrogen bonding makes the molecules "stickier"; more heat is necessary to separate them. The boiling point of ethanol is 78.29°C, compared to 69°C for the hydrocarbon hexane (a common constituent of gasoline), 34.6°C for diethyl ether and -42°C for propane (Clark, 2020).

Ethanol burns very cleanly and easily. When burning, much of the energy produced comes from the breaking of the C-H bonds in the molecules. In addition to the oxygen in the air, the oxygen atoms inside these simple molecules contribute to the combustion reaction. Even some of the oxygen in the water associated with ethanol contributes to the combustion (Suarta, et al., 2016). When impurities such as higher alcohols with more carbon atoms are present, the rapid oxidation of the ethanol helps to oxidize the impurities. Thus, ethanol can contain some impurities and still burn cleanly.

1.2. ETHANOL PRODUCTION

Beverage ethanol dates back to ancient times, with Sumerians and Babylonians making beer before 6,000 B.C. (Wyman, 2004). Ethanol from distillation of wine was one of the earliest compounds studied in an investigation in 11th-century Italy (Wyman, 2004). Ethanol is important because it is the product of fermentation, a major energy-producing pathway, while other simple alcohols are formed only in trace amounts during fermentation. More complex alcohols are produced in fermentation but in small amounts (Shinnosuke, 2016).

Ethanol production is an ancient technology. Although it is possible to produce it through chemical synthesis, ethanol is primarily produced through the fermentation of agricultural products high in starch or sugar, such as sugarcane, corn, wheat, potatoes, cassava, and beets, from agricultural by-products and wastes, such as molasses, and even from cellulose. Whatever can be broken down into sugars can become a primary material for fermentation to ethanol (U.S. DOE, 1982). Thus, the variety of raw materials which can be used for ethanol production is large. However, the conversion of crops with significant human food value to ethanol is not desirable. Fortunately, the production of ethanol usually does not require this as an "either-or" consideration (U.S. DOE, 1982). Fermentation of cereal grains to produce ethanol uses most of the carbohydrates for ethanol while all the protein is recovered in the stillage coproduct. The dried stillage is a high-protein livestock feed used in place of soybean meal. The grain stillage application along with the use of spoiled perishable crops, distressed crops, and marginal crops, provides a feedstock base for ethanol production that requires no displacement of crops for human food (U.S. DOE, 1982).

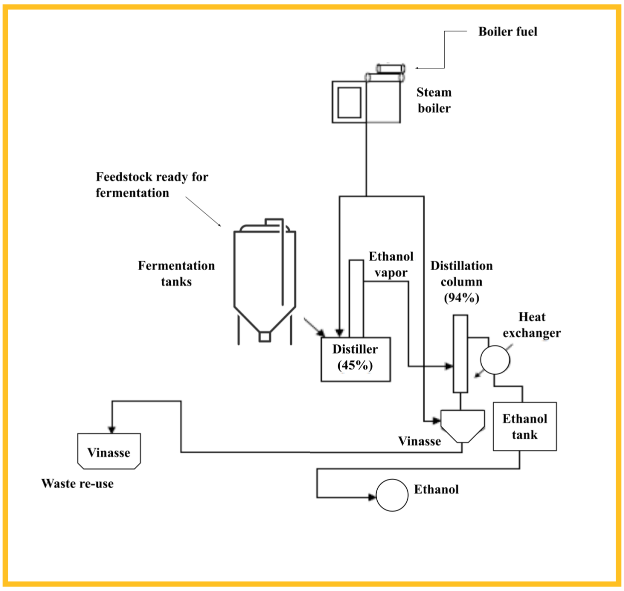
The core process in the production of ethanol is the fermentation of sugars from the feedstock by microorganisms. Some feedstocks directly yield simple sugars; others produce starch or cellulose that must be converted to sugar. The sugar must be fermented. The fermented liquid alcohol-water mixture is called beer or wine. The water is removed from the beer through distillation. Distillation can also reduce the concentration of lighter and heavier impurities to minimal levels. For this, the beer goes through a distillation process to separate the alcohol from the water and the other components in the beer to obtain the alcohol in a pure enough form to be used as fuel. Distillation is the most used industrial separation technique to produce ethanol. Distillation separates two or more compounds by utilizing the difference in their volatilities. Fractional distillation at atmospheric pressure can concentrate ethanol to 95.6 per cent by weight (hydrous grade). This mixture is the azeotrope with a boiling point of 78.1°C.

The degree of separation obtained in a single distillation step depends on the initial composition of the mixture and the difference in boiling points at the operating pressure, which is atmospheric for most commercial ethanol distilleries. Distillation achieves water removal and quality improvement by eliminating organic impurities. A series of distillations on distillation plates is required to achieve high separation of water and impurities from ethanol. The initial fermented mix is vaporized in a distillation tower. The vapour is condensed, obtaining concentrated ethanol at the top of the distillation column.

Repeated vaporization and condensation result in 95.6 per cent ethanol content by weight, with the remaining component being mostly water. The highest achievable concentration of ethanol with distillation is 95.6 per cent. At this concentration, the ratio of ethanol to water in the liquid and vapour phases is the same, and further separation cannot be obtained. This is the azeotropic limit.

Figure 2

Simplified Ethanol Production Process



Note. Project Gaia (2014)

Since other compounds form azeotropes with ethanol, these cannot be easily and completely removed either. There are various purification techniques other than distillation that might be used, such as oxidation, gas stripping, coagulation, adsorption, and ion exchange, which are technologies used in alcohol and water purification and wastewater treatment. Activated carbon filtration is a technique used in making drinking alcohol. Some of these treatments are used in various applications to overcome the limitations of distillation to remove undesirable volatile compounds from ethanol for fuel use (Shinnosuke, 2016).

The basic process of ethanol production involves feedstock preparation, fermentation, distillation, and waste treatment. Figure 2 depicts a simplified ethanol production process.

1.2.1 Fermentation

Ethanol fermentation is one of the oldest and most important fermentation processes used in the biotechnology industry. Fermentation is the conversion of an organic material from one chemical form to another using enzymes produced by living microorganisms. Fermentation of sugar or starch-containing raw materials produces an ethanol-water mixture along with various chemical compounds. The microorganisms break down glucose into ethanol. Yeasts are the microorganisms responsible for producing the enzymes that convert sugar to ethanol. Yeasts are single-cell fungi widely distributed in nature.

Yeasts can grow in the presence or absence of oxygen. In a normal fermentation cycle, yeasts use oxygen from the beginning of the process until all the oxygen is used up. However, it is only during the anaerobic period that yeasts produce ethanol. For this reason, oxygen must be supplied to the mash during the initial stages of fermentation to facilitate the growth of yeasts. During the actual fermentation, oxygenation must be avoided to obtain maximum alcohol while reducing cell growth. Similarly, the temperature should be controlled to minimize undesirable reactions and maximize sugar-to-ethanol conversion (Silva, 2007).

Yeasts used in ethanol production are members of the genus Saccharomyces. These yeasts are sensitive to a wide variety of variables that potentially affect ethanol production. Temperature, pH, and alcohol concentration are the most influential of these variables. Current industrial ethanol fermentation is mainly carried out with Saccharomyces Cerevisiae yeast because of its hardiness (low pH and high ethanol tolerance). Saccharomyces yeasts are most effective in pH ranges between 3.0 and 5.0 and temperatures between 27°C and 35°C. The length of time required to convert a mash to ethanol is dependent on the number of yeast cells per quantity of sugar. The greater the number of yeasts initially added, the faster the job is completed. However, there is a point of diminishing returns. Yeast strains, nutritional requirements, sugar concentration, temperature, infections, and pH all influence yeast efficiency (U.S. DOE, 1982).

Alcoholic fermentation under normal conditions requires a maximum of 36 hours. During the initial phase of fermentation, organisms adapt to the new environment and begin to grow. They must be oxygenated, and the temperature increase in this phase is insignificant. There is no formation of bubbles, which characterize the release of carbon dioxide in the production of ethanol. After 30 minutes, the yeasts begin to reproduce rapidly, and their numbers increase exponentially. Carbon dioxide (CO_2) is released in large quantities, with intense bubbling. As fermentation continues, the yeast tends to clump together (flocculation). This phase is known as the "main fermentation" or "tumultuous fermentation". It is at this stage that a pleasant and characteristic aroma is detected. Temperature and alcohol content increase, with a corresponding reduction in the sugar content of the wort, as the fermenting liquid is called. It is during the tumultuous fermentation, in which there is a large release of CO_2 that it becomes necessary to control the temperature through the internal or external cooling of the fermentation tanks. During the last phase of fermentation, sugar starts to become scarce and the rate of growth of yeasts declines rapidly (Silva, 2007).

The complex sequence of chemical reactions (fermentation) to produce ethanol is summarized by Equation 1.1 (known as the Gay-Lussac equation):

$$\mathbf{C_6H_{12}O_6\ (Glucose) \longrightarrow 2C_2H_5OH\ (Ethanol) + 2CO_2\ (Carbon\ dioxide) + Heat}$$

In 1857, the French chemist Louis Pasteur proved that fermentation is caused by the living process of microorganisms and from 100 g of glucose he obtained 48.5 g or 61 ml of ethanol at 15°C. The yield obtained by Louis Pasteur is used in the evaluation of fermentation efficiency, known as the Pasteur Yield. The Gay-Lussac's equation is also used to calculate the efficiency of the fermentation process, i.e., the yield of alcohol from distillation; however, this is a theoretical value. The Gay-Lussac's equation calculates the fermentation of sugars, the formation of alcohol and the release of carbon dioxide. Differences in results between the two methods are due to losses in the production process, the main cause of which is the consumption of sugar by microorganisms undesirable to the fermentation and evaporation process. The prediction of yields using either of these methods is inexact as the fermentation process is too complex to be perfectly predicted by the Pasteur Yield or calculated by the chemical biodegradation reaction equation of Gay-Lussac (Silva, 2007).

To have a successful fermentation, hygiene and temperature control are necessary in addition to proper mash preparation. Actual yields of ethanol are generally less than theoretical estimated yields because about 5 per cent of the sugar is used by the yeast to produce new cells and minor products such as glycerols, acetic acid, lactic acid and fuel oils (U.S. DOE, 1982). The fermented product, the beer or wine, is a mixture of alcohol, water, substrate, yeast cells and various other substances dissolved in the water. The beer usually has no more than 10–12 per cent alcohol.

Industrial operations to produce alcohol or ethanol by fermentation apply four main types of industrial operations: batch, continuous, batch-fed, and semi-continuous (Caylak, 1996).

Figure 3

Four Process Options for Producing Ethanol

BATCH FERMENTATION	The substrate, culture medium and required nutrients and yeast culture are charged into the bioreactor together with nutrients. Such process is widespread since the investment costs are low, does not require much control and can be completed with low-wage labour. Complete sterilization and management of feedstocks are easier compared to other processes.
CONTINUOUS FERMENTATION FEED	The substrate is pumped continuously into an agitated vessel where the microorganisms are active. The product taken from the top of the bioreactor contains ethanol, cells and residual sugar.
FED-BATCH FERMENTATION	This is a combination of the batch and continuous fermentation processes. The substrate, yeast culture, minerals and vitamins are fed at constant intervals while effluent is removed discontinuously. This process facilitates the breakdown of glucose and related sugars aided by a process called inhibition and catabolite repression to boost the production of ethanol. Intermittent addition can yield fermentable sugars that produce ethanol.
SEMI-CONTINUOUS FERMENTATION	A portion of the culture is withdrawn at intervals while fresh medium is added to the system and there is culture volume variation. This method entails some of the benefits of continuous and batch fermentation processes. Moreover, time is not wasted in non-productive idle time for cleaning and re-sterilization.

Note. Project Gaia (2014)

1.2.2 Distillation

To separate ethanol from the fermented ethanol-water mixture, distillation techniques are applied. Distillation is the most easily operated and thermally efficient separation technique. It uses the different boiling temperatures of the compounds in the mixture. At atmospheric pressure, water boils at 100°C and ethanol boils at 78.2°C. The differences in boiling temperature allow distillation to separate the ethanol-water mixture. Heating a water-alcohol solution to a suitable temperature will cause the alcohol to change state from liquid to vapour and, later, to the liquid state after the vapour cools (condensation). Ethanol obtained from fractional distillation contains about 95.6 per cent ethanol, which is suitable for pharmaceutical, chemical and cookstove fuel applications. Beyond the 95.6 ethanol-water azeotrope, distillation does not easily provide a higher concentration of ethanol (Aslanzadeh et al., 2014).

During alcoholic fermentation, other substances are produced as minor products, including glycerol, acetic acid, esters, higher alcohols (fuel oils), carbonyls, sulphur compounds, acetaldehyde, and methanol (Yang & Zhang, 2007). During distillation, lower boiling point impurities (“heads”) come off separately from higher boiling point impurities (“tails”). As a result, both streams can be controlled. The lower boiling point stream includes methanol, acetaldehyde, and lighter esters. The higher boiling point stream includes fuel oils such as propanol, butanol, amyl alcohols and alcohols with higher boiling points (Project Gaia, 2014).

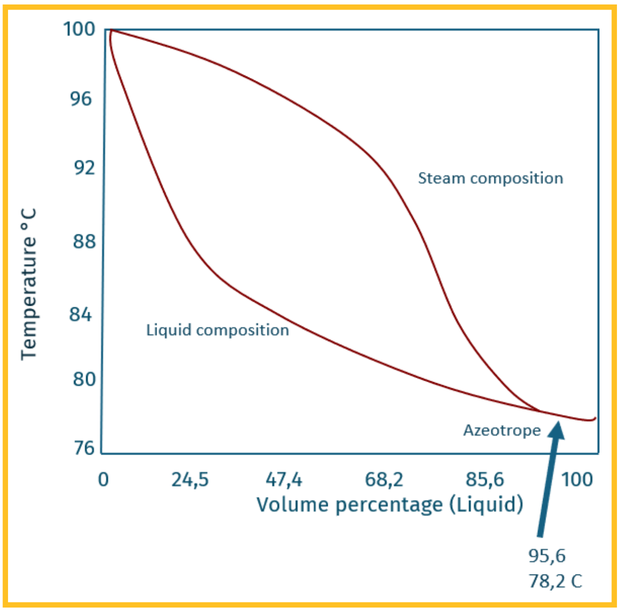
Distillation separates the ethanol-water mixture by using selective boiling and condensation. The challenge is to efficiently separate ethanol and water, that is, with as little energy expenditure as possible. This has made distillation to be a core unit process that needs to be designed and engineered properly to have an energy-efficient processing. The successive distillation process using plates or trays provides increasingly more concentrated ethyl alcohol as the process moves up the distillation column. The separation of substances at once is impossible since the boiling temperature of an alcohol-water mixture varies according to the percentage of each component in the mixture, and this varies throughout the column.

If lighter impurities remain in ethanol that is blended with gasoline, they can create emissions issues during the use of ethanol in gasoline. The impurities are volatile by-products and include aldehydes, acids, alcohols, cyclic/heterocyclic compounds, and esters. The heavier impurities or fuel oils, although separated during distillation, are returned to anhydrous ethanol for fuel blending. This is because the fuel oils have high fuel value, serve as a blending agent between ethanol and gasoline, and have lubricating properties in the engine (Katzen, 1999). Moreover, ethanol for blending with gasoline must have at least 99.2 per cent purity, which is obtained by dehydration or drying of the ethanol after distillation (Aslanzadeh et al., 2014). To achieve a higher concentration of ethanol, the use of an entrainer, molecular sieves, membranes or pressure reduction techniques is necessary. As a result, anhydrous ethanol is more costly and energy-intensive to produce than hydrous ethanol, the azeotrope.

In the simplest terms, there are two main types of distillation, pot-type and continuous-feed distillation, with variations as described in Figure 3 above. In a pot-type distillation system, the beer is simply boiled in a pot to vaporize the alcohol. In a continuous-feed distillation column system, beer containing a constant alcohol content is continuously pumped into a column. Alcohol-water vapour is forced to flow up the distillation column to bring about separation and concentration.

Figure 4

Composition of Steam & Liquid in the Water-Alcohol System as a Function of Temperature (at 760 mmHg)



Note. Silva (2007)

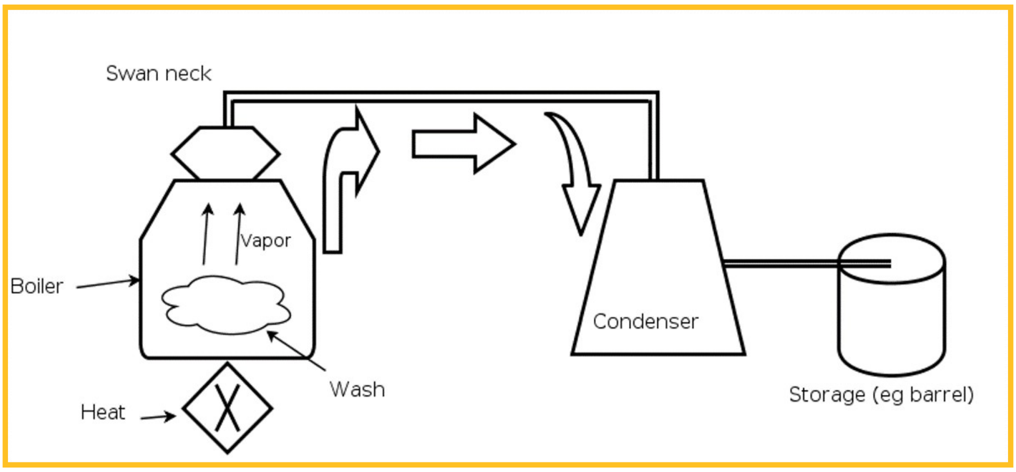
1.2.2.1 Pot-type Distillation Process

In a pot-type distillation process, the entire batch of beer is heated to boiling in a large container, and the alcohol-water vapours are collected and channelled into a distillation column. Such a process will always be a batch procedure and involves only the use of a rectifying (alcohol enriching) column since the stripping (alcohol exhausting) is done as the alcohol vapours are boiled off from the container. The basic advantage of the pot distillation process is its simplicity. It does not require a constant supply of beer and solely needs a very simple equipment system. However, this process has low distillation efficiency. Typically, a pot distillation unit requires about three times the energy of an equivalent continuous distillation system. The pot is continuously boiled and less heat can be recycled to other parts of the process (Kvaalen, 1984).

Pot stills have variations including vacuum stills, reflux stills and solar stills. The two most widely used micro ethanol production units are reflux and solar stills. Reflux stills are the most common and efficient stills, used to make ethanol at home. Reflux stills usually use biomass for heating. Reflux stills use several progressively smaller boiling pots to separate ethanol from water into an increasingly concentrated form. New designs of reflux stills use one boiling pot and a complex reflux column which is broken down into smaller spaces to imitate other boiling pots and produce a purer product. Solar stills are simple and use the sun's energy to heat and separate the product. However, solar stills can achieve only weak ethanol concentration as a product.

Figure 5

Basic Diagram of Pot-type Batch Distillation



Note. Turnbull (2012)

1.2.2.2 Continuous-feed Distillation Column

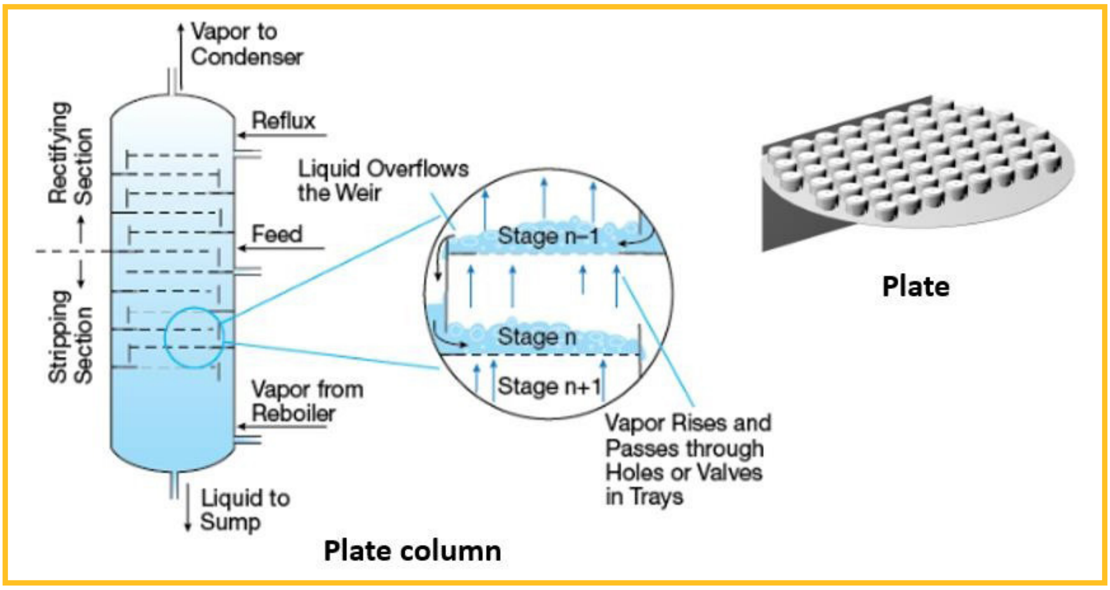
Continuous distillation is carried out in distillation columns, with beer being continuously fed into the column, vinasse continuously removed at the base and distillate (alcohol) taken off at the top of the column (Silva, 2007). The separation of secondary components is carried out at the top of the column and on the side of the column, according to the boiling points of the impurities (Silva, 2007). A continuous-feed distillation process involves a controlled flow of liquid beer, preferably preheated and with all solids removed, which is fed into the top of the stripping portion of the column.

The liquid alcohol-water mixture trickles downward through the column, its flow impeded or slowed by either a series of plates or continuous packing. It passes through vapour (a mixture of water vapour and alcohol vapour, but no air) which moves up the column. The source of the water vapour is either steam injected from a boiler or vapour produced in the reboiler. The plates or packing cause good mixing of the vapour with the liquid, allowing the alcohol to evaporate and the water to condense. Ethanol vapours leaving the top of the column flow into the condenser, where they pass to the liquid phase. Part of this liquid is returned to the column, called reflux, which helps to maintain rich vapours at the head of the column.

A schematic of a continuous distillation column is presented in Figure 6. The column consists of a stripping section (the lower part) and a rectifying section (the upper part). There is a condenser located on the top end of the column and an optional reboiler at the bottom.

Figure 6

Distillation Column

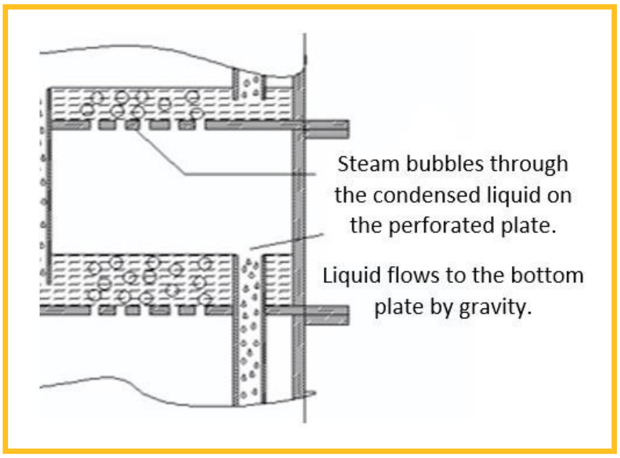


Note. Chemical Engineering World (2022)

The heating of the columns is done at the base using steam injection, or coil or heat exchangers, depending on the richness of the liquid inside and the nature of the operation. The heating of the trays is provided by the heat of the rising vapour in the column. The vapour emitted by an ethanol-water solution is richer in ethanol than the solution it came from. These vapours, condensing in the immediately superior plate or tray, enrich the liquid there and heat it to boiling, generating richer vapours, etc. The temperature in the column decreases from the bottom to the top, while the alcohol content increases (Silva, 2007).

Figure 7

Basic Design of a Series Tray in a Distillation Column



Note. Silva (2007)

A distillation tower has two types of designs, plate or tray, or packed columns. Packed columns are generally used in smaller diameter columns (<0.6 m) and with low-capacity operations. They are less effective in separating alcoholic impurities like fuel oils. A distillation column diameter depends on the feed rate. If the feed rate is doubled, the column area is doubled; the column diameter is proportional to the square root of the feed rate (Kvaalen, 1984). The vapour flow rate increases as the reflux ratio increases. Thus, the required column diameter will also increase when the reflux ratio is increased. In large distillation columns, trays or plates are more economical for alcohol production. In small columns, the cost of fabrication, installation and maintenance of plates may make a packed unit less expensive and more workable. But small columns can use plates as well and once installed, these may give better results. Column design should be done by an experienced column manufacturer. The design considers energy efficiency, cost, and operation to deliver a pre-specified product and functionality (Kvaalen, 1984; Panja, 2023).

Figure 8

Distillation Composite Column Packed Bed and Trays

Note. Project Gaia (2014)

When vapour moves through the stripping and rectifying sections of the column and reaches the top, it should have a concentration of 80–95 per cent alcohol, depending on the column height and the operating conditions used. The concentrated alcohol-water vapour of 80–95 per cent is then condensed to liquid in the condenser by cooling. Roughly two-thirds to three-quarters of the final liquid is returned to the rectifying section of the column as “reflux” (a liquid of high alcohol concentration). It provides a highly volatile source of alcohol vapour to facilitate a high final-product concentration and to condense out some of the remaining water vapour. This reflux is necessary to obtain a concentrated alcohol product. The remaining liquid flowing from the condenser (about one-quarter to one-third of the total) is the finished product. The ratio of the amount of alcohol returned to the column to the amount collected as a product is called the "reflux ratio". This ratio controls both product purity and the amount of energy required for the distillation. The higher the reflux ratio, the purer the alcohol product and the more energy that is required for distillation. When the reflux liquid reaches the bottom of the rectifier, it enters the feed input level and joins the feed in the stripping process (Kyaalen, 1984).

A distillation column can be operated either in continuous or batch mode. The continuous operation consists of a continuous feed input of beer, continuous outflow of "bottoms" (a mixture of condensate water and some beer, in which not all alcohol was removed or distilled), steam input from a boiler or reboiler, and output of highly concentrated alcohol vapour. The alcohol vapour is condensed and piped to the finished product storage tank while the fraction that is refluxed (recirculated) returns to the top of the column to improve the final concentration of the product output. This reflux flow produces a downward-flowing liquid stream in the top section of the column. Without the reflux stream, there would be no liquid in the rectifying section of the column, which means no separation would occur. Once the column is brought into operating balance in continuous mode, the operation should be sustained for several weeks, day and night, to minimize energy losses from start-up and shutdown.

In a batch operation, the column is started, brought to a balanced performance, and operated until the quantity (or batch) of beer on hand is distilled. The column must then be shut down, cooled, and cleaned, ready for start-up for the next batch. A batch system may be the right choice for a small operation with few workers.

1.3. ETHANOL MICRODISTILLERY (EMD)

An EMD is a small unit designed to process starch and sugar feedstocks such as sugarcane, molasses, cassava, sweet potato, corn, rice, sorghum, and cocoa bean juice, as feedstock to produce ethanol. EMDs can be sized to meet different levels of demand, defined in this guidebook as below 5,000 LPD. A typical EMD has a feedstock preparation module, fermentation module, distillation module, control module, boiler, cooling tower, ethanol storage tank and heat exchanger as its main components.

In most production processes, substantial economies of scale are realized with higher plant sizes (U.S. DOE, 1982). However, in the case of on-farm fermentation ethanol production, certain economies of scale are also present for small-scale production (e.g., lower transportation and capital costs), which may balance the economic advantages of large-scale plants (U.S. DOE, 1982). Therefore, small or microscale production of ethanol may be achievable with product costs comparable to those from larger plants.

EMDs have the following significant advantages over large-scale distilleries:

- An EMD has design flexibility to use a variety of feedstocks.
- An EMD can be located next to a feedstock source, reducing handling costs.
- EMD parts can be made locally.
- Wastes from EMD operation (depending on feedstock type) are used as fuel for the boiler, fertilizer, and animal feed.
- EMDs are replicable and scalable.
- EMDs can hire and use unskilled labour.
- The EMD capital investment requirement is reasonable.
- Ethanol produced by such a plant within the community will provide daily cooking fuel to households in small villages.

Most farms in developing countries are remotely located in small communities. A large-scale centralized ethanol plant is not a good option because of increased feedstock delivery costs and logistical and technical difficulties. Therefore, microscale ethanol plants could be a better choice. EMDs are easily replicable since the scale of investment and technical requirements are manageable for small and medium enterprises (SMEs) in these countries.

EMD ethanol provides a sustainable, safe, efficient, and affordable cooking fuel by substituting for fuelwood, charcoal, kerosene, LPG or other cooking fuels. A network of small, integrated ecological distilleries can create a profitable and self-sufficient energy program.

Ethanol fuel produced by EMDs for cooking can result in the following benefits:

- Reduced deforestation and forest degradation.
- Reduced time spent gathering fuel.
- Improved energy efficiency in domestic cooking.
- Reduced cooking times.
- Improved access to a clean, safe, and affordable source of cooking energy.
- Creation of a new market for ethanol.
- Solids from fermentation and distillation can be used as fertilizer and compost.
- Support employment opportunities for both skilled and unskilled labourers.
- Reduction in HAP from the burning of biomass for cooking.
- Reduced GHG emissions.

1.4. EMD INVESTMENT ANALYSIS

The decision to invest in an EMD should be predicated on assurance of continuous and low-cost supply of feedstock to the operation. The potential feedstocks to be utilized for ethanol production should be carefully evaluated before deciding to install the EMD. As the size of the EMD increases, the feedstock will have to be supplied from a larger geographical area. The size of the EMD determines the contours of the feedstock supply zone. A larger supply area will increase the transportation cost and handling times of the feedstock. For ethanol production to be viable, the distillery must be located as close to the feedstock as possible.

The following EMD evaluation and decision-making parameters should be considered carefully.

1.4.1 Feedstocks

Any biological feedstock with reasonable amounts of sugar or starch —or cellulose, in theory— can be used to produce ethanol. The seasonality, availability at competitive prices, production yield per hectare, ethanol yield per tonne of feedstock, and technical viability to produce ethanol are key factors in determining the potential of a feedstock for ethanol production. The size of an EMD is predominantly determined by the availability of feedstock.

Table 1 presents the global average feedstock yield, conversion efficiency and ethanol yield for some typical ethanol feedstocks. It should be noted that a simple comparison of potential ethanol yield per hectare of various crops will not rank the crops in terms of economic value for the production of ethanol. The crops vary considerably in their demands on the soil, demands for water, need for fertilization, susceptibility to disease or insect damage, etc. These factors critically influence the economics of producing a crop. These figures should be used only as indicative figures for initial assessment.

Table 1

Global average feedstock yield, conversion efficiency and ethanol yield for different feedstock types

FEEDSTOCK TYPE	FEEDSTOCK YIELD (TONNES/HECTARE)	CONVERSION EFFICIENCY (LITRES/TONNE)	ETHANOL YIELD (LITRES/HECTARE)
SUGAR BEET	46.0	110	5,060
SUGARCANE	65.0	70	4,550
CASSAVA	12.0	180	2,070
MAIZE	4.9	400	1,960
RICE	4.2	430	1,806
WHEAT	2.8	340	952
SORGHUM	1.3	380	494

Note. FAO (2008)
Note: Sorghum may be cropped several times per year for increased yields.

1.4.2 Water Requirement

A significant amount of water is used in the ethanol production process, about 14 litres of water per litre of ethanol produced. This demand includes requirements for generating steam, cooling, and preparing mashes. If additional irrigation water is necessary for crop production, the increment must be included, but stillage liquids can likely be directly applied to fulfil at least some of these needs. The availability of water to meet the need for ethanol production should be assessed during an initial evaluation of a production site.

1.4.3 Heat Sources

Heat is required to convert feedstocks to ethanol, primarily in heating or cooking mash, producing steam for distillation, and stillage drying. An accurate assessment must be made to determine the type and quantity of available fuels. Waste materials can contribute as heating fuel such as biomass leftover from ethanol feedstocks. In some cases, other renewable sources of energy, such as biogas, solar, wind and geothermal, may be available. Electricity is also needed to run pumps and motors. The energy available to run the operation, for both heat and power, will dictate the type of equipment necessary for the distillery.

1.4.4 Equipment Selection

Determining the best equipment to purchase in order to fulfil the defined production goals will be based on financial capacity, access to loans, the availability and cost of labour and any product compromises that can be made. All of the many decisions that will go into the distillery must be considered as a whole. In general, it can be assumed that the highest quality equipment will cost the most. The most important components should be identified, and investments concentrated there.

The desired feedstock mix will define the feed preparation equipment necessary (e.g., the production of ethanol from cassava requires different front-end processing than sugarcane). Since it may be desirable to process more than one feedstock to bridge seasons, additional equipment may be required for feedstock processing.

The handling of acids and bases requires the choice of resistant construction materials for much of the equipment in the EMD.

1.4.5 Labour Requirements

The availability and cost of labour determine the schedule of plant operations and the degree of automation required.

1.4.6 Investment/Financing

Financing is a major factor in the decision to build. The financing chosen depends initially on capital and operating costs (which are determined by plant size), and on individual financial condition. The potential income from the operation is the second line of consideration.

1.4.7 Maintenance

Equipment maintenance varies according to the equipment and its selection. Non-critical or easily replaceable equipment that is less expensive can be selected. Routine maintenance is important but it should not interfere with production schedules. Availability of skilled maintenance personnel should be considered when equipment is selected.

1.4.8 Regulations

Environmental standards must be reviewed for the project location. EMDs discharge effluents with high Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) that should not be released to the environment without treatment. There is a high likelihood that the authorities will require an Environmental Impact Assessment.

1.4.9 Intended Use of Product

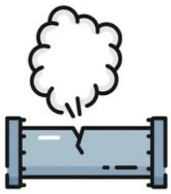
Selected equipment must be capable of producing the quality, quantity and coproducts demanded by the intended market (see Chapter 6, Standards). The properties of ethanol produced by distillation have much to do with how standards are written. Ethanol may need to be denatured to meet legal requirements for customs, the taxing authority or other oversight bodies. Ethanol is susceptible to contamination in the supply chain. Contaminants must be tested for according to the applicable standards. Ethanol cooking fuel tolerates some water content and some impurities and additives, but not other elements, and is different both from beverage ethanol and ethanol for gasoline blending.

1.4.10 Safety and Ethanol Plant Hazards

Ethanol is extremely flammable and must be carefully handled using established safety protocols. Ignition sources must be isolated from all possible ethanol leaks and vapours. This isolation requirement affects both plant layout and equipment selection.

Table 2

Ethanol Plant Hazards

	HAZARDS	PRECAUTIONS
1.	Overpressure/Boiler explosion 	• Regularly maintained/checked safety boiler “pop” valves set to relieve when pressure exceeds the maximum safe pressure of the boiler or delivery lines. • Strict adherence to the boiler manufacturer’s operating procedure. • Continuous operator attendance is required during boiler operation.
2.	Scalding from steam gasket leaks 	• Place baffles around flanges to direct steam jets away from operating areas.
3.	Contact burns from steam lines 	• Insulate all steam delivery lines.

	HAZARDS	PRECAUTIONS
4.	Ignition of ethanol leaks/fumes or grain dust 	• If electric pump motors are used, use fully enclosed explosion-proof motors. • (Option) Use hydraulic pump drives; the main hydraulic pump and reservoir should be physically isolated from ethanol tanks, dehydration section, distillation columns, condenser • Fully ground all equipment to prevent static electricity build-up. • Never smoke or strike matches around ethanol tanks, dehydration sections, distillation columns, and condensers. • Never use metal grinders, cutting torches, welders, etc. around systems or equipment containing ethanol. Flush and vent all vessels before performing any of these operations.
5.	Handling acid/bases 	• Never breathe the fumes of concentrated acids or bases. • Never store concentrated acids in carbon steel containers. • Mix or dilute acids and bases slowly, allowing the heat of mixing to dissipate. • Immediately flush skin exposed to acid or base with plentiful quantities of water. • Wear goggles whenever handling concentrated acids or bases; flush eyes with water and immediately call a physician if any gets in your eyes. • Do not store acids or bases overhead in work or equipment areas. • Do not carry acids or bases in open buckets. • Select proper materials for construction for all acid or base storage containers, delivery aides, valves, etc.
6.	Suffocation 	• Never enter the fermenters, beer well, or stillage tank unless they are properly vented and someone is watching over you.

Note. *U.S. DOE (1982)* ▪


ENERGYPACK

2. ENERGY AND MATERIAL BALANCE

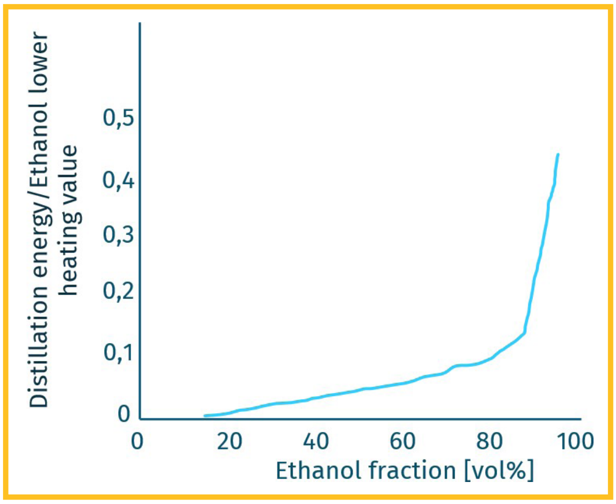
2.1 DISTILLATION ENERGY REQUIREMENT ANALYSIS

Energy is a key parameter in EMD design. The energy input required is proportional to the level of ethanol concentration in the final product. To reach a higher alcohol concentration, the reflux ratio must be increased. Consequently, it takes about twice as much energy to obtain a litre of 95 per cent alcohol (by weight) as it does to obtain a litre of 85 per cent alcohol (Kvaalen, 1984).

For example, the use of an 80 per cent ethanol fuel would require approximately a quarter of the distillation energy required to achieve 96 per cent ethanol. The most obvious disadvantage of decreasing the concentration of ethanol is that the Lower Heating Value (LHV) of the fuel is noticeably reduced. This relationship is shown in Figure 9 (Breaux, 2012).

Figure 9

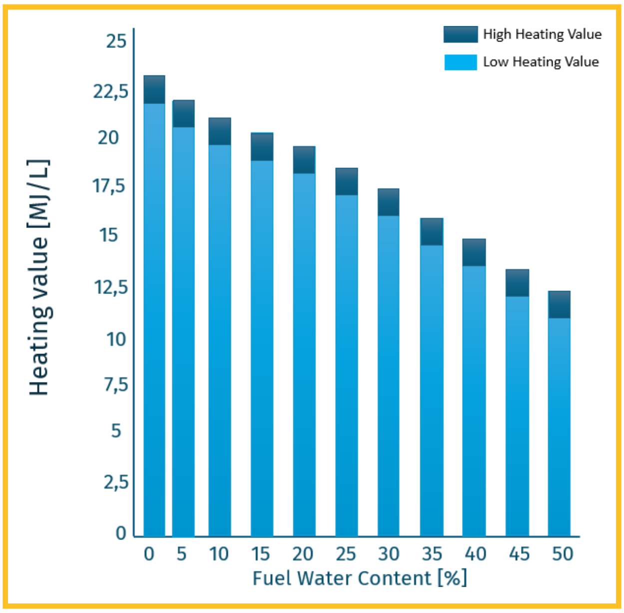
Distillation Energy Required as Function of Purity



Note. Sileghem, et al., (2014)

Figure 10

Effect of Fuel Water Content on Volumetric Heating Value



Note. Breaux (2012)

The removal of most of the water content in fuel-grade bioethanol (ethanol for gasoline blending) has traditionally been considered as essential. Conventional distillation is used for the first part of the dehydration process. As water and ethanol form an azeotropic mixture at 95.63 per cent ethanol —4.37 per cent water by weight— the last water content is removed through an energy-intensive dehydration process. This is done by performing azeotropic distillation. Figure 9 above shows distillation energy as a function of volumetric ethanol fraction. An exponential increase is observed at a concentration of 80 volume per cent ethanol (Sileghem, et al., 2014).

The energy use and column size of an ethanol distillery are affected by the following basic principles:

- Energy usage increases when there is less alcohol in the feed stream (fermented ethanol) or when the product concentration is raised (see Table 3).
- There is a trade-off between energy usage and column height. Columns can be made shorter by using more energy (see Table 4).
- The degree to which the feed is preheated also affects the energy usage. Preheating can be done “for free” by using the feed as a cooling fluid in the condenser (see Table 5).

The tables below present the energy balance (ratio) for a 90 per cent weight by weight (w/w) (92 per cent volume per volume, v/v) ethanol concentration, 0.4 per cent ethanol in the stillage and varying ethanol concentrations in the feed (from fermentation). The estimations are done by varying feed-in alcohol concentration (1 to 12 per cent) while keeping the same product concentration (90 per cent), achieved by increasing the reflux ratio for lower feed-in concentrations. The energy ratio is calculated based on LHV of 90 per cent ethanol. The estimations are based on a packed column using plastic Intalox saddles for packing and 190 litres per hour feed. The result shows more energy is consumed than gained to produce a 90 per cent ethanol product from a 1 per cent concentration feed. As the feed-in concentration increases the energy consumption becomes less and less and at 12 per cent feed-in concentration, there is more than a seven-fold energy gain. The results help in analysing various feedstocks that achieve differing alcohol yields from fermentation.

Table 3

Energy Ratio for a Varying Feed Alcohol Concentration

BEER FEED (WEIGHT PER CENT)	REFLUX RATIO	RECTIFYING COLUMN STAGES	STRIPPING COLUMN STAGES	ENERGY USE (KJ/KG)	ENERGY RATIO IN/OUT
1	33.9	7	2	35,588	1.5
2	16.1	7	3	17,468	0.73
3	10.1	7	4	11,328	0.47
4	7.1	7	5	8,327	0.35
5	5.4	7	6	6,536	0.27
6	4.6	7	6	5,722	0.24
8	3.5	8	5	4,606	0.19
9	3	8	6	4,094	0.17
10	2.7	8	6	3,791	0.16
11	2.5	8	6	3,582	0.15
12	2.3	8	6	3,373	0.14

Note: product = 90 per cent, bottoms = 0.4 per cent
Note. Kvaalen (1984)

The reflux ratio is the ratio of liquid condensate returned as reflux to liquid condensate kept as a product. The lower the feed concentration, the higher the reflux ratio will be, with higher energy consumption, to keep the same product concentration.

It is desirable to lower the stillage concentration as much as possible to be efficient. A 0.4 per cent ethanol content in the stillage and an 8 per cent ethanol content in the feed results in a 5 per cent overall ethanol loss (if the feed is only 4–6 per cent ethanol concentration, the loss ratio will be much higher). But to lower stillage concentration, more energy will be consumed. The design must balance these two percentages.

Table 4 shows the amount of energy needed for varying alcohol concentration in the product while keeping the feed concentration at 8 per cent and the stillage at 0.4 per cent.

Table 4

Varying the Distillate Concentration

ALCOHOL PRODUCT (WEIGHT PER CENT)	REFLUX RATIO	RECTIFYING COLUMN STAGES	STRIPPING COLUMN STAGES	ENERGY USE (KJ/KG)	COLUMN DIAMETER (CM)	ENERGY RATIO IN/OUT
50	0.2	2	11	1,886	12.4	0.15
50	4	2	6	2,200	13.5	0.18
60	0.7	2	10	2,442	13.0	0.16
60	1	2	6	2,861	14.0	0.19
70	1.2	3	10	2,861	13.0	0.16
70	1.5	3	6	3,233	13.7	0.18
80	1.8	4	12	3,256	12.7	0.15
80	2.2	4	7	3,698	13.7	0.18
85	2.3	5	9	3,605	13.2	0.16
85	2.7	5	6	4,024	14.0	0.18
90	2.6	9	11	3,675	13.0	0.15
90	3	8	7	4,094	13.5	0.17
90	3.5	8	5	4,606	14.5	0.19
93	3	18	10	3,931	13.0	0.16
93	4	14	6	4,908	14.5	0.2
93	5	13	4	5,885	16.0	0.24
95	5.5	67	4	6,187	16.3	0.24
95	6	53	3	6,676	16.8	0.26
95	7	41	3	7,629	18.0	0.3
95	8	36	3	8,583	19.1	0.34
95.5	8.5	90	3	8,978	19.6	0.35
95.5	12	57	3	12,305	22.9	0.48

Note: feed = 8 per cent, bottoms = 0.4 per cent
Note. Kvaalen (1984)

The energy gained by burning the product is higher for higher product concentration while at the same time, more energy is consumed to achieve higher product concentration. As a result, the energy-in to energy-out ratio is rather constant up to about 93 per cent product concentration. After this point, the process becomes energy intensive (as it gets close to the azeotrope point, 95.6 per cent), which makes the ratio increase dramatically. It takes about twice as much energy to get a litre of 95 per cent alcohol (by weight) as it does to get a litre of 85 per cent alcohol (Kvaalen, 1984).

Table 5 presents the effect of varying the alcohol concentration in the stillage while keeping the feed concentration at 8 per cent and the product at 90 per cent. The reflux ratio is kept constant, and the same product is produced by varying distillation stages. More stages are needed in the bottom section (the stripping section) to get less alcohol in the bottoms. The higher the stillage alcohol concentration, the higher the loss of ethanol. However, the energy ratio remains the same, implying that keeping the alcohol lower at the bottom means less demand for raw materials.

Table 5

Varying Bottoms Concentration

ALCOHOL BOTTOMS CONCEN-TRATION (WEIGHT PER CENT)	ALCOHOL LOSS (WEIGHT PER CENT)	REFLUX RATIO	RECTI-FYING COLUMN STAGES	STRIPPING COLUMN STAGES	ENERGY USE (KJ/KG)	COLUMN DIAMETER (CM)	ENERGY RATIO IN/OUT
3	35.3	3	8	3	4,094	11.2	0.17
2	23.3	3	8	3	4,094	12.2	0.17
1	11.5	3	8	5	4,094	13.0	0.17
0.5	5.7	3	8	7	4,094	13.5	0.17
0.5	5.7	5	7	3	6,141	16.5	0.26
0.2	2.3	3	8	9	4,094	13.7	0.17
0.2	2.3	5	7	5	6,141	16.8	0.26
0.1	1.1	3	8	12	4,094	13.7	0.17

Note: feed = 8 per cent, product = 90
Note. Kvaalen (1984)

In Table 6, the reflux ratio is varied while bottoms, feed and product are kept the same. To achieve this, the distillation stages and column diameter must be varied, affecting the energy ratio.

Table 6

Varying Reflux Ratio

REFLUX RATIO	RECTIFYING COLUMN STAGES	STRIPPING COLUMN STAGES	ENERGY USE (KJ/KG)	COLUMN DIAMETER (CM)	ENERGY RATIO IN/ OUT
2.5	10	16	3,582	12.7	0.15
3	8	7	4,094	13.5	0.17
3.5	8	5	4,606	14.5	0.19
4	7	5	5,117	15.2	0.21
5	7	4	6,117	16.5	0.26
6	7	3	7,141	18.0	0.3
8	6	3	9,188	20.3	0.38
10	6	3	11,235	22.6	0.47

Note: bottoms = 0.4 per cent, feed = 8 per cent, product = 90 per cent
Note. Kvaalen (1984)

The trade-off is between energy usage and column length. The same product can be made by using a small reflux ratio (low energy) and a column of 26 total stages, or with a high reflux ratio (high energy) and only nine column stages. Preheating the feed helps in reducing energy consumption. Small changes in the temperature of the feed can cause rather large changes in the reflux ratio needed, and hence in the energy cost. The stillage can be used to preheat the feed using a heat exchanger.

2.2 ENERGY AND MATERIAL BALANCE: BATCH VERSUS CONTINUOUS PRODUCTION

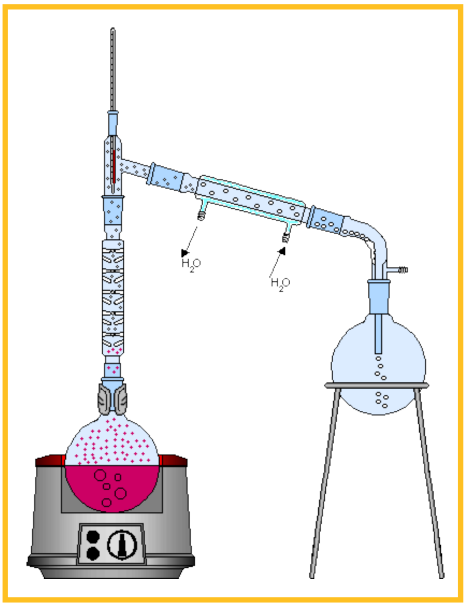
Energy balance is the relationship between the energy used to produce one litre of ethanol and the amount of energy produced by each litre of ethanol. Ideally, a continuous process is the preferred ethanol production technique for energy and operational efficiency. However, a continuous process is not always an option due to technical constraints so a batch process can be used. Batch (pot-type) and continuous (column) distillation processes are discussed below.

Fermented alcohol distillation can be done by a pot-type distillation entirely to produce a high ethanol concentration (95 per cent v/v) product. However, running an entirely pot-type distillation process is not an option since the energy requirement is huge (about three times what is needed in continuous distillation).

A pot-type distillation is a simple process. The entire batch of fermented juice is heated to boiling in a large container. The high alcohol-water mixture vaporizes and condenses in a container. This option has the advantage of simplicity and low capital cost requirements, making it an executable operation in rural communities.

Figure 11

Pot-type Distillation



Note. Unesp (n.d.)

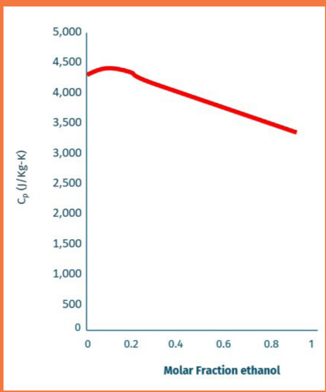
Figure 12

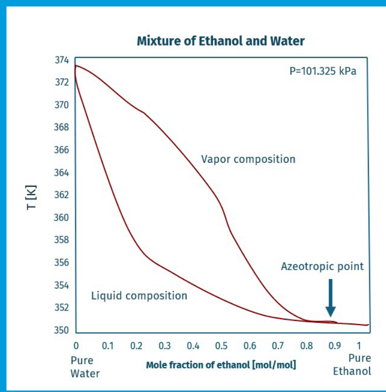
Energy Requirement of a Pot-Type Distillation Unit (42 per cent product)

Total heat required to vaporize is the sum of sensible heat (heat change) and latent heat (vaporization). The equation for the sensible heat (energy to undergo a heat change, heat required to bring the mixture up to its boiling temperature) is calculated by the equation below.

$$Q = mc\Delta T$$

Where: $Q = Quantity\ of\ heat, = Mass\ undergoing\ a\ temperature\ change, = Specific\ heat$ capacity $of\ the$ mixture $\Delta T = Temperature\ final - Temperature\ initial$





Mole fraction for 8 per cent v/v ethanol in a water: (Molecular weight of ethanol = 46.07 g/mol Molecular weight of water = 18 g/mol)
Moles of ethanol = 0.789 g/cm³ x 1,000 cm³ x 0.08/ 46.07 grams = 1.37 moles
Moles of water = 1 g/cm³ x 1,000 cm³ x 0.92/ 18 grams = 51.11 moles
Mole fraction = moles of component/total moles in solution = 1.37/(1.37 + 51.11) = 0.026 → $C_P \approx$ 4,200 J/kg-K

$Q = mc\Delta T$, m = water + ethanol = 0.92 kg + (0.08 * 0.789) = 0.983 kg

ΔT = T_f - T_i (T_i, initial temperature estimated to be 298 K and T_f is the final temperature, 368 K from the above figure) = 368 K – 298 K = 70 K

Q = 0.983 kg x 4,200 J/kg-K x 70 K = 289 KJ (total sensible heat required per litre of fermented feed)

Latent heat (energy required to vaporize following the temperature change) is calculated as follows:

$$Q = mLv$$

Where: Q is quantity of heat, $m = mass\ undergoing\ a\ phase\ change, = Latent\ heat\ coefficient$)

Product alcohol concentration is expected to be 42% w/w (Spaho, 2017). Assuming 95% of the alcohol is captured
= 0.95 * 0.08 lit = 0.076 lit = 0.076 lit x 0.789 kg/lit = 0.06 kg (alcohol in the product, 42%) 0.42 m = 0.06 kg → m = 0.14 kg
Lv Water = 2,256 KJ/kg → Q for Water = 187 KJ Lv Ethanol = 854 kJ/kg → Q for Ethanol = 51.2 KJ

Total latent heat of vaporization = 238.2 KJ

2.3 CONTINUOUS-FEED DISTILLATION COLUMN

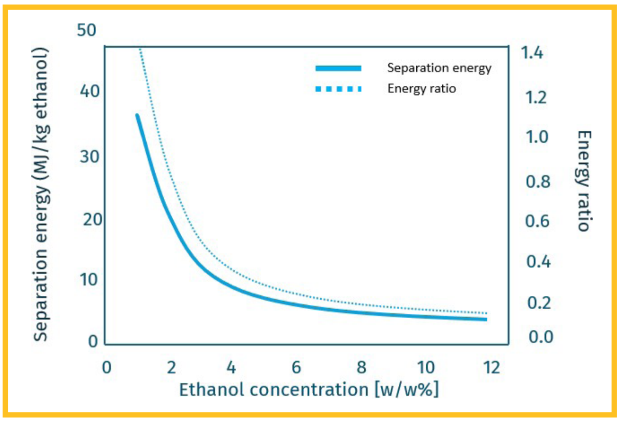
As discussed in the previous sections, concentrating ethanol further from 90 per cent w/w (92 per cent v/v) becomes a highly energy-intensive process. The use of product ethanol as cooking fuel works well with an ethanol of 92 per cent v/v. However, if ethanol is desired to be used as a gasoline blend, it needs to be distilled to above 99 per cent which can be challenging for micro-scale distilleries to be energy efficient. Using hydrous ethanol directly as fuel would imply a substantial economic advantage over and above 95 per cent concentrated ethanol. The relationship between energy in the product and ethanol concentration in the product is expressed by the following equation (Equation 1.2).

LHV (MJ/kg) = 435.22 * (% alcohol in volume) – 16,875 (Martins, 2016)

Figure 13 shows the exponentially increasing energy requirement to dehydrate the last water remaining in ethanol.

Figure 13

Energy Ratio for Varying Ethanol Concentrations



Note. Huang (2011)

2.3.1 EMD Energy and Feedstock Requirements

The steam requirement of modern column distillation for EMDs is 3 to 4 kg of steam per litre of ethanol (95 per cent v/v) produced.

Producing 1 kg of saturated steam at a pressure of 1 bar (boiling point 100°C) requires the following energy:

Heating fresh water (assume 25°C) to boiling point of 100°C $Q = mCp\Delta T$ = 1 kg x 4.2 kJ/kg.K x (100- 25) K = 0.315 MJ

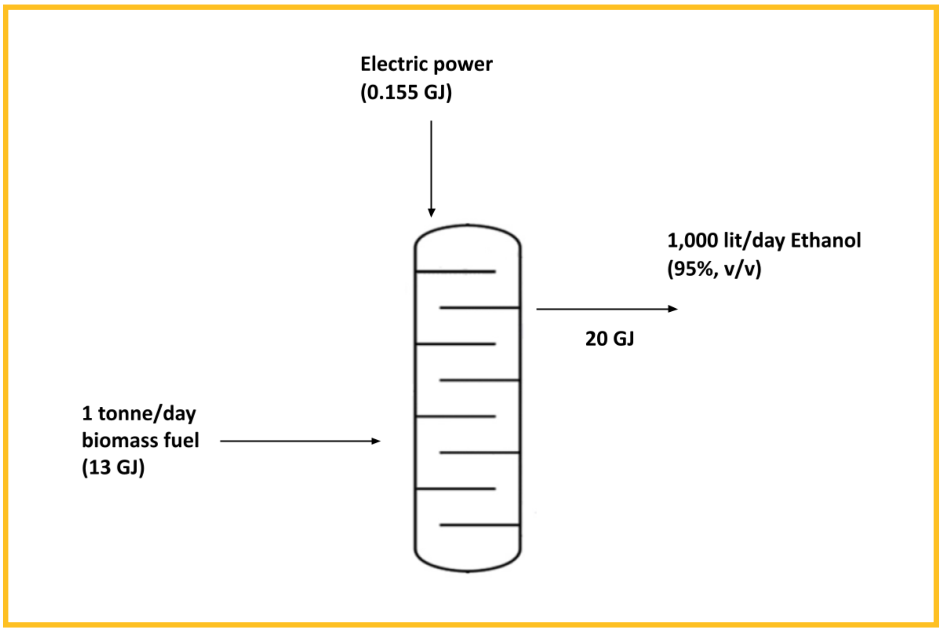
Evaporating water to steam at 1 bar $Q = m\Delta hv$ = 1 kg x 2,260 KJ/kg = 2.26 MJ

Total energy input required to produce 1 kg steam = 2.56 MJ

Steam boilers have an efficiency of 80–88 per cent. Here an efficiency of 80 per cent is assumed for our energy requirement calculation. It is thus implied that 3.2 MJ/kg of steam (2.56 MJ/0.80) is required to be delivered to the boiler. Assuming biomass fuel use (13 MJ/kg) in the boiler, 0.25 kg of biomass fuel must be burned to produce 1 kg of steam. The biomass fuel requirement to produce a litre of ethanol becomes 0.75 to 1 kg (3 to 4 kg steam per litre of ethanol).

Figure 14

Simplified Energy Balance of a Column Distillation Based on a 1,000 litres/day EMD, an 8 per cent v/v Ethanol Yield



Note. Project Gaia (2014)

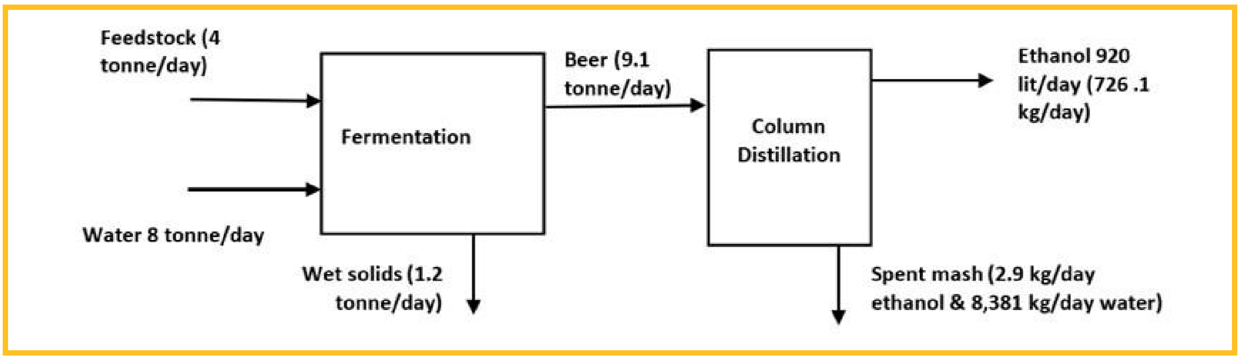
Production of ethanol (95 per cent, v/v) using column distillation results in a 0.65 energy ratio showing energy return. The ratio lowers to 0.50 if the steam requirement is 3 kg/litre of ethanol signifying the energy return. Energy requirements, next to feedstock cost, determine a significant part of the total ethanol production cost.

The quantity of feedstock required to produce a litre of ethanol is dependent on the fermentable sugar in the feedstock. For example, if the feedstock results in an 8 per cent ethanol yield from fermentation,

12.5 litres of fermented beer are required to produce a litre of ethanol.

Figure 15

Simplified Material Balance for Ethanol Production Based on a 1,000 litres/day EMD and Molasses Feedstock (8% v/v Ethanol Yield)



Note. Project Gaia (2014) ▪

3. ETHANOL FEEDSTOCKS

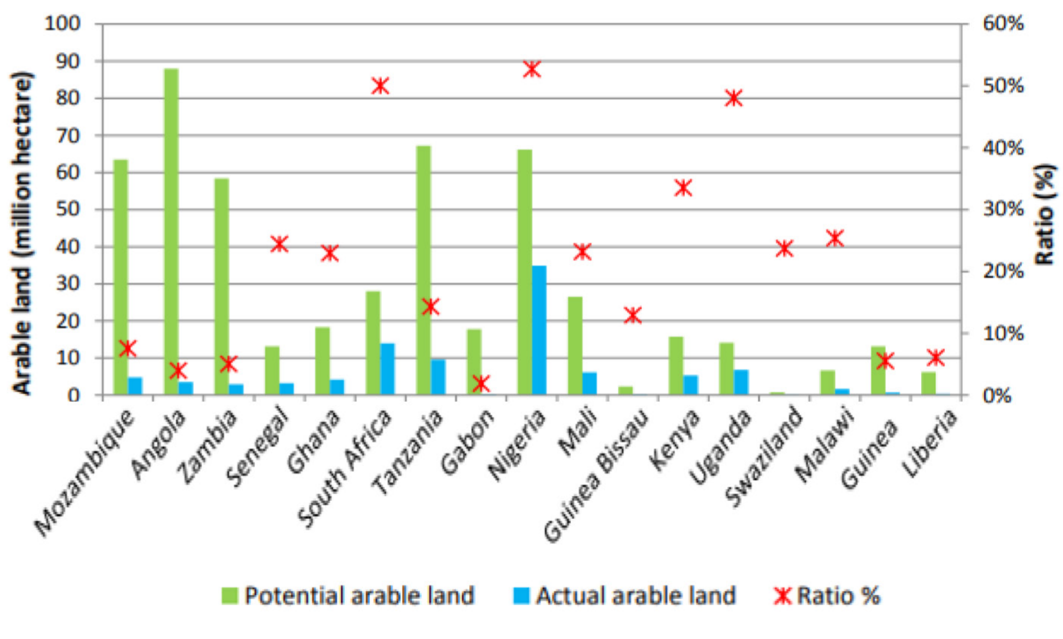
Bio-ethanol production is accomplished by yeast through fermentation of six-carbon sugar units (principally glucose). All crops and crop residues contain six-carbon sugars or compounds of these sugars. Thus, any biological feedstock with reasonable amounts of sugar, starch, or cellulose can be used to produce ethanol. Bioethanol production through fermentation of sugars extracted from sugar-rich crops (such as sugarcane and sugar beet) and starchy crops (such as maize and cassava) is a technically mature, commercially successful process. The technology to produce bioethanol from sugary and starchy crops is known as "first generation". Ethanol can also be produced from lignocellulosic materials such as cassava peels and corn cobs. Ethanol production from lignocellulose materials is referred to as "second generation." However, "second generation" ethanol production from lignocellulosic materials is relatively costly, due to the low yield and high cost of the hydrolysis process required to unlock the sugars (Wi et al. 2015). Efforts are being made to lower the cost through the pretreatment of lignocellulosic materials to remove lignin and hemicellulose and optimize the cellulase enzymes (Wi et al. 2015).

Feedstocks such as sugarcane, sugar by-product molasses and fruit wastes are considered the "low- hanging fruit" for ethanol production. For sugar-rich crops, the feedstock's juice is extracted via crushing, and then yeast is added for fermentation to occur. Starch crops such as maize and sorghum undergo several preprocessing steps before being considered fermentable for ethanol production. The conversion of starchy crops into fermentable sugar starts with milling, liquefaction, and enzyme-based saccharification. Then fermentation occurs where yeast metabolically converts these sugars into ethanol, and ultimately the end-product is separated and purified from other by-products by distillation.

Although energy security concerns have pushed some developed economies toward the adoption of liquid biofuels, there is a long-standing debate about whether edible or first-generation biological feedstocks are better used for food rather than a source of fuel. High food prices limit biofuel production since the food market is generally a more attractive option for farmers (Ohimain, 2013). In regions with ample arable land, there may be a positive correlation between biofuel investments and food production. An analysis carried out in Brazil (Gauder, Graeff-Hönninger, and Claupein, 2011) shows no conflict between food and energy production. Nasidi et al. (2010) and Reddy et al. (2008) argue that such investments in the countryside result in increased agricultural productivity and improved production of food in parallel with agro-energy. Nevertheless, the food versus fuel issue must be adequately and seriously considered in every developing country's biofuel project. An analysis of biofuel-related sustainability issues for developing countries (Amigun, Sigamoney, and Von Blottnitz, 2008) advocates for the exploitation of "low-hanging fruits" but with cautious analysis to avoid conflict with food production. Undernourishment exists in most developing countries, but this is primarily a result of poverty rather than a general deficit in arable land.

Figure 16

Ratio between Actual Arable Land and Potential Arable Land in Sub-Saharan Africa



Note. IRENA (2016)

Some developed countries have concerns about food security and prevent biofuel deployment. However, such restraints could reduce job opportunities in rural areas and limit the income of farmers in poverty-affected areas (IRENA, 2016). Food security issues can be directly resolved by increasing investment in public assets, crop breeding research and infrastructure for more intensive food production at lower costs (IRENA, 2016). New approaches such as Integrated Food Energy Systems (IFES) are expected to address food security issues by simultaneously producing food and energy as a way to address the energy component of sustainable crop intensification through an ecosystem approach (Bogdanski et al., 2010).

The following sections discuss potential feedstocks for ethanol production in developing countries. The discussion here provides only an insight into potential feedstock. However, each potential feedstock in each country should be evaluated further in detail to determine its viability in social, economic, and environmental dimensions.

3.1 SUGARCANE AND MOLASSES

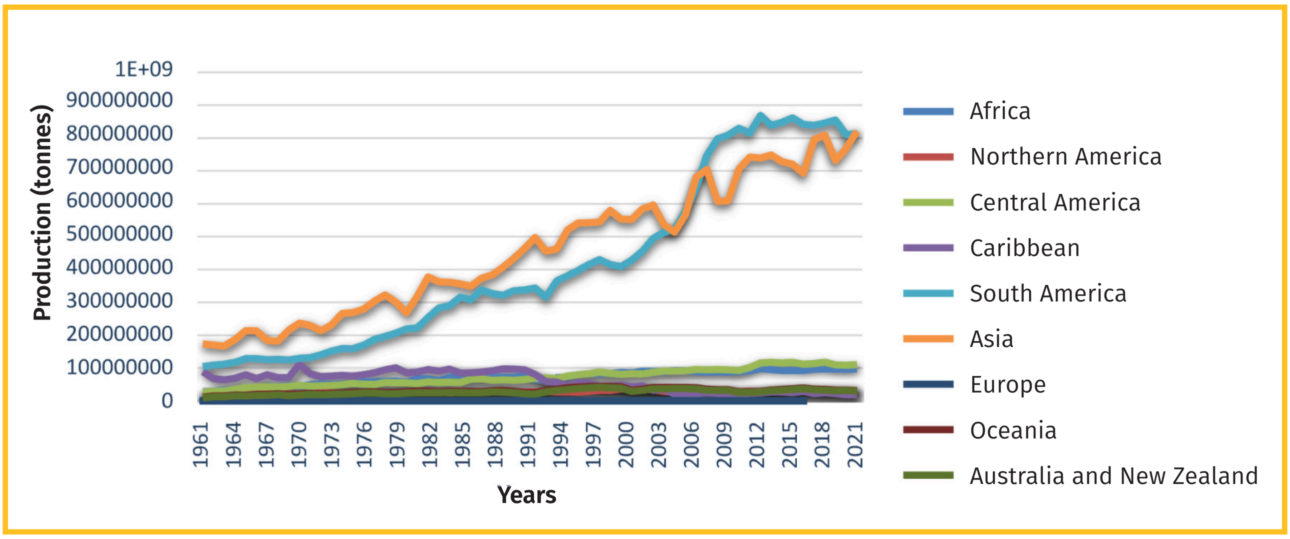
Sugarcane is one of the essential food and energy crops widely cultivated globally and the most viable feedstock for ethanol production in developing countries, whether used directly or indirectly (i.e., using molasses after sugar production). Sugarcane is a tall-growing plant that is cultivated in tropical and subtropical regions. It is known primarily for its ability to store high concentrations of sucrose, or sugar, in the internodes of the stem.

According to the Food and Agriculture Organization of the United Nations (FAO), the world production of sugarcane in the 1950s was approximately 260 million tonnes, cultivated on about 6.3 million hectares (Fischer et al., 2009). In 2020, the global sugarcane production was 1.9 billion tonnes, grown on 26.5 million hectares (FAO, 2022). The data shows the global harvest of sugarcane increased more than sevenfold from 1950 to 2020, while the harvested area increased 4.15 times. During the same period, the average global yield increased from 41.4 tonnes per hectare in 1950 to 72.5 tonnes per hectare in 2018, down slightly to 70.6 tonnes per hectare in 2020.

About 80 per cent of the world's sugarcane production is concentrated in 10 countries, with Brazil and India accounting for over half the global output. On average, sugarcane production cycles range over six years with five harvests (Florentino, 2015). The productive process of sugarcane begins with preparing the land and the selection of the variety of sugarcane to be planted. The process then involves planting, development, ripening and harvesting. The sugarcane regrows (ratoons) and follows the cycle again and can be regrown up to five times (Florentino, 2015). Then replanting takes place, and all steps are repeated. As ratooning approaches the fifth cycle, the crop suffers progressively in biomass production, sucrose content and fibre. Thus, replanting becomes necessary. Considerable investment has been made to reduce the cost of cultivating sugarcane and to improve sugarcane output without affecting environmental sustainability. Key elements include appropriate management, choice of the optimal variety to be planted, soil preparation and relevant planting and harvesting dates (Hess et al., 2016).

Figure 17

Global Sugarcane Production in Tonnes from 1961-2018, by Broad Geographic Region



Note. FAOSTAT (2022)

Sugarcane must be processed within 48 hours after harvesting to produce ethanol, otherwise, sugar yields will decrease significantly. Sugarcane is also a bulky crop, which increases transport costs. Therefore, sugarcane should be grown close to the bioethanol plant.

A sugar mill used for crushing the raw sugarcane stalks produces considerable volumes of a pulpy left-over product called bagasse. This bagasse, made up of lignocellulosic materials, is often used in a furnace in the plant to produce heat for steam. It is increasingly used in Combined Heat and Power (CHP) plants to produce electricity supplied to the grid. As a result, electricity is produced without producing GHG emissions (Sven et al., 2008). High oil prices can pave the way for developing countries to increase ethanol production, but efficient production of sugarcane is essential to this.

Most developing countries do not fully utilize the molasses from their existing sugar industry to produce ethanol and in some cases do not utilize the molasses at all. Taking this a step further, many developing countries do not produce enough sugar to meet their domestic needs, despite the clear potential to do so from their sugarcane production. However, many countries do have a plan, as part of their agricultural policy, to become self-sufficient in sugar production.

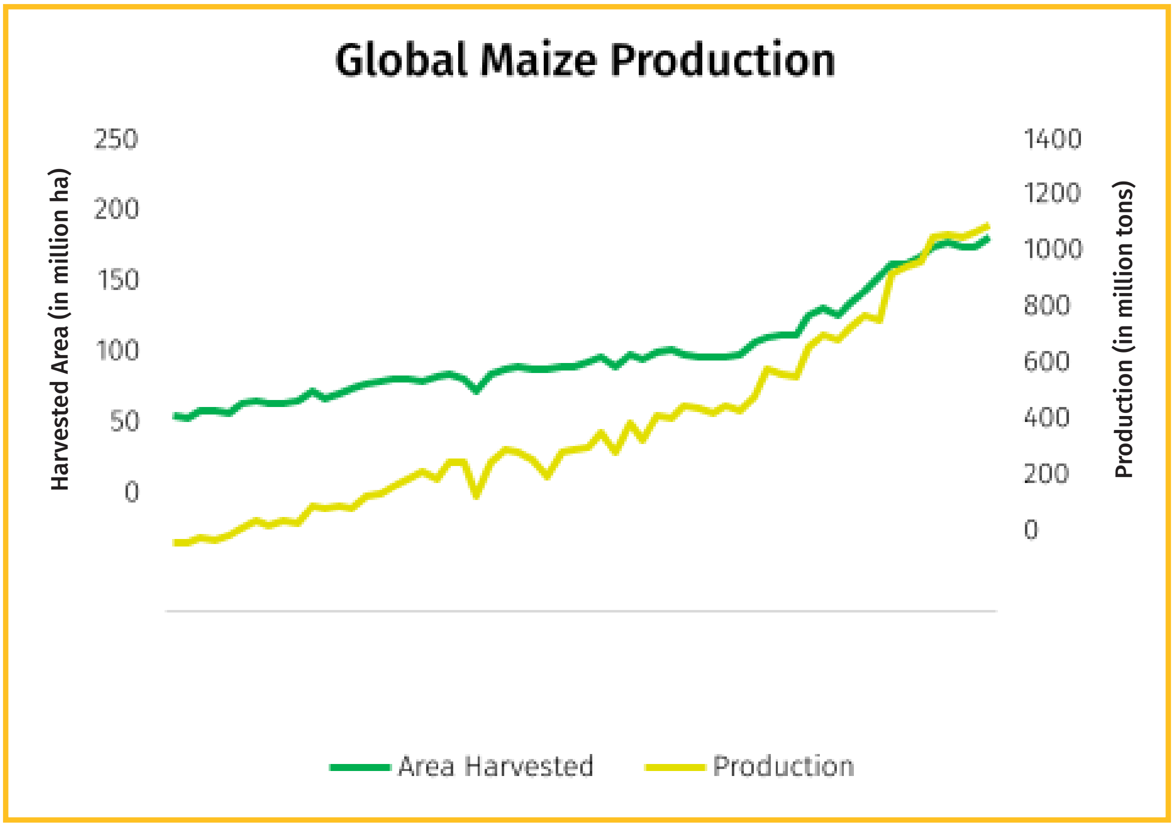
3.2 MAIZE

Maize is one of the most widely cultivated cereal grain crops globally and serves as food, feed, fuel, and a source of fibre. It is a tall annual diploid plant with 10 chromosomes that belong to the grass family, including rice, wheat, millet and sorghum. Maize is a highly photosyntheticefficient C4 grass* and has the widest cultivated geographical range of all crop plants. The grain consists of a large endosperm, 82–83 per cent of the grain (Arendt and Zannini, 2013). The pericarp and the outermost layer are characterized by high crude fibre content, mainly hemicellulose, cellulose and lignin (Singh, Singh, and Shevkani, 2011). Archaeological evidence shows maize in the Balsas River valley of Mexico around 8,700 years ago. Following the European discovery of the Americas, maize was taken to Europe, Africa and Asia. The first historical record showing the European introduction of maize is from Christopher Columbus in 1493 (Arendt and Zannini, 2013). Historical evidence shows maize spread across the African continent after its introduction in the mid-17th century and rapidly became one of Africa's popular food crops (Cherniwchan and Moreno-Cruz, 2019). Maize provides some 30 per cent of the food calories of more than 4.5 billion people in 94 developing countries and contributes over 20 per cent of total calories in human diets in 21 low-income countries. Of 22 countries where maize forms the highest percentage of calorie intake in the national diet, 16 are in Africa. Maize's critical role as a staple food in Sub-Saharan Africa is similar to the role of rice or wheat in Asia (Maize AFS Phase-II, 2016).

** Certain plants use what is known as the C4 pathway to fix CO_2 at higher rates, increasing the rate of photosynthesis and thus growth of the plant. C4 photosynthesis can function at higher temperatures.*

Figure 18

Global Maize Production



Note. FAOSTAT (2022)

Global maize production reached 1.2 billion tonnes in 2020 (FAO, 2022). Maize is cultivated on 24 per cent of farmland in Africa, with an average yield of around 2 tonnes/hectare/year (IITA, 2020). Nigeria is the largest African producer of maize, with over 10 million tonnes, followed by South Africa and Egypt. Global maize production has multiplied close to six-fold since 1961, from 200 million MT to 1.2 billion MT in 2020 (FAO, 2022). The rise in production is achieved mainly due to investment in maize breeding programs to develop improved maize varieties, expand areas from 100 million hectares to 201 million hectares, and access farmers' machinery (FAO, 2022).

The increasing need for food crops such as maize to meet the growing population has made the traditional bush-fallow system less productive and too short for restoring soil fertility in developing countries. Shortening fallow periods lead to the mining of soil nutrients, including severe and partly irreversible soil degradation. The rapidly declining crop yields and soil fertility impairment are the repercussions smallholder farmers face while producing their crops on increasingly scarce land. Lose et al. studied the impact of agroforestry treatments and fertilizer application on the root development of the cassava-based cropping system in Southern Benin. The study found that intercropping of maize and cassava reduces the cassava's root length density. Inorganic fertilizer application increases the yield compared to a site with no fertilizer mulch treatment (Lose et al., 2003).

3.3 CASSAVA

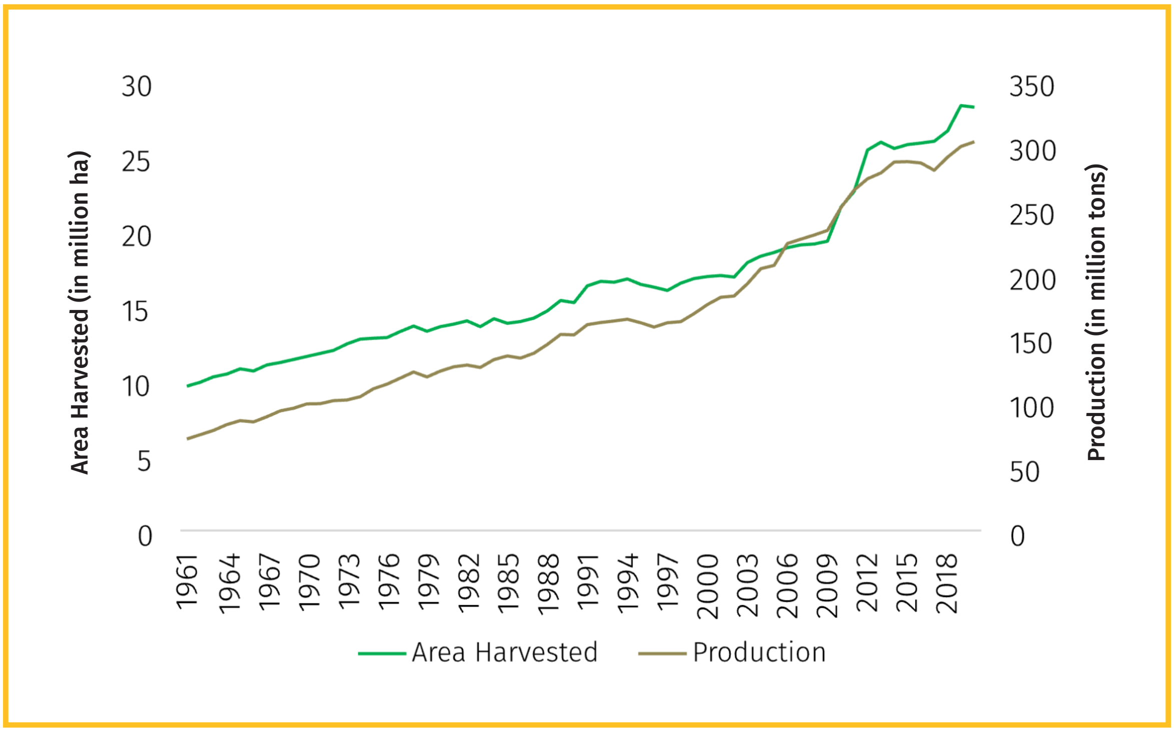
Cassava is a shrub belonging to the family of Euphorbiaceae that originated in South America. The plant's roots have an average length of 5-10 cm, and a diameter of 15-35 cm. Cassava requires an annual rainfall of approximately 760-1,015 mm and grows well in tropical and subtropical regions (Ray et al., 2019). Cassava is a climate-resilient crop with exceptional drought tolerance because of its unique ability to utilize nutrients from both its stalks and storage roots (Patil, 2020). Cassava production depends on the quality of the stem. The multiplication rate of planting materials is lower than grain crops, propagated by the right seeds. Also, cassava stem cuttings are bulky and highly perishable as they dry up within a few days (Kristensen et al., 2014).

Cassava is a crucial food security crop for smallholders and marginal farmers in developing countries. It serves as a staple food for more than one billion people in the tropical region (Patil, 2020). According to FAOSTAT, the world's cassava production reached 303 million tonnes in 2020; 28.2 million hectares are being harvested mainly in Africa, Asia and Latin America (FAO, 2022). In SSA, the rapid, ubiquitous adoption of cassava was described as an innovation after the Portuguese traders introduced the crop from Brazil in the 16th century and adopted a more reliable staple food during drought, locust attack, and famine season (Nweke, 2005). Currently, cassava is Africa's most important non-cereal food in terms of per capita calorie consumption. The crop is consumed daily, and, in some countries, cassava contributes more than 1,000 calories per day to the average diet of a typical household. It is estimated that 37 per cent of food consumption in SSA comes from cassava, and the Democratic Republic of Congo is the largest consumer of cassava in the continent, followed by Nigeria (IITA, 2020). A study also shows that cassava production is expanding in SSA. The crop is replacing other root crops, especially yam in the humid zone, maize in the non-humid area, and other food crops in the sub-humid region (Dunstan & Ezedinma, 2017).

Cassava is a well-established crop with a continuous supply of new varieties for various purposes. The plant is very versatile, and its derivatives are applicable to many types of products, such as food, confectionery, sweeteners, glues, plywood, textiles, paper, biodegradable products, and drugs (IITA, 2020). The crop has several advantages over rice, maize, and other grains as a food staple in regions with a declining resource base, uncertain rainfall, and weak market infrastructure. It is the most suitable crop during a famine (Adekunle et al., 2016). Cassava is processed into various products for human and industrial needs, ranging from simple cooking to alcoholic beverages. Most of the products are consumed locally in the countries in which they are produced. However, there is a growing export trade in dried cassava chips and other industrial products.

Figure 19

Global Cassava Production



Note. FAOSTAT (2022)

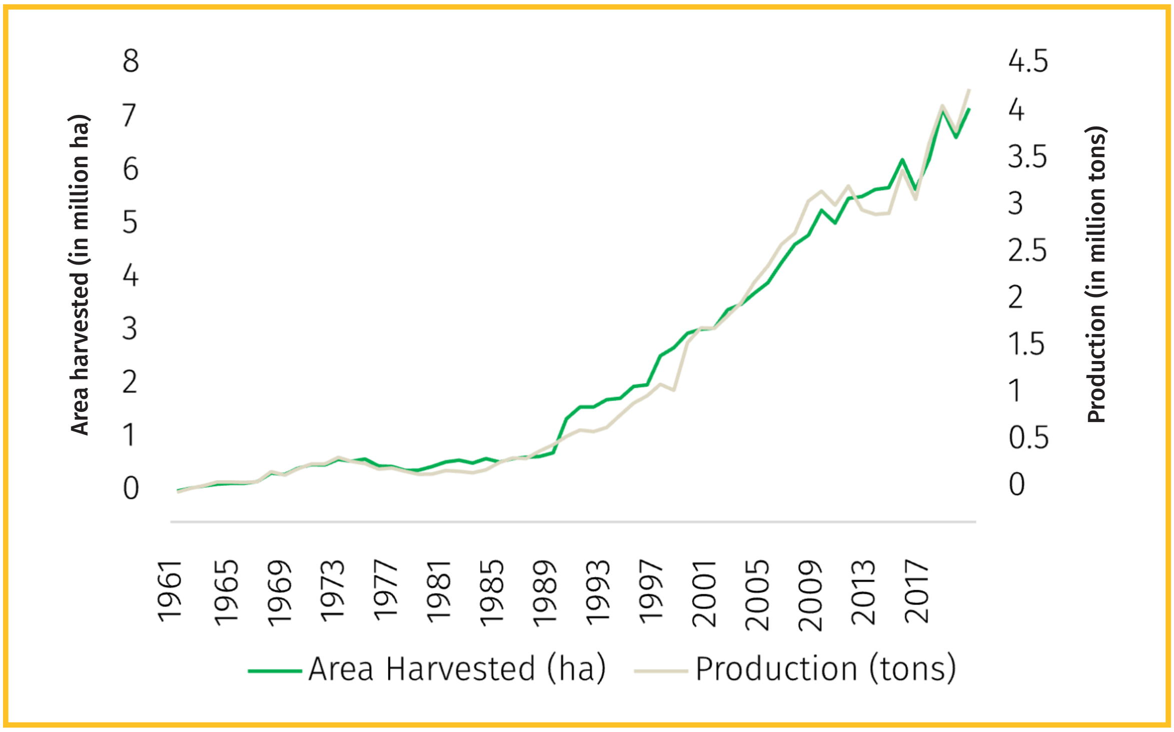
Global cassava production has increased more than four-fold since 1961, from 71 to 303 million MT as of 2020, due to an increase in area cultivated (from 9.6 million to 28.2 million ha) and a small increase in average yield (from 0.74 to 1.07 mt/ha) (FAOSTAT, 2022). In countries such as Thailand and China, cassava ethanol is a relatively developed concept, and the technology receives attention worldwide, not least because of its potential in developing countries (Amatayakul & Berndes, 2007). Cassava as feedstock has the advantage that the root can remain in the ground for months without deterioration, allowing for flexibility to have a continuous harvest. Cassava is preferably processed into ethanol within two to three days after harvest, which means the cassava can be grown within one to two days of travel time from the ethanol plant. The cassava roots are not as voluminous as sugarcane and sorghum stalks, which makes them more affordable to transport.

3.4 CASHEW

Cashew (Anacardium occidentale) is a shrub or tree of the sumac family. It is cultivated for its characteristically curved edible seeds, which are commonly called cashew nuts. Cashew is a drought-resistant evergreen perennial small tree with dense foliage that can grow to 12 meters (40 feet) in height where the soil is fertile and the humidity high. The cashew apple, an accessory fruit, is reddish or yellow. Cashew apples are picked by hand or allowed to drop and then gathered. The nut is detached from the apple and sun-dried. The cashew apples begin to deteriorate within 24 hours so need to be processed promptly.

Figure 20

Global Cashew Nuts Production



Note. FAOSTAT (2023)

Recent archaeological data from 47-million-year-old lake sediment in Germany have shown the earlier distribution of cashews in Europe during the Tertiary period, suggesting a bio-geographic link between the cashew supply in America and the one in Africa (Aliyu, 2012). According to the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT), the global production of cashew nuts with shells reached 4.2 million tonnes in 2020, cultivated on 7.1 million hectares (FAO, 2022). Over 2.5 million farmers in Africa currently cultivate about 57 per cent of the global cashews. The cashew sector in Africa has become a highly visible contributor to African exports during the last ten years as smallholder farmers on the continent have more than doubled their production. In 2015, 1.6 million tonnes of raw cashew nut (RCN) were harvested, making the continent the world's largest producer of RCN (African Cashew Alliance, 2020).

Large-scale production using automatic equipment is an advantage held by leading cashew nuts processors in Vietnam, India, and Brazil. Machines for shelling cashew nuts are currently limited and there is a high dependency on manual (hand or pedal-operated) shelling machines. Forty kilograms of nuts can be shelled using the manual method while processing with automatic machines can process over 100 kg per hour. While processing in Africa remains low, it is on the rise, growing from 35,000 MT in 2006 to 105,700 MT in 2015. It is estimated that a 25 per cent increase in RCN processing in Africa would generate more than $100 million in household income, improving the lives of many families in rural areas (African Cashew Alliance, 2020).

3.5 SORGHUM

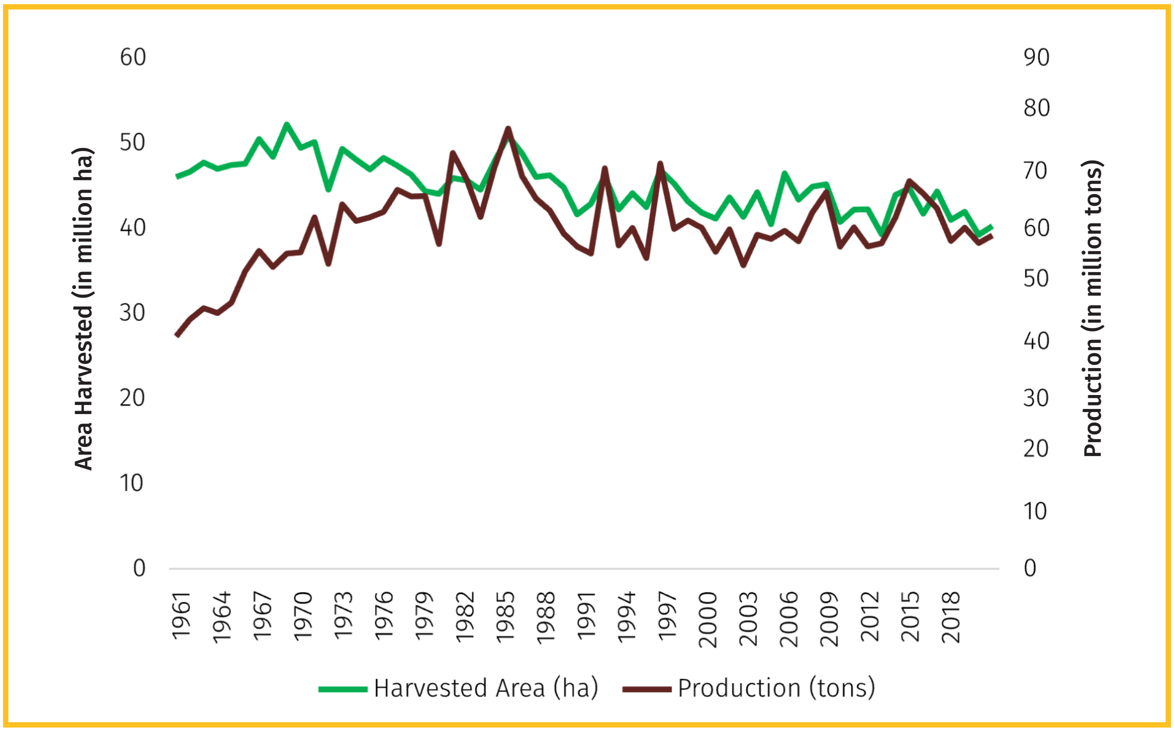
Sorghum is a cultivated flowering plant species of Poaceae, the seeds of which are widely used for human food and animal feed. The crop is generally cultivated in the tropical and subtropical agroecological zones in semiarid and arid regions (Taylor and Duodu, 2016). The agronomic characteristic of sorghums is that they typically have a low water requirement. Unlike maize, which is a rhizomatous plant, sorghum is a deep-rooted plant.

The minimum water requirement for sorghum is 400 mm (Ray and Ramachandran, 2019). Furthermore, sorghum is notable for its ability to withstand long periods of drought and tolerate very high temperatures. As a result, the crop has a competitive advantage over maize, sugarcane, cassava and sugar beet (Ray and Ramachandran, 2019). Even when cropped under conditions favourable to other crops, the characteristics of sorghum still provide the advantage of not needing to be irrigated during dry periods when rains fail or are late in coming.

According to FAOSTAT data, the global sorghum production was 59.2 million tonnes, equivalent to 8 kg per person, based on the world population estimate of 7.27 billion (FAO, 2020). In part of Africa, sorghum is a widely grown traditional staple food, and its importance in providing food security cannot be overemphasized. While the climate conditions favour sorghum farming in most countries in Africa, the yields per hectare are small compared to developed countries like France, the U.S., Australia and Italy. The low yields per hectare are because of the ubiquitous dependency on the traditional smallholder farming system, inefficient breeding strategies, pest infections and post-harvest loss. Vom Brocke et al. reported the positive impact of Participating Breeding (PB) of sorghum in Burkina Faso as a response to address the limited adoption of the traditional breeding program. The PB program, which started in the late 1990s, has helped with the expansion and yield performance of sorghum; thus, reducing hunger and increasing revenues for local farmers (Vom Brocke et al., 2020).

Figure 21

Global Sorghum Production



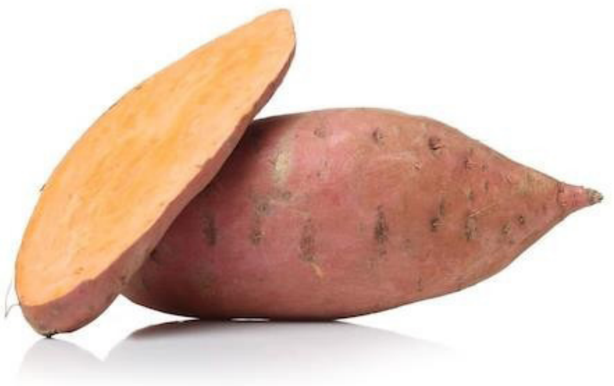
Note. FAOSTAT (2023)

Globally, sorghum has gained interest as a renewable feedstock to produce bioethanol. Of the approximately 60 billion litres of bioethanol produced in the U.S., only four per cent is from sorghum, using an estimated 45 per cent of the grain sorghum harvested (Bailey, 2016). In developing countries, the use of sorghum as a resource for bioethanol production is not well developed. Still, it has much potential based on the climate suitability of growing the crop in the region (Biofuels Digest, 2014). Research conducted in Brazil has shown sorghum can be processed in sugarcane mills and can be used in crop rotation in sugarcane fields.

Like maize, sorghum is an economically viable feedstock for ethanol production. However, maize's alcohol conversion efficiency is higher (387 litres/tonne grain) than that of sorghum (374 litres/tonne grain). The lower yield is because the digestibility of sorghum grain by microorganisms is 95–96 per cent that of corn (Aruna et al., 2018). If the sorghum grain is used for ethanol production, and the sorghum bagasse is used for green electricity, 3,500 litres of crude oil equivalence can be saved per hectare of cultivation area (Aruna, 2018). The non-food parts of the sorghum plant are also a promising feedstock for ethanol production. Sorghum thus offers many advantages, such as low production inputs and less competition with food production.

3.6 SWEET POTATO

The sweet potato (Ipomoea batatas) is a large, sweet-tasting, and starchy tuber distantly related to the potato (Solanum tuberosum). Sweet potatoes are rich in dietary fibre with moderate vitamin C, potassium, and other micronutrients. Sweet potato is a perennial crop cultivated in both tropical and warm temperate regions. It is regarded as the seventh most important food crop in production, and most of its cultivation is done at the subsistence level (Patil, 2020).



Sweet potato crops have several agronomic characteristics that determine their adaptation to marginal lands, such as saline-base tolerance, high multiplication rate and low degeneration of the propagation material. They cover the soil rapidly and protect it from erosive rains and weed propagation (Ray and Ramachandran, 2019). The sweet potato can be cultivated without much fertilizer and is drought-resistant, not requiring irrigation. The harvest period is approximately 4–6 months. Adequate post-harvest genetic material is used to propagate the next crop. Harvest of sweet potato may be on a need basis and can be hand-dug. This is a typical practice on farms with no farm machinery (Maynard and O'Hair, 2003).

During harvest season, roots are dug from the soil, cleaned and graded. The well-shaped roots that are free from defects and diseases can be sold. Proper handling after harvest includes curing seed roots and adequate sanitation, including removal of all old sweet potatoes and fumigation of the storage house before storing new roots (Maynard and O'Hair, 2003).

Sweet potato is mainly used as food and commercialized as fresh tubers, with minor quantities sold as dried tubers, either sliced or as pellets. Although the crop is widely cultivated globally, production tends to be concentrated in lower per capita income populations. More than 90 per cent of the world's current sweet potato production occurs in Asia and Africa, with China being the largest producing country. In 2014, China produced 67 per cent of world production. Significant producers outside of SSA include Indonesia, Vietnam, India, Brazil, and the U.S. (Ray and Ramachandran, 2019).

Sweet potato is a promising raw material for producing ethanol because of its minimal requirements for cultivation and its high starch content. Industrial sweet potato developed for bioenergy is not intended for use as a food crop. Rather than being selected for attractiveness, colour and taste, the industrial sweet potato is selected for the higher content of starch and better agricultural yields. For sustainable ethanol production, it is necessary to select sweet potato varieties with high starch content, low moisture level, small size to economize transport and storage costs, and low fibre content (Ray & Ramachandran, 2019).

3.7 MILLETS

Like sorghum, millet belongs to the grass family of Poaceae and is a C4-carbon fixation tropical-type plant. Millet is primarily used for human food and animal feed. It is more efficient in utilizing the high solar radiant energy in tropical latitudes than wheat and rice, which are C3 temperate plant types. Millets are not a single species or even different species within a single genus, as can be seen in a phylogenetic tree of cereal species relationships (Taylor and Duodu, 2016). Millet is derived from the French word "mille" which means "thousand" implying that thousands of millet seeds could fit in one's palm. The crop belongs to the same subfamily as sorghum and has similar agronomic and beverage-end-use characteristics. Hence, millets are cultivated in the same geographies as sorghum (Taylor & Duodu, 2016).

There are many species of millet, but the two major ones globally are pearl millet (Pennisetum glaucum) and finger millet (Eleusine coracana). Pearl millets originated in the West African drylands, and the earliest evidence of pearl millet cultivation is from Mali, dated 4,500 B.C. The finger millet was derived from the East African sub-humid uplands. These two millet species are prominent because they are globally cultivated in different geographical areas, account for most millet trade, and have been the focus of most research work and programs on millets. Pearl and finger millets are widespread and grown throughout SSA, mostly by smallholder farmers. They are cultivated in some rural areas outside the Sub-Saharan African continent in India, China, and Nepal. In SSA, millet is an important crop, even in the Sahel region. It contributes to rural food security and livelihood systems, as it provides a good nutritional supply and income to small-scale farmers. According to FAOSTAT data, the global millet production was 31 million tonnes in 2018, equivalent to 1.04 per cent of the entire world's cereals production. Millets are mostly produced in mixtures either by intercropping, double-cropping, or relay-cropping with other semiarid tropical (SAT) cereals like sorghum, legumes, groundnuts, cowpeas, sesame, and root crops, mostly cassava.

Unlike maize and sorghum, the potential of millet for industrial applications such as feedstock for ethanol production has not been extensively studied. Wu et al. studied bioethanol production from pearl millet by evaluating four millet genotypes. It was reported that 35 per cent of the grain solids content yields 15.7 per cent to 16.8 per cent (v/v) ethanol, and the fermentation efficiency is 94.3 to 95.6 per cent (Taylor & Duodu, 2016). The results showed that pearl millets on a starch basis have a similar fermentation efficiency to that of maize and sorghum (Taylor & Duodu, 2016).

3.8 COCOA BEAN JUICE

Cocoa (Theobroma cacao) is a tropical tree from the Malyaceae family. Cocoa is grown commercially in West Africa and tropical Asia, and its seeds are much prized as cocoa beans. Cocoa grows to heights ranging from 6–12 meters. Its oblong leaves measure up to 30 cm in length and are periodically shed and replaced with new leaves bright red when young. Its flowers are either foul-smelling or odourless; they are often present but appear in abundance twice a year.

It takes five years of care cultivation for cocoa trees to reach peak production. Yields can continue for the next 10–20 years. Although ripe pods are often found on the cocoa tree at any time, most countries have two periods with peak production (IITA, 2020). Each pod holds 20 to 60 oval seeds covered with a sticky white pulp and arranged around the pod's long axis.

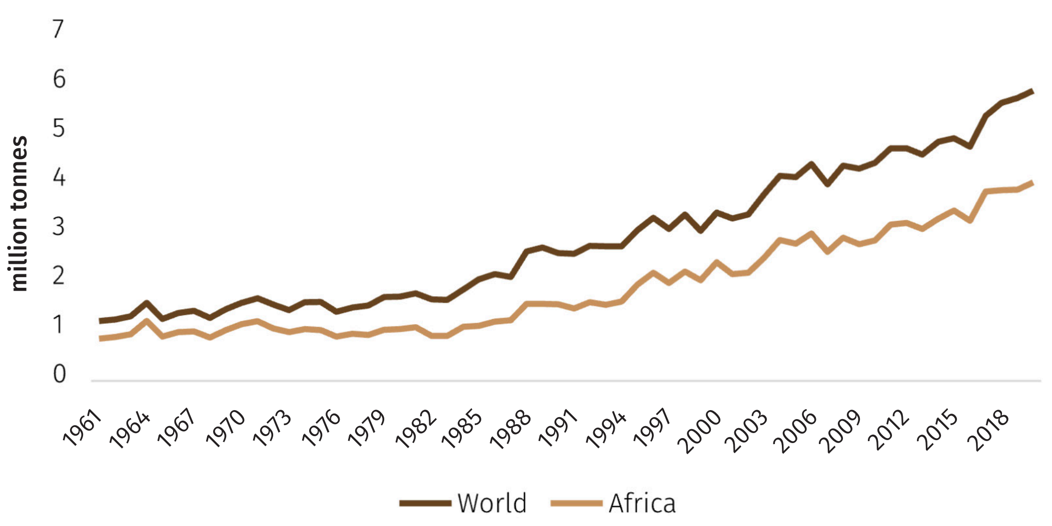
Cocoa thrives at an altitude of 30 to 300 meters above sea level in locations with temperatures that do not range much below 20°C or above 28°C. The minimum rainfall requirement is approximately 100 cm, but optimal rainfall ranges between 150–200 cm. Successful cocoa farming requires deep, porous, well-drained soil rich in humus. The tree's root system is shallow so trees must be protected against strong wind (Britannica, 2001).

The first evidence of cocoa as food dates from the Mayans and Aztecs, who made a drink from cocoa beans. Chocolate was known as a beverage until edible chocolate was developed. Cocoa beans are crushed and ground into powder after roasting. Cocoa is highly nutritious and contains 40 per cent carbohydrate, 40 per cent fat and 20 per cent protein. It also has magnesium, iron, and potassium. Worldwide consumption of chocolate in 2017 was estimated to be at least 7.2 million tonnes (IITA, 2020).

Production increases have been achieved by investing in programs to train small farmers on best practices in planting cocoa. Nearly 70 per cent of world cocoa production takes place in West Africa. Cultivation in West Africa has increased from 2.75 million hectares to 7.24 million hectares in just two decades, aided by mechanization (FAOSTAT, 2020). Côte d'Ivoire is the single largest cocoa bean producer, accounting for approximately 37 per cent of worldwide supply (FAOSTAT, 2020). Other leading producer countries include Brazil, Cameroon, Ghana, Indonesia, and Nigeria. Beans are processed into cocoa powder, cocoa butter, and chocolate.

Figure 22

Cocoa Production



Note. FAOSTAT (2023)

Many cocoa varieties exist. They can be grouped into three general divisions: forastero, criollo and trinitario. Forastero varieties are mostly used in commercial productions, whereas criollo varieties are very susceptible to disease and are not widely grown. Trinitario, a hybrid of forastero and criollo varieties, produces a bean prized for its flavour and used in high-quality dark chocolate.

In countries such as Côte d'Ivoire, Ghana, and Nigeria a by-product of cocoa processing done by the grower has prospects as a bioethanol feedstock. Each year, the quantity of pulp solution (cocoa sweating) produced in these countries is estimated at 550,000 m^3. Unfortunately, only a small amount of this sweet cocoa juice is consumed as a beverage, and most of it is disposed of on the farms. Cocoa juice valorisation as a feedstock for ethanol could produce financial benefits for farmers and others in the supply chain of cocoa production. It could offset the negative impacts of cocoa bean price swings in the international market and help stabilize income for the farmers (Anvoh et al., 2010).

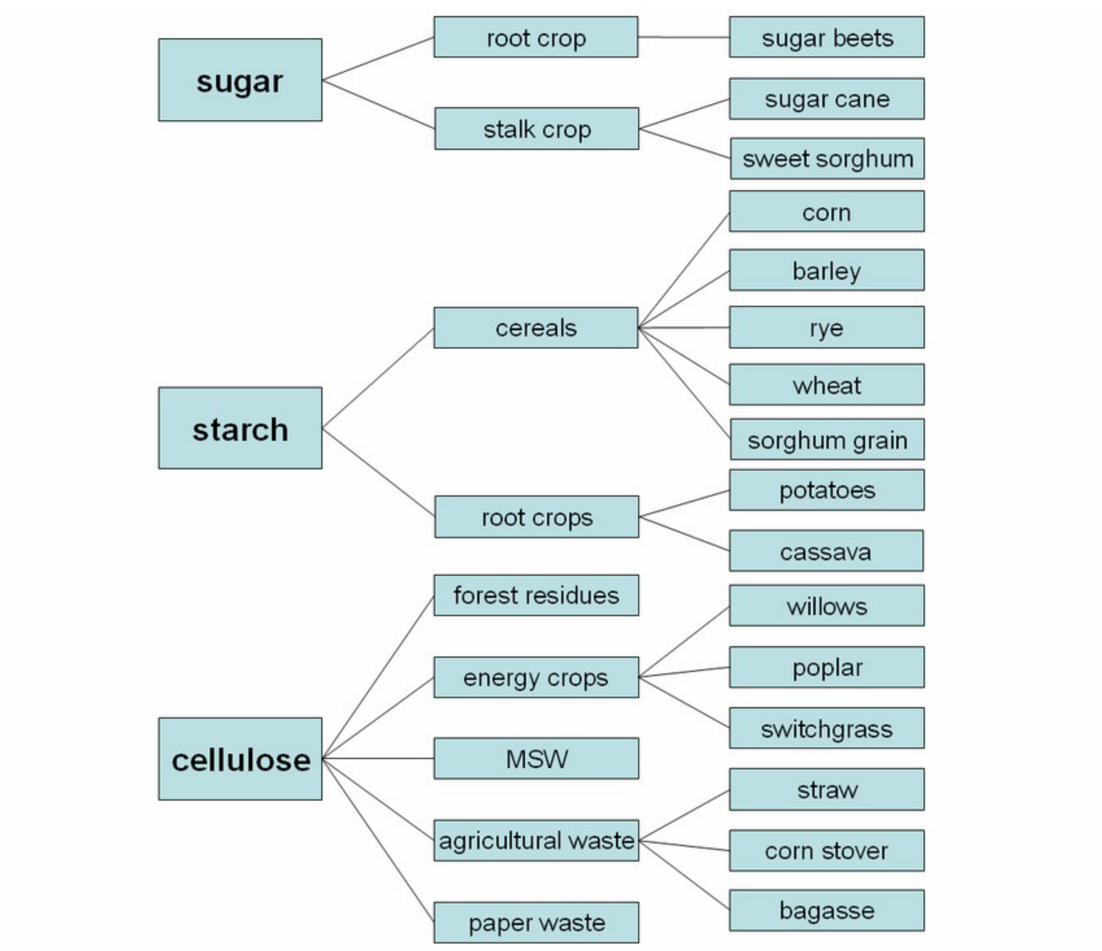
The microflora that ferments cocoa juice at the farm level contains several wild strains of microorganisms of yeasts, bacteria, and moulds. These microorganisms can ferment cocoa bean juice and degrade its sugars into alcohol and several secondary products such as organic acids. Assays on cocoa bean juice transformation in pot stills to low-strength alcohol have been conducted, showing a 12.5 per cent yield of ethanol. If a more developed biotechnology process is used with Saccharomyces cerevisiae (brewer's yeast —used in industrial alcohol production), better alcohol yield at 17 per cent concentration is achieved (Anvoh et al., 2010).

3.9 OTHER FEEDSTOCKS

Apart from the highlighted food crops, wheat, barley, rye, and other cereals are typical, starch-rich feedstocks that could be used as bioethanol feedstock, as they are available at a commercial quantity. Also, sugar beet, a biennial crop cultivated in temperate regions, is an excellent feedstock to produce ethanol and has a sugar content approximately 25 per cent higher than sugarcane (Ray and Ramachandran, 2019). The next-generation feedstocks, mostly inedible, could also provide a significant opportunity for bioethanol production. A variety of these feedstocks contains a large amount of cellulose and hemicellulose and are readily available in many developing countries. With the right technology, they could be converted to sugar and further to ethanol. Cellulosic resources include agricultural wastes, forest residues, municipal solid waste (MSW) and energy crops. Cellulosic agricultural wastes include wheat straw, corn stover, rice straw and sugarcane bagasse. While the use of cellulosic feedstocks is still developing, they show potentially enormous potential for ethanol production (Lynd et al., 2015).

Figure 23

Types of Feedstocks for Ethanol Production



Note. Rutz and Janssen (2007)

Three different arrangements of the basic sugar units are possible, as seen in the three different types of agricultural feedstocks available for fermentation: sugar crops, starch crops and lignocellulosic residues. The starch crops and lignocellulosic residues contain six-carbon sugar compounds which must be broken down into simple six-carbon sugar units before fermentation can take place.

From the standpoint of ethanol production, the long, branched chain arrangement of six-carbon sugar units in starch crops has advantages and disadvantages. The principal disadvantage is the additional equipment, labour, and energy costs associated with breaking down the chain so that the individual sugar units can be used by the yeast. However, this cost is relatively minor in relation to all of the other costs involved in ethanol production. The principal advantage of starch crops is the relative ease with which these crops can be stored, with minimal loss of the fermentable portion. Ease of storage is related to the fact that a conversion step is needed before fermentation: many microorganisms, including yeast, can utilize individual or small groups of sugar units, but not long chains (U.S. DOE, 1982).

Table 7

Advantages and Disadvantages of Ethanol Feedstocks

TYPE OF FEEDSTOCK	PROCESSING NEEDED BEFORE FERMENTATION	MAIN ADVANTAGE(S)	MAIN DISADVANTAGE(S)
Sugar crops (e.g., sugar beets, sweet sorghum, sugarcane, fodder beet, Jerusalem artichoke)	Milling to extract sugar	• Preparation is minimal. • High yields of ethanol per hectare. • Coproducts have value as fuel, livestock feed, or soil amendment.	• Crop storage may result in loss of sugar (molasses is an exception).
Starch Crops: grains (e.g., corn, and wheat, sorghum, barley)	Milling, liquefaction and saccharification	• Storage techniques are well developed. • Cultivation practices are widespread with grains. • Livestock coproduct is relatively high in protein.	• Preparation involves additional equipment, labour, and energy costs. • DDG from aflatoxin contaminated grain is not suitable as animal feed.
Cellulosic: crop residues (e.g., corn stove, wheat straw)	Milling and hydrolysis of the linkages	• Use involves no integration with the livestock feed market. • Availability is widespread.	• No commercially cost-effective process exists for hydrolysis of the linkages.

Note. U.S. DOE (1982)

Cellulosic ethanol is often held out as the ideal solution for providing sustainable feedstocks for bioethanol, primarily because these are not associated with food crops. Yet, it should be noted that sugar and starch feedstocks are abundant and the cheapest and easiest pathway to bioethanol production. Cellulosic ethanol distilleries have struggled in the U.S. and Europe to achieve competitiveness with distilleries using conventional feedstocks. If sugar and starch feedstocks are selected in a manner to complement the production of food and other essential products, or if agricultural sugar and starch co-products or wastes are used effectively, such as molasses produced in the sugar industry, or starch crops damaged or with no market, then these feedstocks should also be considered sustainable, provided the facts warrant. Moreover, where grains are used as feedstocks, the food value of the grain can be fully recovered as a co-product of the distillation process, enhanced by the treatment with enzymes during fermentation. So, even the use of grains could provide sustainable solutions. The FAO has shifted from a “food vs. fuel” to a “food and fuel” paradigm for bioethanol and biofuels since sustainability is a value that must be borne out in case-specific analyses of how resources are being used. Thus, sustainability is not associated with any feedstock per se, but rather with the use and management of the feedstock and other associated resources, what benefits are derived from them (Bogdanski et al., 2011; FAO, 2012, 2013, 2015).

Cellulosic ethanol could prove feasible for developing countries, provided the abundance and low cost of producing and delivering a cellulosic feedstock can offset the higher cost of processing ethanol from cellulose the higher capital cost of installing a cellulosic ethanol plant. This technology may not be conducive to cost-effective downsizing. In contrast, sugar- and starch-based distilleries are built and operated economically on a microscale (World Bank, 2011; Practical Action, 2012).


Meseret
SNV

4. EMD WASTE

Ethanol production results in the discharge of high-strength liquid effluents with high concentrations of organic matter and nitrogen compounds, low pH, high temperature, and dark-coloured, high salinity effluent. Distillery stillage (vinasse) is an environmental concern, as it pollutes water in several ways. The dark-coloured stillage can block sunlight, inhibiting photosynthesis and reducing the oxygenation of the water, affecting aquatic life. It also causes eutrophication (a gradual increase in the concentration of phosphorus, nitrogen, and other nutrients in the aquatic ecosystem). Eutrophication leads to excessive plant and algal growth.

The level of pollution from distillery stillage depends on the characteristics of the substrates and the unit operations used for alcohol production; therefore, the characteristics of stillage can differ from distillery to distillery. For every litre of alcohol produced from different feedstocks, 8–14 litres of stillage can be generated. The stillage can be high in COD and BOD due to the presence of organic compounds such as polysaccharides, proteins, polyphenols, waxes and melanoidin. Distillery stillage contains about two per cent of natural products of sugar and amino acid condensates known as melanoidins, which contain dark brown pigment. These substances lead to environmental pollution and antioxidation.

Distillery stillage or vinasse can be used for direct soil fertilization (spreading on fields and ploughing in) due to their high content of nitrogen, phosphorus, and organics. In addition, vinasse increases the water retention power in the soil, as well as the population of microorganisms. As an example, vinasse generated from sugarcane juice fermentation is used as a fertilizer in Brazil. However, at high doses (> 250 m^3/ha), the use of distillery stillage is harmful to plant growth and soil properties, but its application at lower doses (125 > 250 m^3/ha) significantly improves the sprouting, growth, and yield of dryland plants, due to its content of nutrients (P, N, K and Ca) (Ashis Kumar Biswas, 2009). Moreover, the combined application of distillery stillage and natural organic compounds (cattle manure, green leaf manure and bio-compost) is suitable under dryland conditions (Ashis Kumar Biswas, 2009).

The methods used for the treatment of distillery stillage are biological (aerobic and anaerobic), physio- chemical (coagulation or flocculation, electrocoagulation, adsorption, advanced oxidation, and membrane processes) and thermal (evaporation or combustion). The choice of treatment method depends on factors such as efficiency and cost, the type of land where the treated distillery stillage will be used, regulatory constraints and public acceptance (See Annex III).

4.1 PHYSICOCHEMICAL TREATMENT

Physicochemical methods of distillery stillage treatment combine physical and chemical processes, in which the first process leads to the removal of suspended materials and the second to the elimination of soluble COD. Such processes involve coagulation/flocculation, electrocoagulation, adsorption, advanced oxidation, and membrane treatment.

4.2 EVAPORATION OR COMBUSTION

Large-scale plants use thermal treatment widely. Combustion of distillery stillage is also gaining interest. The treatment relies on the utilization of stillage as a fuel source. Direct combustion of distillery stillage is more effective if the stillage is pre-dried (to less than 55 per cent moisture content). However, the technology is currently expensive, particularly when applied in small to medium-sized applications. The challenge lies in the high energy requirement for the pre-drying stage and the treatment of toxic gas emissions.

4.3 BIOLOGICAL TREATMENT

The biological treatment of distillery stillage depends on the natural growth and selection of microorganisms. During this process, the microorganisms utilize pollutants for growth and convert the organic substrates into simpler substances in the presence or absence of oxygen. Aerobic or anaerobic methods can be used separately for the treatment of distillery stillage. However, a combination of both is applied for wastewater with high concentrations of organic pollutants.

Biological treatment is the most cost-effective and efficient way to treat EMD stillage. Both aerobic and anaerobic treatment rely on a process of microbial decomposition to treat wastewater. The key difference between anaerobic and aerobic treatment is that aerobic systems require oxygen, while anaerobic systems do not. This is a function of the types of microbes used in each type of system. Though both anaerobic and aerobic systems can treat many of the same biological constituents, some differences make each technology better suited for specific contaminants, concentration levels, temperatures, or other wastewater stream characteristics. In general, aerobic treatment systems are best suited for streams with relatively low BOD or COD and are also used for the removal of nitrogen and phosphorus. On the other hand, anaerobic systems are typically used for the treatment of waste streams with high concentrations of organic contaminants and warm wastewater streams (SAMCO, 2019).

4.3.1 Aerobic Treatment

Aerobic treatment is more suitable for low-strength wastewater while anaerobic treatment is suitable for high-strength wastewater. Aerobic treatment is used as both a preliminary and final treatment. Many microorganisms (bacteria, cyanobacteria, yeast, fungi, etc.) can be used for the treatment of distillery stillage in aerobic conditions. The efficiency of the treatment depends on temperature, pH, COD, and nutrients (nitrogen from ammonia and phosphorus from phosphate).

4.3.2 Anaerobic Treatment

Anaerobic treatment results in less overall sludge production and generates valuable by-products such as biogas. The sludge is stable and safe for use as an agricultural fertilizer. Anaerobic and aerobic systems are most often paired for the treatment of streams with high concentrations of organic contaminants. For these setups, anaerobic treatment is used for the initial reduction of organic contaminant levels, while aerobic treatment is used as a secondary polishing step to further reduce BOD and Total Suspended Solids (TSS). In general, using both technologies results in more efficient treatment and more complete contaminant removal than either technology used alone. The decision to use both technologies will typically result in higher capital costs but lower operational and waste discharge costs. The appropriateness of using one or both types of biological treatment ultimately depends on the unique application and local conditions at a given facility (SAMCO, 2019).

Anaerobic treatment processes have several advantages over the aerobic treatment process (Behera, 2014):

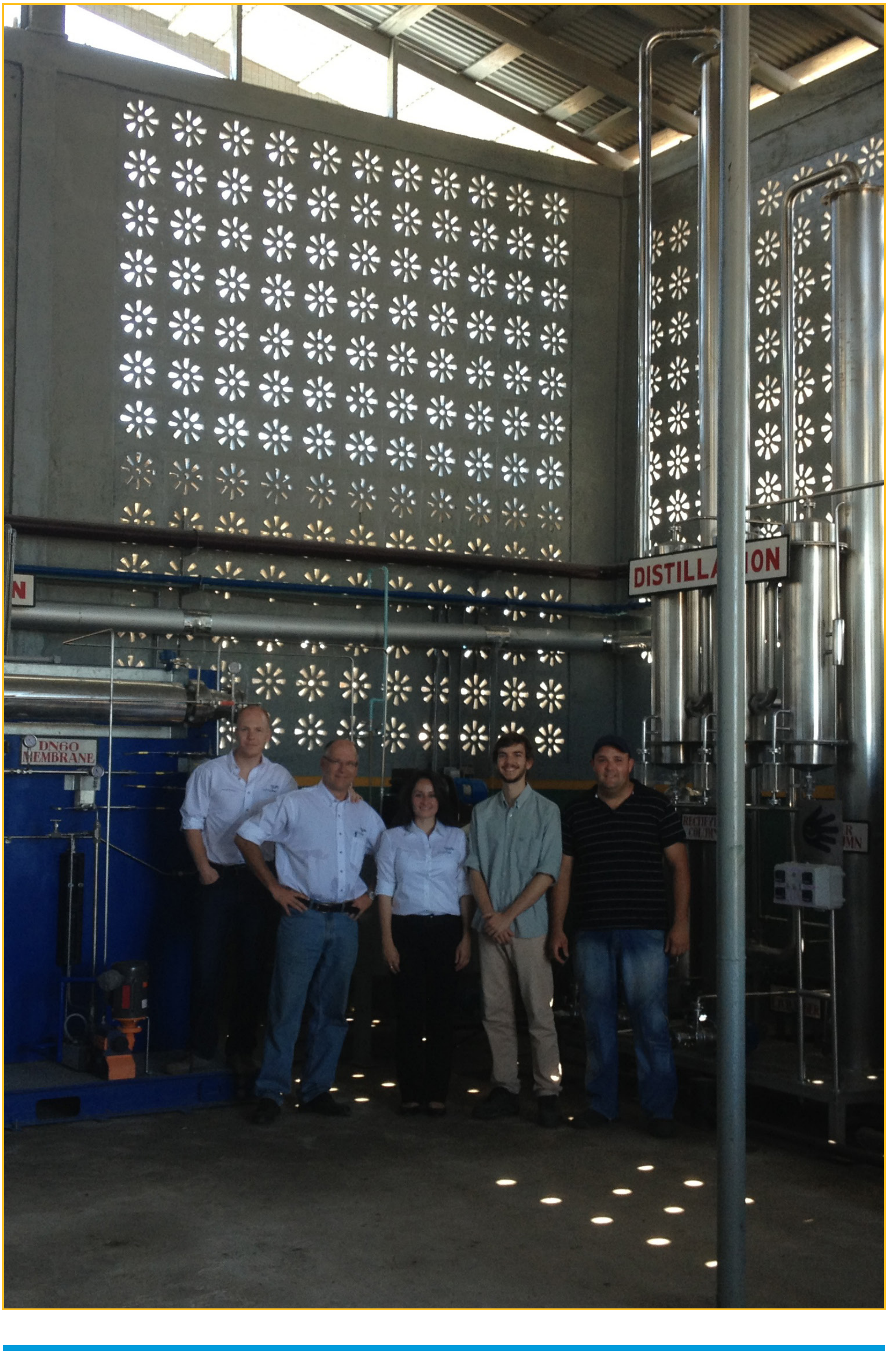
4.4 RECOMMENDED EMD WASTE TREATMENT

A combination of anaerobic processing with aerobic processing will achieve the desired levels of COD and BOD of distillery stillage discharge. The stillage first undergoes anaerobic processing followed by an aerobic process. A plastic-covered lagoon can be placed in an excavated hole for this purpose. The plastic is used to cover and create an anaerobic environment. The retention period is 20 days followed by aerobic treatment. Biogas generation from the anaerobic process can be piped to the boiler as fuel. The feasibility of biogas generation must be evaluated based on the characteristics of the EMD effluent to achieve a pollution-free operation (See Annex III).

Figure 24

Waste Treatment Aerobic Lagoons

Note. Musa and Idrus (2021); Indiamart.com (2022) ▪

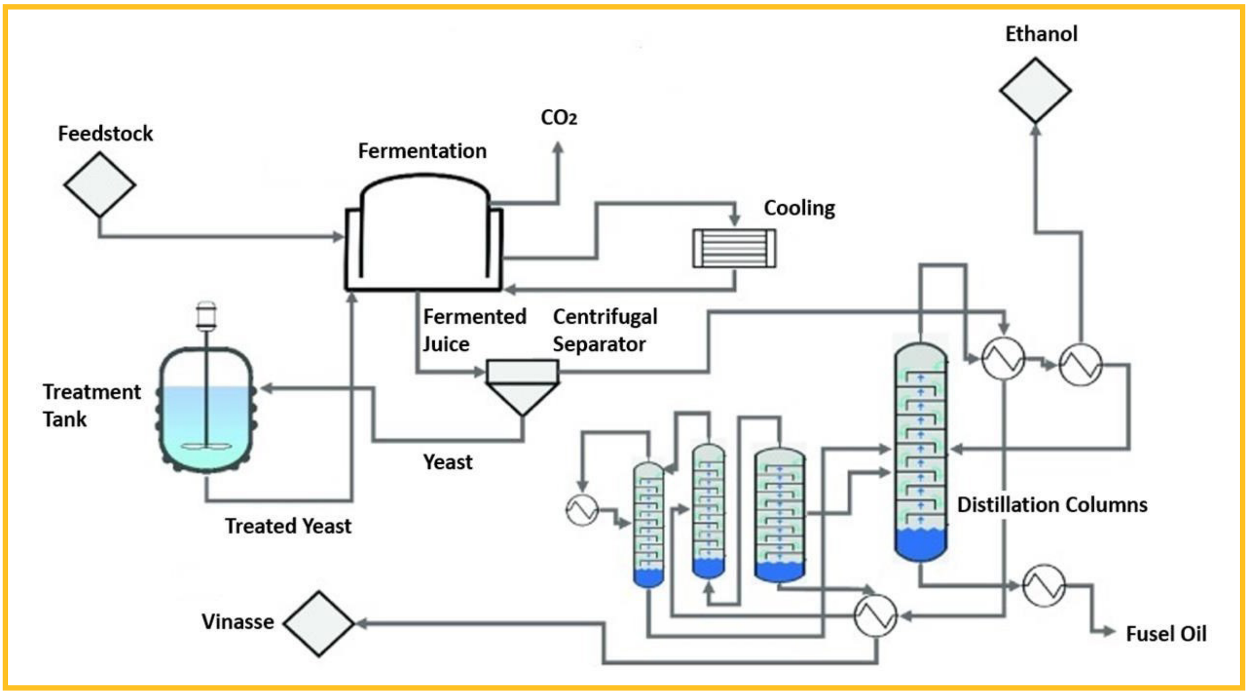

DISTILLATION
DN60
MEMBRANE

5. EMD EQUIPMENT AND INFRASTRUCTURE

A typical EMD has a layout similar to what is shown in Figure 26.

Figure 25

Layout of a typical EMD



Note. After DeBlasio (2019)

Depending on the feedstock type, equipment included in the feedstock preparation unit can vary. Equipment for crushing, milling, liquefaction and saccharification will be determined based on the feedstock type. However, the rest of the equipment after fermentation remains essentially the same. Table 8 shows the equipment included in an EMD set-up for sugarcane feedstock.

Table 8

EMD Equipment for sugarcane feedstock

UNIT PROCESS	EQUIPMENT INCLUDED IN THE SECTION
Feedstock preparation unit	• Cane feed conveyor • Cane crusher • Bagasse conveyor • Juice collection tank • Juice pump • Piping materials & valves
Fermentation section	• Pre-fermenter (yeast rehydration pot) • Fermenter tanks • Fermented wash recirculation pump • Harvest tank • Air blowers & motor • Fermenter cooling circuit pump • Supporting steelwork and access platforms
Distillation section	• Beer feed pump • Beer heater • Stripper column • Rectifier column • Condenser • Fusel decanter • Piping and valves • Supporting steelwork and access platforms
Biomass fired boiler	• Fans, feed-water tank & pumps, controls and ancillaries • Water pumps • Piping materials & valves
Storage tanks	• Storage tanks and pumps
Piping and instrumentation	• All necessary piping and valves • Electrical control equipment
Water treatment unit (softener)	• Water filter • Water softener
Effluent treatment & disposal unit	• Anaerobic digester • Aerobic treatment pond
Firefighting equipment	• Fire extinguisher and water tank
Laboratory equipment	• Testing materials and equipment

Note. Project Gaia (2014)

The equipment required in the feedstock preparation unit varies depending on the feedstock type. For example, sugarcane requires a crusher and juice extractor while molasses requires only a storage tank. The fermentation room should be well-ventilated and easily accessible to facilitate washing and sanitization. Fermentation tanks or vessels where fermentation takes place should be constructed of carbon steel or preferably stainless steel, have conical bottoms, have coils installed to control the temperature of the wine, have agitators, and be installed on suspended bases. The main tanks should be arranged next to each other in the fermentation unit, maintaining space between them to facilitate cleaning and the free movement of operators (Silva, 2007).

Figure 26

Fermentation Room with Tanks with Conical Stainless-Steel Bottoms

Note. Silva (2007)

During fermentation, yeast metabolism releases 11.7 kilocalories (kcal) per kilogram of substrate consumed (Silva, 2007). The temperature is an important factor, as it influences the transformation process and can destroy the yeasts. As a result, temperature regulation of fermentation tanks is very important.

Figure 27

Fermentation tanks in open pavilion, Addis Ababa, Ethiopia

Note. Project Gaia (2014)

Depending on the feedstock type, supplementary addition of nutrients might be required for fermentation to occur satisfactorily. This addition must be carried out in specific proportions for each process. Excessive addition of these nutrients increases the production of by-products and can impact yeast yield.

After fermentation, the wine has various constituents, including gaseous, solid, and liquid substances. The gases are mainly represented by carbon dioxide dissolved in a small proportion of the wine. The wine contains suspended solids, including cells of yeasts, bacteria, mineral salts, non-fermented sugars, and unfiltered impurities after grinding. Water and ethanol are the most important liquid substances present in the wine. By-products such as acetic aldehyde, succinic acid, acetic acid, lactic acid, esters, higher alcohols and sometimes furfural are present (Silva, 2007).

6. ETHANOL STANDARDS AND RECOMMENDED ETHANOL COOKING FUEL STANDARDS

Ethanol is produced on an industrial scale for many different markets and a variety of uses, including chemical, industrial, pharmaceutical, fuel, food and beverages. While all these markets have quality standards associated with them, standards for the use of cooking fuel are least developed and perhaps least understood.

The highest quality ethanol that is widely produced, Extra Neutral Alcohol (ENA), is produced primarily for the food and beverage industry.

Beneath ENA in quality are several industrial grades of ethanol. Of these, rectified extra-neutral (REN) ethanol is very low in impurities. In the industry, this is referred to as REN Ethanol/Rectified Spirit (min. 95-96 per cent vol.). This is an industrial or second-grade fermentation ethyl alcohol. Also referred to as rectified spirits, it is commonly used in numerous industrial applications such as industrial solvents and cleaning products. It has also traditionally been used as a fuel for alcohol stoves and cooking around the world.

A second choice for stove fuel is crude industrial-grade ethanol or low-grade REN (min. 95 per cent vol.). This is a lower-grade fermentation REN ethanol that has undergone some purification through rectification. This ethanol is used as an industrial feedstock for further rectification. It is adequately free of impurities to burn cleanly in ethanol stoves. In the industry, it is often referred to as “Korean Grade B” or REN-B.

REN ethanol can be sold as undenatured or denatured ethanol. Normally, denaturing is a legal or regulatory requirement for traded ethanol. When ethanol is purchased for the stove fuel market, it should be denatured, with a denaturant that is appropriate for stove fuel use (i.e., one that is non-toxic and burns cleanly). This should not be a petroleum-fuel-based denaturant.

Another grade of ethanol is fuel grade, produced for automotive fuel blending. This is produced using distillation configurations that are somewhat different from what is used to produce rectified ethanol. Fuel-grade ethanol is used for low, mid, and even high-level blending with gasoline, such as E5, E10, E35 or E85. Applicable standards are D4806 or EN 15376 (American Society for Testing and Materials, ASTM).

Yet another grade of ethanol in the market is not a product with a formal grade but a leftover product resulting from producing ENA and REN ethanol. It is often referred to as Technical Alcohol (TA). It generally contains about 85 per cent ethanol, and includes excess water and light and heavy fractions extracted during the rectification process. This product contains light impurities such as methanol, acetaldehyde, and ketones. Since these are low-carbon fractions, they burn cleanly. Heavier fractions include fuel oils, which are mostly five-carbon amyl alcohols but include a mixture of higher alcohols, including amyl, isoamyl, propyl, isopropyl, butyl and isobutyl alcohols and acetic and lactic acids. These alcohols range from three to eight carbons. The higher carbon alcohols have an oily feel, noticeable to the distiller, hence the term fuel oil. Because they contain more carbon atoms than ethanol, they do not burn as easily and cleanly as ethanol itself and will produce some soot when burned in the ethanol stove.

Ethanol of all grades and quality, including the TA, has been used in stoves. This includes extremely high-quality and very low-quality ethanol and ethanol of high strength or highly diluted with water. Ethanol as low as 60 per cent will burn, although its flame temperature is much reduced by the presence of water vapour. Ethanol at 80 per cent is commonly used in gel fuels. The added water used in gel fuel assists the gelling agent, usually calcium acetate or carboxymethyl cellulose (CMC), a cellulose gum, to gel and to remain gelled. However, rectified ethanol at 95 per cent strength is preferred for stove fuel because it burns hotter without any added water. In burning hotter, it also burns more cleanly and completely (Project Gaia, 2014).

Some key characteristics of ENA, REN, B-grade REN, and fuel ethanol are compared in Table 8.

Table 9

REN Ethanol Compared with ENA and Fuel-grade Ethanol

TEST PARAMETER	ENA	REN A OR B	FUEL GRADE
Alcohol strength at 20°C % by vol	96.1	95 to 99.3	92 to 98
Water % by vol	3.9	0.7 to 5	0.7 to 1
Density at 20°C mg/ml	0.807	0.812	0.818
Methanol, mg/L	10	50 to 800	5,000 (0.5%)
Aldehydes (Acetaldehyde), mg/L	5	50 to 300	60 to 200
pH	neutral	neutral +/-1	6.5 to 9.0
Acidity (as Acetic Acid), mg/L	10	30 to 100	50 to 100
Total Higher Alcohols, mg/L	5	60 to 600	1,000 to 20,000
Aromatics, hydrocarbons % by vol	absent	absent	2 to 5
Phosphorus mg/L			1.3
Sulphur, mg/kg			10 to 30
Sulphate, mg/kg			<4
Solvent washed gum mg/100 mL			5.0
Chlorides, mg/kg		<1.0	6.7 to 10

Note. Collected industry specifications

Key parameters to note in this side-by-side comparison of REN ethanol with fuel-grade ethanol are the higher alcohols, the presence of petroleum denaturants (aromatics and hydrocarbons) and acetaldehyde. One can see from the comparison that the REN grades remain low in higher alcohols, which include fuel oils (n-propanol, isopropyl alcohol, isobutanol, n-butanol, isoamyl alcohol, etc.). These are the heavier fractions of distillation, three- to eight-carbon alcohols produced during fermentation, which burn less cleanly as stove fuel due to their higher content of carbon. The REN grades are also low in the lighter fractions of distillation, most notably acetaldehyde, which, while burning without soot, causes odour and eye irritation. At the levels present in the REN ethanol, these heavier and lighter impurities do not produce any noticeable effect —they combust completely or almost completely in the ethanol. Methanol, a one-carbon alcohol, is another light fraction produced and, like ethanol, burns cleanly. Methanol is used as a stove fuel in its own right.

When fuel ethanol is produced for gasoline blending, it also undergoes a rectification step. Some of the higher alcohols are removed to facilitate the maximum separation of ethanol from the reflux vapour. However, once ethanol is separated and dehydrated in the molecular sieve, or by other methods, the higher alcohols are returned to ethanol because they are beneficial to its use as a motor fuel. These higher alcohols have fuel value; moreover, they help in blending ethanol with gasoline (Katzen, et al., 1999). Therefore, fuel ethanol for blending and flex-fuel vehicles contains elevated levels of fuel oils. Aldehydes, which are not conducive to clean tailpipe emissions, are partially removed, but generally not as completely as in REN ethanol. To meet the U.S. legal requirements and to facilitate trading, fuel ethanol is denatured with natural gasoline or another petroleum constituent, which may contain aromatic compounds (benzene, toluene, etc.). Further, if benzene was used in the dehydration step at the distillery, the ethanol may also contain small amounts of benzene from the dehydration process. These constituents of fuel ethanol —higher alcohols, acetaldehyde and petroleum denaturants— are what render it undesirable for stove fuel. Other parameters of concern are acidity, solvent- washed gum, chlorides and other metals and chemicals that may be present in fuel ethanol.

In 2016, a standard for cookstove fuel was created based on fuel ethanol produced in the United States of the ASTM D4806 type (Standard Specification for Denatured Fuel Ethanol for Blending with Gasolines for Use as Automotive Spark Ignition Engine Fuel). This was done by ASTM Committee E48 on Bioenergy and Industrial Chemicals from Biomass (ASTM, 2016). The new standard is identified as ASTM E3050-2016. The strategy behind this new standard was to leverage an existing ethanol product that is abundantly produced in the U.S., priced competitively, and readily available for shipping from U.S. hubs. This ASTM standard was recently slightly updated and issued as ASTM E3050-2022. It seeks to reduce the standard for higher alcohols down from 2 per cent to 0.6 per cent (ASTM, 2022).

The ASTM E3050-2016 standard for denatured ethanol cooking fuel specifies the following:

Table 10

Denatured Ethanol Cooking and Appliance Fuel Specification E3050 – 16

PROPERTY	UNITS	LIMIT	MIN/MAX	TEST METHOD
Ethanol	Volume percentage	90	Min	D5501
Water	Volume percentage	10	Max	E203 or E1064
Higher Alcohols (C3-C8)	Volume percentage	2	Max	D4815
Hydrocarbon (denaturant)	Volume percentage	1	Max	Documented Addition
Acidity (acetic acid)	mg/Kg	40	Max	D7795
Denatonium Benzoate (denaturant)	mg/Kg	10-20	Min-Max	Documented Addition
Coloured Dye	mg/Kg	10	Max	Documented Addition

Note: The hydrocarbons approved for use under this specification are as follows: gasoline, unleaded gasoline, natural gasoline, heptane, or rubber hydrocarbon solvent.
Note. ASTM, 2016

Microdistilleries are not limited in the quality of ethanol they can produce. A microdistillery, if designed to do so, can produce REN ethanol. Nor does this desired level of quality represent a significant capital investment over a distillery producing an inferior grade of ethanol. The REN ethanol is a quality fuel with value in the market, the sale of which will help to pay off the distillery more quickly than inferior ethanol that may not satisfy consumers. Still, another consideration is that ethanol with impurities is hard on the stoves and may result in stoves needing to be maintained or replaced more often.

A modern microdistillery should have trays rather than packed columns. The beer stripper section is below the product feed-in tray in the column and a rectifier section is above. The beer stripper may contain 8–22 trays and the rectification section 14–30 trays. The rectifier takes the overhead vapour from the beer stripper and concentrates the ethanol to 190 proof, which is the azeotrope. The rectifier section also removes the “middle boilers” and heavier impurities along with some aldehydes in a side stream and a few trays from the bottom of the rectifier section. The configuration of the distillery could be one tall column or separate stripper and rectifier columns. It could have a third column, such as an extra side stripper on the rectification column to recycle vapour from the bottom of the rectifier to extract any remaining ethanol. A properly designed tray column microdistillery will thus produce very clean ethanol fuel for cookstoves. When producing fuel for cookstoves, it is advisable to aim for the REN quality ethanol. ●

Nosy Maitso (Renew Life)

7. ANALYSIS OF AN EMD INVESTMENT

7.1 DECISION-MAKING GUIDANCE

A sequential detailed analysis is required to make the necessary decisions on investment in ethanol production. An initial pre-feasibility assessment will indicate whether or not to proceed with further investigation. The pre-feasibility assessment should examine the following four areas, which will guide the decision-making:

- What is the market for ethanol and its coproducts?
- What is the production potential?
- What is the investment required for a market-fit plant size and the production potential?
- What is the potential revenue?

An initial negative answer to any of the pre-feasibility questions does not necessarily mean that all approaches are unfeasible. Changes made to some aspects of the project may turn the investment analysis around. However, such changes should be carefully considered and realistic. Answering the following questions can help you with the analysis.

A. Market for the ethanol and coproducts

- ✓ Are you aware of the opportunity to use ethanol for fuel in your location?
- ✓ Is there a potential local market for fuel ethanol?
- ✓ Will ethanol be a competitive cooking fuel in your market?
- ✓ At what price would ethanol be competitive with other cooking fuels in your market?
- ✓ How large is your market for ethanol fuel?

B. Production potential

- ✓ What is the feedstock you have in mind for ethanol production?
- ✓ How much feedstock is required to produce a litre of ethanol?
- ✓ What is the cost of the feedstock you are considering?
- ✓ Is the feedstock available year-round?
- ✓ What is the quantity of feedstock available in your area?
- ✓ What other feedstocks could you consider?

C. Investment requirements

- ✓ If your market can consume all the ethanol you can produce, and finance is available, the plant size will be determined by the amount of feedstock available.
- ✓ The investment required to build the microdistillery will roughly approximate the gross earnings of the annual production.
- ✓ Do you have the capacity to invest in the EMD as a sole proprietor or do you need partners?

- ✓ Can you obtain finance to invest in the EMD?
- ✓ Are you willing to consider an investment partnership?

D. Potential for revenues

- ✓ At what price will you be able to sell the ethanol you produce?
- ✓ Will you have a market for coproducts and other distillery products? At what price?

This information can be used for the initial analysis of an EMD investment. You will be able to make the financial analysis with the model provided for this purpose. If the ROI is positive, a detailed feasibility study should be your next step.

7.2 FINANCIAL ANALYSIS OF AN EMD

Development of an ethanol plant involves planning not only the production technology but also the management and financial strategies (U.S. DOE, 1982). The financial requirement of the EMD and the choices for financing must be determined.

Capital requirements for the EMD include investment in land (the EMD site), equipment, business formation, engineering, installation and licenses. Operating costs include labour, maintenance, taxes, supplies (raw materials, additives, enzymes, yeast, and water), transport, energy (electricity and fuels), insurance and interest on short- and long-term financing.

Potential earnings are determined by estimating the sales price of ethanol per litre and then multiplying that figure by the production volume of the EMD. If there are coproducts (compost, wet and dry fertilizers, biogas, excess heat, excess electricity, and other distillery products), earnings are determined by the sales price times the quantity of goods and services that can be sold. Once the financial requirements and potential earnings are determined, these can be related to the project on the ground. Operation costs are compared to potential earnings to determine cash flow. Once this information is acquired and analysed in light of the business investor's specific situation, a decision can be made about how the business will be organized and what steps need to be taken to get into business.

This guidebook has developed a mathematical model to aid in conducting a financial analysis for an EMD business based on various feedstocks (See Annex I — Ethanol Microdistillery Financial Module). The model is interactive, with users able to plug in assumptions for the key project variables that will determine the financial feasibility of the project. This will permit users to examine the impact of their decision-making on the EMD investment and its return. The model allows the user to consider loans, grants and other financing mechanisms in the investment and be able to consider how they will impact the investment.

7.3 FINANCIAL ANALYSIS OF A 2,500 LPD EMD INVESTMENT (A SAMPLE CASE)

This discussion takes as an example a 2,500 LPD EMD with 300 active production days in a year. Projected financial statements are included in the model and summaries are presented for discussion. Although this is a realistic example, factors will differ for every project. This model may be used by anyone considering an ethanol plant development, but the numbers must be taken from one's situation.

The following are the basic assumptions for the analysis of this example case. These assumptions are interactive in the Assumptions Sheet of the Microsoft Excel financial model.

- Active production dates in a year: 300 days
- Daily processed feedstock: 36 tonnes
- Daily product (95 per cent ethanol): 2,500 litres
- Quantity of feedstock processed annually: 10,800 tonnes
- Boiler fuel: bagasse
- Price of feedstock: $15/tonne
- Equity: 50 per cent ($419,500)
- Debt: 50 per cent ($419,500)
- Selling price of the product (95 per cent ethanol): $0.70/litre

The table below presents the estimated required investment.

Table 11

Required Investment for a 2,500 LPD EMD

INITIAL INVESTMENT COST	AMOUNT (US DOLLARS)	PERCENTAGE
Land cost	10,000	1.3
Civil works and buildings	20,000	2.5
Plant machinery, equipment and commissioning	660,000	83.6
Office equipment and furniture	10,000	1.3
Pre-operational expenses	10,000	1.3
Working capital requirement	79,088	10.0
Total initial investment	**789,088**	**100.0**
Financed by:		
Loan amount	419,500	53.2
Equity contribution	369,588	46.8

Note. Financial model: Investment Costs, Financing and Loan Repayment Sheet, Project Gaia (2014)

The model allows the user to evaluate the impact of equity, loans, or other financing mechanisms on the investment. Here, a 46.8 per cent equity contribution and a 53.2 per cent loan are assumed. A second case is considered with a 100 per cent equity investment.

The results of the financial analysis show the following result (See Annex I).

Table 12

Net Present Values (NPVs) and Internal Rate of Return (IRR)

ROI	
NPV at long-term loan borrowing interest rate, 10%	**$215,243.21**
NPV at a 5% discount rate	**$577,744.33**
NPV at 7.5% discount rate	**$369,806.80**
IRR on Equity	**15.4%**

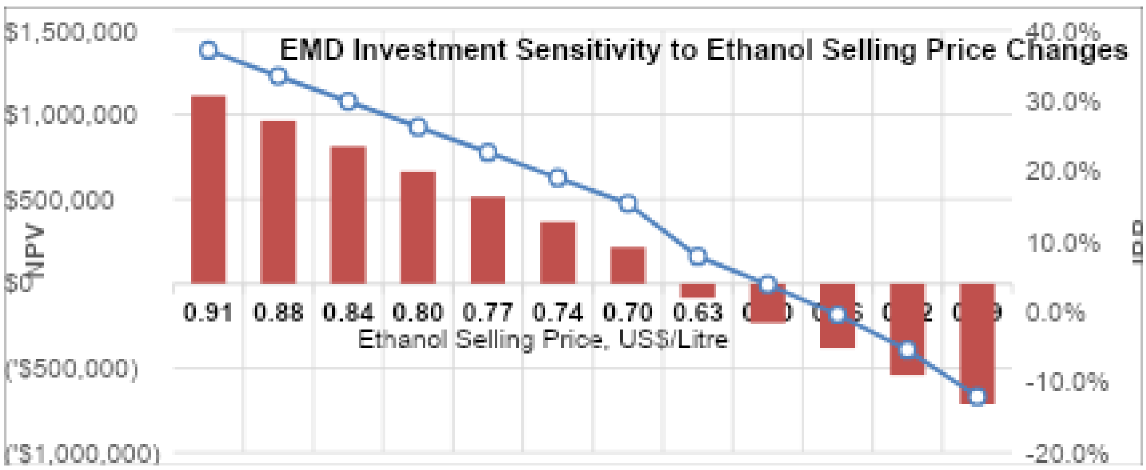
Note. Financial model: Investment Costs, Financing and Loan Repayment Sheet, Project Gaia (2014)

The results show that the investment has a reasonable ROI of 15.4 per cent. Also, all the NPV of the investment is positive for discount rates of 5, 7.5 and 10 per cent, indicating a satisfactory financial return.

A sensitivity analysis is conducted by varying the product (ethanol) selling price and the feedstock (sugarcane) purchasing price. The results are shown in the figures below. A reduction beyond 10 per cent in the selling price of ethanol, while other variables remain the same, would cause a loss on the investment. An increase in feedstock price by 25 per cent does not cause a loss on the investment. However, it should be noted that the feedstock base price considered here is at the lower end of the price range.

Figure 28

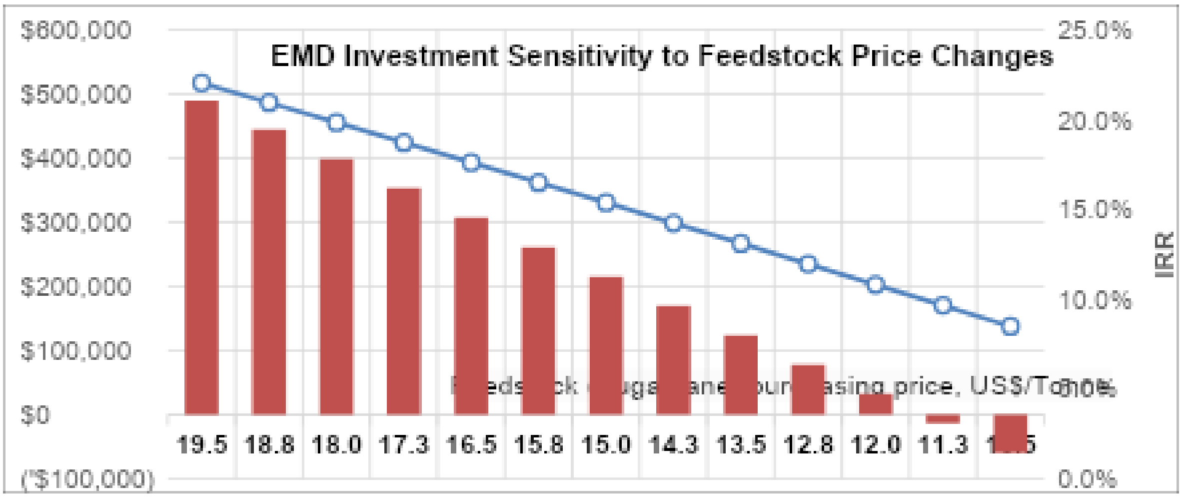
EMD Investment Sensitivity to Ethanol Selling Price



Note. Financial model: Investment Costs, Financing and Loan Repayment Sheet, Project Gaia (2014)

Figure 29

EMD Investment Sensitivity to Feedstock Cost ($/tonne)



Note. Financial model: Investment Costs, Financing and Loan Repayment Sheet, Project Gaia (2014)

Table 13

Projected Cash Flow Statement

Inflow of funds	Jan/23	Jan/25	Jan/26	Jan/27	Jan/28	Jan/29	Jan/30	Jan/31
Increase in equity capital	369,588							
Long-term loans received	419,500							
Operating income before depreciation	-	209,544	208,597	207,630	206,645	205,640	204,615	203,569
Total cash inflow	789,088	209,544	208,597	207,630	206,645	205,640	204,615	203,569
Outflow of funds								
Increase/decrease in Fixed Assets								
Land cost	10,000		-	-	-	-	-	-
Civil works and buildings	20,000		-	-	-	-	-	-
Plant machinery, equipment, commissioning	660,000		-	-	-	-	-	-
Office Equipment and furniture	10,000		-	-	-	10,000	-	-
Vehicles	-		-	-	-	-	-	-
Pre-operative expenses	10,000							
Interest payment on long-term loan	-	-	-	65,189	58,318	50,760	42,445	33,300
Repayment of long-term loan	-	-	-	68,713	75,584	83,143	91,457	100,603
Profit tax paid		-	23,919	22,890	21,774	23,240	24,868	26,675
Dividends paid			-	64,093	60,968	65,072	69,631	74,690
Total cash outflow	710,000	-	23,919	220,885	216,644	232,214	228,401	235,268
Cash surplus/deficit	89,088	209,544	184,678	(13,255)	(9,999)	(26,574)	(23,786)	(31,699)
Cumulative cash balance	89,088	298,632	483,309	470,054	460,055	433,481	409,695	377,996

Inflow of funds	Jan/32	Jan/33	Jan/34	Jan/35	Jan/36	Jan/37	Jan/38	Jan/39
Increase in equity capital								
Long-term loans received								
Operating income before depreciation	202,503	201,415	200,305	199,173	198,019	196,841	195,640	194,415
Total cash inflow	202,503	201,415	200,305	199,173	198,019	196,841	195,640	194,415
Outflow of funds								
Increase/decrease in Fixed Assets								
Land cost	-	-	-	-	-	-	-	-
Civil works and buildings	-	-	-	-	-	-	-	-
Plant machinery, equipment, commissioning	-	-	-	-	-	-	-	-
Office Equipment and furniture	-	-	10,000	-	-	-	-	-
Vehicles	-	-	-	-	-	-	-	-
Pre-operative expenses								
Interest payment on long-term loan	-	-	-	-	-	-	-	-
Repayment of long-term loan	-	-	-	-	-	-	-	-
Profit tax paid	28,679	30,901	30,683	30,461	30,435	30,204	29,968	29,728
Dividends paid	80,302	86,521	85,912	85,291	85,217	84,570	83,911	83,238
Total cash outflow	108,981	117,422	126,595	115,752	115,652	114,774	113,879	112,966
Cash surplus/deficit	93,521	83,993	73,710	83,421	82,367	82,067	81,761	81,448
Cumulative cash balance	471,518	555,511	629,220	712,642	795,009	877,076	958,836	1,040,285

Note. Financial model: ROI Projected Statements, Project Gaia (2014)

Table 14

Projected Income Statement

Revenue	Jan/23	Jan/25	Jan/26	Jan/27	Jan/28	Jan/29	Jan/30	Jan/31
Ethanol Sales		525,000	525,000	525,000	525,000	525,000	525,000	525,000
By-product sales		-	-	-	-	-	-	-
Total Revenue		525,000	525,000	525,000	525,000	525,000	525,000	525,000
Cost of sales		249,704	249,704	249,704	249,704	249,704	249,704	249,704
Gross profit		275,296	275,296	275,296	275,296	275,296	275,296	275,296
General Administrative and Sales								
Salaries		47,355	48,302	49,268	50,254	51,259	52,284	53,329
Staff uniforms		500	500	500	500	500	500	500
Telecom & Posts		600	600	600	600	600	600	600
Marketing Expenses		5,000	5,000	5,000	5,000	5,000	5,000	5,000
Office Supplies		600	600	600	600	600	600	600
Legal & Audit fees		1,000	1,000	1,000	1,000	1,000	1,000	1,000
Fuel and Lubricants		3,000	3,000	3,000	3,000	3,000	3,000	3,000
Miscellaneous expenses		2,000	2,000	2,000	2,000	2,000	2,000	2,000
Personnel Insurance		947	947	947	947	947	947	947
Plant Insurance		4,750	4,750	4,750	4,750	4,750	4,750	4,750
Depreciation		48,000	48,000	48,000	48,000	48,000	48,000	48,000
Sub-total		113,752	114,699	115,665	116,651	117,656	118,681	119,727
Operating Profit		161,544	160,597	159,630	158,645	157,640	156,615	155,569
Interest on long-term borrowing		41,950	46,145	50,760	42,445	33,300	23,239	12,173
Profit before taxes		119,594	114,452	108,871	116,200	124,341	133,376	143,396
Profit tax		23,919	22,890	21,774	23,240	24,868	26,675	28,679
Net profit after tax		95,675	91,561	87,097	92,960	99,472	106,701	114,717
Dividends payable			64,093	60,968	65,072	69,631	74,690	80,302
Retained Profit		95,675	27,468	26,129	27,888	29,842	32,010	34,415

Revenue	Jan/32	Jan/33	Jan/34	Jan/35	Jan/36	Jan/37	Jan/38	Jan/39
Ethanol Sales	525,000	525,000	525,000	525,000	525,000	525,000	525,000	525,000
By-product sales	-	-	-	-	-	-	-	-
Total Revenue	525,000	525,000	525,000	525,000	525,000	525,000	525,000	525,000
Cost of sales	249,704	249,704	249,704	249,704	249,704	249,704	249,704	249,704
Gross profit	275,296	275,296	275,296	275,296	275,296	275,296	275,296	275,296
General Administrative and Sales								
Salaries	54,396	55,484	56,594	57,725	58,880	60,058	61,259	62,484
Staff uniforms	500	500	500	500	500	500	500	500
Telecom & Posts	600	600	600	600	600	600	600	600
Marketing Expenses	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Office Supplies	600	600	600	600	600	600	600	600
Legal & Audit fees	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Fuel and Lubricants	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
Miscellaneous expenses	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000
Personnel Insurance	947	947	947	947	947	947	947	947
Plant Insurance	4,750	4,750	4,750	4,750	4,750	4,750	4,750	4,750
Depreciation	48,000	48,000	48,000	47,000	47,000	47,000	47,000	47,000
Sub-total	120,793	121,881	122,991	123,123	124,277	125,455	126,656	127,881
Operating Profit	154,503	153,415	152,305	152,173	151,019	149,841	148,640	147,415
Interest on long-term borrowing	-	-	-	-	-	-	-	-
Profit before taxes	154,503	153,415	152,305	152,173	151,019	149,841	148,640	147,415
Profit tax	30,901	30,683	30,461	30,435	30,204	29,968	29,728	29,483
Net profit after tax	123,602	122,732	121,844	121,739	120,815	119,873	118,912	117,932
Dividends payable	86,521	85,912	85,291	85,217	84,570	83,911	83,238	82,552
Retained Profit	37,081	36,820	36,553	36,522	36,244	35,962	35,674	35,380

Note. Financial Model, ROI Projected Statements Sheet, Project Gaia (2014)

If we consider a second case with a 100 per cent equity investment (i.e., without a loan of approximately 50 per cent), while other assumptions remain the same, the results show that the investment return rate jumps from 15.5 to 24.3 per cent. This illustrates the importance of grants or soft loans to assist EMD businesses to get off the ground. The EMD can be viable at higher feedstock prices or lower ethanol selling price. This should serve as a lesson to development entities that wish to help with the shift to modern biofuels away from solid biofuels or petroleum fuels. The cost of capital plays a big role in the viability of an EMD investment, and this is especially so for local African businesses with limited capital to invest. Once operational, EMDs can generate excellent earnings, but they need low-cost capital to get established.

As previously mentioned in this guidebook, the cost of feedstock is the largest cost component in the production of ethanol. Feedstocks should be evaluated carefully for fermentation yield and shelf-life before building an EMD. From there, the potential markets for ethanol should be looked at to determine the price the market will pay. If the ethanol produced is to be used as a cooking fuel, its price competitiveness with other fuels in the market should be evaluated based on useful energy cost. Table 15, below, provides an example.

Table 15 shows how to analyse cooking fuel prices based on their useful energy cost. Price examples are applied to make the comparison. This calculation should be helpful for ethanol producers who are targeting the cooking fuel market. In this example, if ethanol fuel is retailed at $0.70/litre, it will be competitive with other cooking fuels at the given prices. Savings in the form of health, socio- economic and environmental benefits are not accounted for, but they are real and can play a role in the marketing strategy.

Table 15

Useful Energy Cost of Fuels

6,000 MJ useful energy/ household-year	FUEL	FIREWOOD	CHARCOAL	ETHANOL	LPG	KEROSENE	ELECTRICITY
	Stove	Threestone stove	Traditional Metal	Ethanol stove	Single burner	Wickstove	Single burner
	Unit	kg	kg	Litre	kg	Litre	kWh
The energy content of fuel (LHV)	MJ/ (kg,lt,kWh)	19	27	23.8	44.7	35.3	3.6
Retail price of fuel	$/ (kg,lt,kWh)	0.085	0.25	0.70	1.00	0.90	0.096
Stove life	Year	-	1	5	5	1	5
Stove efficiency	%	13%	20%	60%	60%	40%	40%
Stove price	$/ (kg,lt,kWh)	0	8.00	23.27	44.93	8.00	32.09
Useful energy cost (c)	$/MJ	0.0344	0.0476	0.0498	0.0388	0.0651	0.0677
Energy cost (a)	$/MJ	0.0344	0.0463	0.0490	0.0373	0.0637	0.0667

Stove cost (b)	FUEL	FIREWOOD	CHARCOAL	ETHANOL	LPG	KEROSENE	ELECTRICITY
	$/MJ	0.0000	0.0013	0.0008	0.0015	0.0013	0.0011
Ratio to the least cost stove and fuel		1.00	1.38	1.45	1.13	1.89	1.97
Rank		1	3	4	2	5	6
Percentage cost of stove per useful energy cost (d)		0.0%	2.7%	1.6%	3.9%	2.0%	1.6%
Percentage cost of fuel per useful energy cost (e)		100.0%	97.3%	98.4%	96.1%	97.8%	98.4%

Note. Project Gaia (2021)

To work this table, fill in the retail price for each type of fuel. Fill in the stove price for each stove. Stoves are defined by their fuel type, whether wood, charcoal ethanol, LPG, kerosene or electric.

Next, compute value (a), energy cost, for each stove. This is the retail price of fuel/(energy content x stove efficiency). Compute value (b), stove cost, for each stove. This is stove price/(useful HH energy/year x stove life). The value for the useful HH energy/year is found in the upper lefthand box of the table.

Then, compute value (c), useful energy cost. This is energy cost (a) + stove cost (b).

This allows you to rank the stoves. To determine the ratio to the least-cost stove and fuel, select a stove and divide its useful energy cost by the useful energy cost of the cheapest stove. Thus, for the ethanol stove, this is 0.0498 divided by the value for the three-stone stove, 0.0344. This yields a value of 1.45.

Once these ratios are computed for each stove, they can be ranked.

Value (d), the percentage cost of the stove per useful energy cost, is computed by dividing stove cost

(b) by useful energy cost (c). Value (e), the percentage cost of fuel per useful energy cost, is computed by dividing energy cost (a) by useful energy cost (c). Note that the cost of the stove for any of the fuels is only a tiny fraction of the useful energy cost of the stove–fuel system.

To test the competitiveness of ethanol fuel in the market relative to other fuels, enter the fuel prices as well as the stove prices in your area. Vary the fuel prices up and down to determine the price sensitivity. Ethanol stoves are generally the closest competitors either to charcoal or LPG stoves, or kerosene, where it is in use. As you see in Table 16, if charcoal increases to $0.30 per kg and LPG to $1.50 per kg, ethanol at $0.70 per litre becomes the cheapest fuel next to firewood.

Table 16

Price Sensitivity of Charcoal and LPG with Ethanol

	FUEL	FIREWOOD	CHARCOAL	ETHANOL	LPG	KEROSENE	ELECTRICITY
6,000 MJ useful energy/ household-year	Stove	Three stone stove	Traditional Metal	Ethanol stove	Single burner	Wickstove	Single burner
	Unit	kg	kg	Litre	kg	Litre	kWh
Energy content of fuel (LHV)	MJ/ (kg,lt,kWh)	19	27	23.8	44.7	35.3	3.6
Retail price of fuel	$/ (kg,lt,kWh)	0.085	0.30	0.70	1.50	0.90	0.096
Stove life	Year	-	1	5	5	1	5
Stove efficiency	%	13%	20%	60%	60%	40%	40%
Stove price	$/ (kg,lt,kWh)	0	8.00	23.27	44.93	8.00	32.09
Useful energy cost	$/MJ	0.0344	0.0568	0.0498	0.0574	0.0651	0.0677
Energy cost	$/MJ	0.0344	0.0556	0.0490	0.0559	0.0637	0.0667
Stove Cost	$/MJ	0.0000	0.0013	0.0008	0.0015	0.0013	0.0011
Ratio to the least cost stove and fuel		1.00	1.65	1.45	1.67	1.89	1.97
Rank		1	3	2	4	5	6
Percentage cost of stove per useful energy		0.0%	2.3%	1.6%	2.6%	2.0%	1.6%
Percentage cost of fuel per useful energy		100.0%	97.9%	98.4%	97.4%	97.8%	98.4%

Note. Project Gaia (2021)

It is important to emphasize that the use of ethanol has several advantages over other fuels. This includes LPG. Cooking with ethanol is quite safe, compared to LPG, which must be kept under pressure and which, if a leak occurs, can result in a catastrophic explosion. For every litre of ethanol supplied to the cooking fuel market, one litre (or 0.5 kg) of LPG consumption (and thus importation) can be avoided. Because ethanol is locally produced, it provides employment and business opportunities along the value chain, from production to distribution. Ethanol enables the country to benefit from using underutilized resources.

However, ethanol production is very sensitive to the cost of the feedstock, as shown in Figure 29 above, using a sensitivity analysis. Thus, it must be realized that the price of feedstock will play the determining role in whether it can be used to produce a value-added fuel that will compete with other fuels. High- priced feedstock will result in expensive ethanol, which will not be competitive for use as cooking fuel and may not be competitive for other uses.

7.4 ECONOMIC VIABILITY OF EMDS

Economic analysis can help to quantify the many benefits that are associated with ethanol use as a fuel. This includes the value of avoided energy-related deforestation, GHG emission reductions, benefits to health from reduced household air pollution (HAP), and time savings resulting from cooking with ethanol (both time saved in cooking and from avoided fuel collection and management). Some of these values may be captured in carbon credit payments to a business when the business is able to enroll into an ethanol cookstove carbon finance program.

Ethanol produced for cooking fuel will have a positive impact on forest cover because of the reduction in fuelwood and charcoal use. Over 15 years, the ethanol produced from a 2,500 LPD EMD (750,000 litre/annum) will avoid the use of 38,000 or more tonnes of fuelwood. The avoided GHG emissions over the 15 years will approximate to 156,000 tCO_2e. There will be gains in health, wellbeing, and time savings. Studies by scientists continue to measure these gains. Many studies on resource protection, health benefits and time savings already exist, and we have included some of them in a bibliography (See Annex II) for further reading. The economic opportunity of EMDs reaches their greatest potential when they can take advantage of wasted, undervalued, or underutilized feedstocks to produce ethanol fuel for uses such as cooking. We hope this guidebook will help identify these opportunities and aid our readers in bringing them to fruition. •

8. AN ETHANOL MICRO-DISTILLERY IN ADDIS ABABA, ETHIOPIA

Figure 30

The Gaia Clean Energy and Former Women Fuelwood Carriers Association (FWFCA) Distillery in Gelan, Addis Ababa

8.1 PROJECT BACKGROUND

Gaia Clean Energy is an Ethiopian NGO established in 2005 to transform the Ethiopian household energy sector by introducing ethanol cooking technology. In partnership with the Stockholm Environment Institute (SEI), the World Bank, the Nordic Climate Fund (NCF) and Project Gaia Inc., it successfully completed the installation of an ethanol micro-distillery to demonstrate the feasibility of ethanol micro-distilleries (EMDs) in Ethiopia. The EMD plant was installed and commissioned in 2015 and handed over to the Former Women Fuelwood Carriers Association (FWFCA). The FWFCA is an Ethiopian women's association counting with more than 4,000 members. The association creates income generating activities to support its member women[1]. The EMD was owned by the FWFCA while Gaia Clean Energy supported its operation.[2]

1 For more information, visit: https://projectgaia.com/beautiful-hand-loomed-scarf-sale-benefit-fwfca/

2 In June 2020, violent unrest in Addis Ababa and other parts of the country caused several infrastructure destructions, including the EMD which was destroyed by a mob. Gaia Clean Energy is working with its partners to return the EMD back to operation.

Figure 31

EMD under construction in Addis Ababa (Ethiopia)

The EMD was procured from Spectrum Technologies Ltd. and their partner Vapco of Mumbai, India. Spectrum and Vapco completed the installation and commissioning with Gaia Clean Energy at the project site in Addis Ababa. Equipment shipping from India and installation took seven months. The team in Addis Ababa was supported by an engineer from India to complete the construction and commissioning of the plant.

Ethanol used for cooking reduces household air pollution and provides access to clean, safe and renewable locally-produced household cooking fuel. The EMD in Addis Ababa was producing 1,000 LPD of hydrous ethanol at 92-95 per cent (v/v) using feedstock molasses. The FWFCA was selling the ethanol they produced to ethanol stove users in the neighbourhood, mostly to the female association members.

8.2 LOCATION OF THE DISTILLERY

The EMD is located on the outskirts of Addis Ababa, in the Gelan area, at an elevation of 2,072 m above sea level. The EMD was installed on a 600 m^2 plot (30 m x 20 m) next to the city's Solid Waste Disposal and Treatment Facility. The land was utilized to accommodate the distillery plant, facilities (laboratory, office and dressing rooms) and liquid waste pH correction and equalization pond.

Figure 32

EMD in Addis Ababa

Figure 33

CAD aerial view of the EMD site

8.3 EMD PLANT MAIN UNITS AND COMPONENTS

8.3.1 Molasses storage tank

The molasses storage is a ground pit tank made with concrete. It has a 56 m^3 molasses storage capacity. The molasses storage capacity is sufficient to cover at least 10 ethanol production days (1,000 LPD). Feedstock molasses was being sourced from the Wonji sugar factory, located 110 km south of Addis Ababa.

Figure 34

Feedstock, molasses and dumping

8.3.2 Feedstock preparation (Daily molasses tank)

This is a vessel made from mild steel with an open top and is used to receive or store molasses in the fermentation section from the ground molasses storage tank. It has a capacity of 6,000 litres. The molasses which contains approximately 45-50 per cent sugar is first diluted with water and acidified with sulfuric acid to reach a pH range of 4-5. The diluted molasses is then pumped into the yeast activator and the fermenters.

8.3.3 Yeast propagation

The yeast multiplication vessel is made from stainless steel installed 170 cm above the ground and has a capacity of 1,500 litres. Nutrients such as urea and multivitamins are added to nourish the yeast in the diluted molasses. The overall propagation process takes 10-12 hours. Air is introduced to the vessel by a 1.5 kW electric high-pressure air compressor. This system aerates the mixture of molasses and water throughout the entire process. The optimum working pressure is 8 kg/cm^2 (114 PSI) and the test pressure is 21 kg/cm^2 (300 PSI).

Figure 35

Yeast activation vessel

8.3.4 Fermentation

Diluted molasses and activated yeast are pumped into the fermentation tanks. The fermentation converts the sugars in the molasses to alcohol. The fermentation section is composed of three fermentation vessels (each with a capacity of 7,700 litres) and one beer well vessel. Nutrients such as Urea and multivitamins are added to the fermentation to nourish the yeast. Penicillin is added to make sure the fermentation process is free from the growth of harmful bacteria. The temperature in the fermenters is controlled at a maximum of 34-35°C by a plate heat exchanger. The overall fermentation process takes 24 hours. The fermented mash stays 2-3 hours in the beer well tank (settling tank) where flocculated substances are evacuated and sent for distillation.

Figure 36

Diluted molasses pumping into the fermentation tank

Figure 37

Fermentation tanks

8.3.5 Distillation

The distillation process separates the alcohol from the water in the fermented beer. The distillation system has two columns operating at atmospheric pressure, the beer stripper and the degassing and rectification column.

The alcohol content of the fermented beer is 6 to 8 per cent. The fermented beer is first preheated by the overhead vapours in the preheater and then introduced into the upper side of the stripper column. Steam is introduced at the base of the column and the steam distills the alcohol out of the descending stream of beer.

In the rectifying column, the concentration of alcohol reaches about 95 per cent purity.

Figure 38

Distillation Unit

Figure 39

Inside the distillation column/tray

8.3.6 Steam boiler

The boiler is a water tube type boiler with an operating pressure of 7 kg/cm^2. The production of 1,000 litres of ethanol requires about 3 MT of steam. The boiler is fired by biomass fuel including coffee husk available in the area. The control panel of the boiler enables smooth operation with automatic water level and fan control.

Figure 40

Biomass Boiler in operation

8.3.7 Ethanol storage tank

The final product (ethanol) is stored in a 12,000-litre mild steel vessel. The storage tank can store up to 12 days of ethanol production.

Figure 41

Product and impurity storage tankers

Backup electric generator

A 42 kVA generator powered by diesel fuel was installed to serve during grid electricity interruption.

Figure 42

Backup electric generator

8.3.8 Cooling water system

Heated water coming directly from the distillation heat exchangers is sprayed over the cooling tower and a fan blows air across the tower. The process cools the water before it re-circulates for re-use.

Figure 43

Cooling tower

8.3.9 Water source

The main source of water for production comes from a public water pipeline. A water treatment system was installed at the plant to reduce the hardness of the water.

Figure 44

Water softener

8.3.10 Quality control unit

Figure 45

Control Board

A quality control laboratory and other basic facilities (office, dressing rooms and toilets) were constructed. The laboratory is equipped with all the necessary apparatuses and chemical reagents to monitor the process and test the quality of the product. An electronic control system was placed to control the production processes. The semi-automated system made it easier for the operators to run the plant.

8.4 COST OF EQUIPMENT

Table 17

Cost of the Addis Ababa Ethanol Microdistillery in 2012

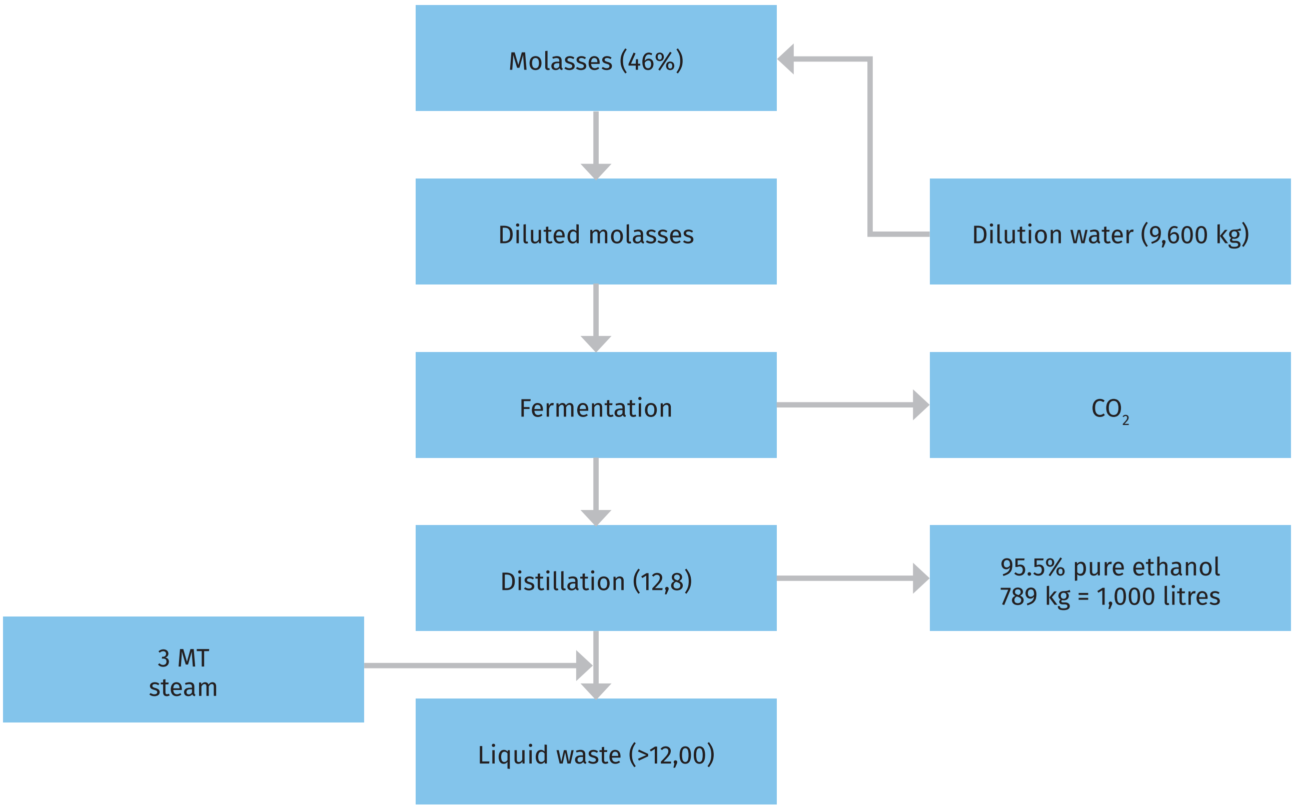
EQUIPMENT	COST ($)
Feedstock storage and handling system	**$18,500**
Fermentation system (including yeast propagation)	**$26,300**
Distillation system (including product storage for 15 days and storage of impure alcohols)	**$66,800**
Steam boiler or thermal system	**$26,600**
Utilities and other peripheral systems (including water treatment system)	**$21,600**
Total	**$159,800**

The civil work which included the construction of the concrete foundation for equipment placement, shade for fermentation tanks, compound fencing, and laboratory, office and other facility construction has cost $50,000.

EMD Mass Balance

Figure 46

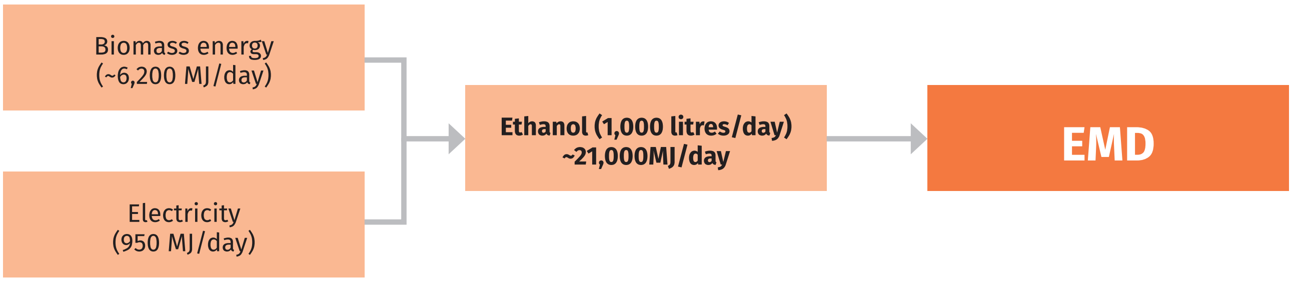
EMD Mass Balance



Energy balance

Figure 47

Energy balance



Cost of ethanol production during production time (Prior June 2020)

Table 18

Cost of Ethanol Production During Production Time, October 2017

COST ITEM	QUANTITY/DAY	PRICE PER UNIT	TOTAL COST/DAY
Feedstock (molasses)	3.2 ton	700 Birr/ton	2,240 Birr
Biomass (boiler fuel)	0.75 ton	1,000 Birr/ton	750 Birr
Electricity	264 kWh	0.7 Birr	184.80 Birr
Labour	25 persons	3,150 Birr/lumpsum/day	3,150 Birr
Consumables	1	220 Birr/day	220 Birr
Maintenance	1	200 Birr/day	200 Birr
Feedstock transportation	3.2 ton	350 Birr/ton	1,120 Birr
Biomass transportation	0.75 ton	120 Birr/ton	90 Birr
Ethanol transportation	1,000 lit	0.30 Birr/lit	300 Birr
Miscellaneous expenses	1	50 Birr/day	50 Birr
TOTAL COST/DAY			**8,305 Birr/day**
DAILY ETHANOL PRODUCTION	**1,000 litres/day**	**15 Birr/lit sale price**	**15,000 Birr/day**
GROSS PROFIT			**6,695 Birr/day**

Note: The cost is based on the plant operation experience in 2017 (1$=23.51 Birr, rate as of October 2017).

8.5 LESSONS LEARNED AND OPPORTUNITIES

Table 19

Lessons Learned

ADVANTAGES/OPPORTUNITIES	LIMITATIONS
• The EMD is of manageable size even with limited experience and the equipment is easy to operate and relatively easy to maintain. • The amount of feedstock required to serve the distillery is manageable, easy to haul and store on site. • Other inputs including water and boiler fuel are likewise manageable in size. • The plant can be easily shut down and started up. • The plant can be made to run manually. • The size of the EMD is small, therefore the amount of land required is relatively small. • Emissions and effluent pollution are smaller with a smaller plant; therefore, environmental regulations might be easier to meet. • This distillery can be located near a large market such as a town or city. This helps to secure labour as well as market wastes for feedstock and biomass processing wastes for the boiler.	• Operational costs should be managed effectively to lower overhead costs and ensure the profitability of the plant. • Even a micro plant produces waste and this waste must be cleaned up before transport off-site. The cost of waste disposal increases capital costs. A plan should be in place before the plant is built. • EMDs can become a focus of interest to regulators, who may be uncertain about what expectations to have and what regulations to implement. • Utilities such as electricity and water are critical to the operation of the plant. In theory, an urban setting will be better served by utilities, but this may not be the case. Availability of utilities is key. • Site selection and long-term, secure site control (15+ years) are essential. Be sure that land use regulations and zoning requirements can be met. Be cognizant of who the neighbors are or likely to be.

The major lessons learned during the implementation and operation of the EMD in Addis Ababa are consolidated below:

- **Infrastructure:** securing access to water and electricity has been detrimental to the project, causing delays, as had been the absence of an access road. Site selection should thoroughly consider this.
- **Local manufacture:** some parts of the EMD plant can be manufactured locally. This includes but is not limited to fermentation and yeast propagation tanks and auxiliary tanks. Local production of some parts of the plant will significantly reduce costs, mainly by reducing transportation and shipping costs and avoiding import duties.
- **Feedstock:** reliance on one type of feedstock limits the flexibility of the distillery and may hinder production during feedstock shortages. A feedstock flexible plant can minimize the risk associated with a feedstock supply shortage.

9. GLOSSARY

ACID HYDROLYSIS: decomposition or alteration of a chemical substance by acid.

ACIDITY: the measure of how many hydrogen ions a solution contains.

ALCOHOL: the family name of a group of organic chemical compounds composed of carbon, hydrogen, and oxygen; a series of molecules that vary in chain length and are composed of a hydrocarbon plus a hydroxyl group, written as CH -(CH)n-OH; includes methanol, ethanol, isopropyl alcohol, and others.

AZEOTROPIC DISTILLATION: distillation in which a substance is added to the mixture to be separated in order to form an azeotropic mixture with one or more of the components of the original mixture; the azeotrope formed will have a boiling point different from the boiling point of the original mixture which will allow separation to occur.

ALDEHYDES: any of a class of highly reactive organic chemical compounds obtained by oxidation of primary alcohols, characterized by the common group CHO, and used in the manufacture of resins, dyes, and organic acids.

ALKALI: soluble mineral salt of a low density, low melting point, highly reactive metal; characteristically "basic" in nature.

ALPHA-AMYLASE — AMYLASE: enzyme which converts starch into sugars.

AMBIENT: the prevalent surrounding conditions usually expressed as functions of temperature, pressure, and humidity.

ANAEROBIC DIGESTION: without air; a type of bacterial degradation of organic matter that occurs only in the absence of air (oxygen).

ANHYDROUS: a compound that does not contain water either absorbed on its surface or as water of crystallization.

ATMOSPHERIC PRESSURE: pressure of the air (and atmosphere surrounding us) which changes from day to day.

AZEOTROPE: chemical term for two liquids that, at a certain concentration, boil at the same temperature; alcohol and water cannot be separated further than 194.4 proof because at this concentration, alcohol and water form an azeotrope and vaporize together.

BAGASSE: a fibrous residue resulting from the crushing of sugarcane to extract the juice. Depending on the mill, bagasse has between 40 and 50 per cent of moisture, with a mass of 250 to 350 kg per tonne of cane.

BASIC HYDROLYSIS: decomposition or alteration of a chemical substance by alkali (basic) solution.

BATCH FERMENTATION: fermentation conducted from start to finish in a single vessel.

BEER: the product of fermentation by microorganisms; the fermented mash, which contains about 11-12 per cent alcohol; usually refers to the alcohol solution remaining after yeast fermentation of sugars.

BEER STILL: stripping section of a distillation column for concentrating ethanol.

BEER WELL: surge tank used for storing beer prior to distillation.

BETA - AMYLASE: see Amylase.

BIOMASS: for plant material, includes cellulose, hemicellulose, lignin,carbohydrates,ash-forming minerals, and chemicals.

BOILING POINT: the temperature at which the transition from the liquid to the gaseous phase occurs in a pure substance at fixed pressure.

CALORIE: amount of heat required to raise one gram of water one degree centigrade.

CARBOHYDRATE: a chemical term describing compounds made up of carbon, hydrogen, and oxygen; includes all starches and sugars.

CARBON DIOXIDE: a gas produced as a by-product of fermentation; chemical formula is CO_2.

CASSAVA: a starchy root crop.

CELL RECYCLE: the process of separating yeast from fully fermented beer and returning it to ferment a new mash; can be done with clear warts in either batch or continuous operations.

CELLULASE: an enzyme capable of splitting cellulose.

CELLULOSE: the main polysaccharide in living plants forms the skeletal structure of the plant cell wall; can be hydrolysed to glucose.

CELSIUS (Centigrade): a temperature scale commonly used in the sciences; at sea level, water freezes at 0 °C and boils at 100 °C.

COLUMN: vertical, cylindrical vessel used to increase the degree of separation of liquid mixtures by distillation or extraction.

COMPOUND: a chemical term denoting a combination of two or more distinct elements.

CONCENTRATION: ratio of mass or volume of solute present in a solution to the amount of solvent.

CONDENSER: a heat-transfer device that reduces a thermodynamic fluid from its vapour phase to its liquid phase.

CONTINUOUS FERMENTATION: a steady-state fermentation system that operates without interruption; each stage of fermentation occurs in a separate section of the fermenter, and flow rates are set to correspond with required residence times.

COOKER: a tank or vessel designed to cook a liquid or extract or digest solids in suspension; the cooker usually contains a source of heat; and is fitted with an agitator.

COPRODUCTS: the resulting substances and materials that accompany the production of ethanol by the fermentation process.

DEHYDRATION: the removal of 95 per cent or more of the water from any substance by exposure to high temperature or chemical action.

DENATURANT: a substance that makes ethanol unfit for human consumption.

DENATURE: the process of adding a substance to ethyl alcohol to make it unfit for human consumption; the denaturing agent may be gasoline or other substances specified by the Standards Body.

DESICCANT: a substance having an affinity for water; used for drying purposes.

DEWATERING: to remove the free water from a solid substance.

DEXTRINS: a polymer of glucose which is intermediate in complexity between starch and maltose formed by hydrolysis of starches.

DEXTROSE: same as glucose.

DISACCHARIDES: the class of compound sugars which yield two monosaccharide units upon hydrolysis; examples are sucrose, mannose and lactose.

DISPERSION: the distribution of finely divided particles in a medium.

DISTILLATE: that portion of a liquid which is removed as a vapour and condensed during a distillation process.

DISTILLATION: the process of separating the components of a mixture by differences in boiling point; a vapour is formed from the liquid by heating the liquid in a vessel and successively collecting and condensing the vapours into liquids.

DISTILLERS DRIED GRAINS (DDG): the dried distillers grains by-product of the grain fermentation process which may be used as a high-protein (28 per cent) animal feed.

DRIED DISTILLERS GRAINS WITH SOLUBLES (DDGS): a grain mixture obtained by mixing distiller's dried grains and distiller's dried solubles.

DRIED DISTILLERS SOLUBLES (DDS): a mixture of water-soluble oils and hydrocarbons obtained by condensing the thin stillage fraction of the solids obtained from fermentation and distillation processes.

DISTILLERS FEEDS: primary fermentation products resulting from the fermentation of cereal grains by the yeast Saccharomyces cerevisiae.

DISTILLERS GRAIN: the non-fermentable portion of a grain mash composed of protein, unconverted carbohydrates and sugars, and inert material.

ENRICHMENT: the increase of the more volatile component in the condensate of each successive stage above the feed plate.

ENZYMES: the group of catalytic proteins that are produced by living microorganisms; enzymes mediate and promote the chemical processes of life without themselves being altered or destroyed.

ETHANOL: C_2H_3OH; the alcohol product of fermentation that is used in alcoholic beverages and for industrial purposes; also known as ethyl alcohol or grain alcohol.

ETHYL ALCOHOL: also known as ethanol or grain alcohol; see Ethanol.

EVAPORATION: conversion of a liquid to the vapour state by the addition of latent heat of vaporization.

FEED PLATE: the theoretical position in a distillation column above which enrichment occurs and below which stripping occurs.

FEEDSTOCK: the base raw material that is the source of sugar for fermentation.

FERMENTABLE SUGAR: sugar (usually glucose) derived from starch and cellulose that can be converted to ethanol (also known as reducing sugar or monosaccharide).

FERMENTATION: a microorganically mediated enzymatic transformation of organic substances, especially carbohydrates, generally accompanied by the evolution of a gas.

FERMENTATION ETHANOL: ethyl alcohol produced from the enzymatic transformation of organic substances.

FLASH HEATING: very rapid heating of material by exposure of small fractions to temperature and using high flow rates.

FLASH POINT: the temperature at which a combustible liquid will ignite when a flame is introduced.

FLOCCULATION: the aggregation of fine suspended particles to form floating clusters or clumps.

FOSSIL FUEL: any naturally occurring fuel of an organic nature such as coal, crude oil or natural gas.

FRACTIONAL DISTILLATION: a process of separating alcohol and water (or other mixtures).

FRUCTOSE: a fermentable monosaccharide (simple) sugar of chemical formula $C_6H_{12}O_6$. Fructose and glucose are optical isomers; that is, their chemical structures are the same but their geometric configurations are mirror images of one another.

FUSEL OIL: a clear, colourless, poisonous liquid mixture of alcohols obtained as a by-product of grain fermentation; generally amyl, isoamyl, propyl, isopropyl, butyl, isobutyl alcohols and acetic and lactic acids.

GASOLINE: a volatile, flammable liquid obtained from petroleum that has a boiling range of approximately 29-216°C and is used as fuel for spark-ignition internal combustion engines.

GELATINIZATION: the rupture of starch granules by temperature which forms a gel of soluble starch and dextrins.

GLUCOSE: a monosaccharide; occurs free or combined and is the most common sugar; chemical formula $C_6H_{12}O_6$.

GRAIN ALCOHOL: see Ethanol.

HEAT EXCHANGER: a device that transfers heat from one fluid (liquid or gas) to another, or the environment.

HEAT OF CONDENSATION: the same as the heat of vaporization, except that the heat is given up as the vapour condenses to a liquid at its boiling point.

HEAT OF VAPORIZATION: the heat input required to change a unit mass of liquid at its boiling point

HEATING VALUE: the amount of heat obtainable from a fuel.

HEXOSE: any sort of simple sugar that has six carbon atoms per molecule.

HYDRATED: chemically combined with water.

HYDROCARBON: a chemical compound containing hydrogen, oxygen and carbon.

HYDROLYSIS: the decomposition or alteration of a polymeric substance by chemically adding a water molecule to the monomeric unit at the point of bonding.

HYDROMETER: a long-stemmed glass tube with a weighted bottom; it floats at different levels depending on the relative weight (specific gravity) of the liquid; the specific gravity of other information is read where the calibrated stem emerges from the liquid.

INTALOX SADDLES: packing for distillation columns, similar to Raschig rings. Packing is designed to maintain consistent contact and even distribution between the gas and liquid within a distillation column to promote the separation of reactants.

LIGNIFIED CELLULOSE: cellulose polymer wrapped in a polymeric sheath extremely resistant to hydrolysis because of the strength of its linkages called lignin.

LINKAGE: the bond or chemical connection between constituents of a polymeric molecule.

LIQUEFACTION: the change in the phase of a substance to the liquid state; in the case of fermentation, the conversion of water- insoluble carbohydrates to water-soluble carbohydrates.

MALT: barley softened by steeping in water, allowed to germinate and used especially in brewing and distilling.

MASH: a mixture of grain and other ingredients with water to prepare wort for brewing operations.

MEAL: a granular substance produced by grinding.

MEMBRANE: a polymer sheet capable of separating liquid solutions.

METHANOL: a light volatile, flammable, poisonous, liquid alcohol, CH_3OH, formed in the destructive distillation of wood or made synthetically and used especially as a fuel, a solvent, an antifreeze, or a denaturant for ethyl alcohol, and in the synthesis of other chemicals; methanol can be used as fuel for motor vehicles; also known as methyl alcohol or wood alcohol.

METHYL ALCOHOL: also known as methanol or wood alcohol; see Methanol.

MOLECULAR SIEVE: a column which separates molecules by selective adsorption of molecules based on size.

MOLECULE: the chemical term for the smallest particle of matter that is chemically identical to the whole mass.

MONOMER: a simple molecule which can combine with a number of like or unlike molecules to form a polymer.

MONOSACCHARIDES: see Fermentable Sugar.

OCTANE NUMBER: a rating which indicates the tendency to knock when a fuel is used in a standard internal combustion engine under standard conditions.

OSMOTIC PRESSURE: pressure required to prevent the passage of a solvent across a membrane which separates solutions of different concentrations.

PACKED DISTILLATION COLUMN: a column or tube constructed such that a packing of ceramics, steel, copper or fiberglass-type material.

PH: a term used to describe the free hydrogen ion concentration of a system; a solution of pH 0 to 7 is acid; pH of 7 is neutral; pH over 7 to 14 is alkaline.

PLATE DISTILLATION COLUMN (Sieve tray column): a distillation column constructed with perforated plates or screens.

POLYMER: a substance made of molecules composed of long chains or cross-linked simple molecules.

PROTEIN: any class of high molecular weight polymer compounds composed of a variety of amino acids joined by a peptide linkage.

RECTIFICATION: with regard to distillation, the selective increase of the concentration of the lower volatile component in a mixture by successive evaporation and condensation.

RECTIFYING COLUMN: the portion of a distillation column above the feed tray in which rising vapour is enriched by interaction with a countercurrent falling stream of condensed vapour.

REFLUX: part of the product stream that may be returned to the process to assist in giving increased conversion or recovery.

SACCHAROMYCES: a class of single-cell yeasts which selectively consume simple sugars.

SETTLING TIME: in a controlled system, the time required for entrained or colloidal material to separate from the liquid.

SIMPLE SUGARS: see Fermentable Sugars.

SPECIFIC GRAVITY: the ratio of the mass of a solid or liquid to the mass of an equal volume of distilled water at 40°C.

SPENT GRAINS: the non-fermentable solids remaining after fermentation of a grain mash.

STARCH: a carbohydrate polymer composed of glucose monomers linked together by a glycosidic bond and organized in repeating units; starch is found in most plants and is a principal energy storage product of photosynthesis; starch hydrolysis to several forms of dextrin and glucose.

STILL: an apparatus for distilling liquids, particularly alcohols; it consists of a vessel in which the liquid is vaporized by heat and a cooling device in which the vapour is condensed.

STILLAGE: the non-fermentable residue from the fermentation of a mash to produce alcohol.

STRIPPING SECTION: the section of a distillation column below the feed in which the condensate is progressively decreased in the fraction of more volatile components by stripping.

SUCROSE: a crystalline disaccharide carbohydrate found in many plants, mainly sugarcane, sugar beets and maple trees; $C_{12}H_{22}O_{11}$.

THERMOPHILIC: capable of growing and surviving at high temperatures.

THIN STILLAGE: the water-soluble fraction of a fermented mash plus the mashing water.

VACUUM DISTILLATION: the separation of two or more liquids under reduced vapour pressure; reduces the boiling points of the liquids being separated.

VAPORIZE: to change from a liquid or a solid to a vapour, as in heating water to steam.

VAPOUR PRESSURE: the pressure at any given temperature of a vapour in equilibrium with its liquid or solid form.

WORT: the liquid from a brewing mash preparation following the filtration of fermentable beer. The wort is fermented.

YEAST: single-cell microorganisms (fund) that produce alcohol and CO_2 under anaerobic conditions and acetic acid and CO_2 under aerobic conditions; the microorganism that is capable of changing sugar to alcohol by fermentation.

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NO SMOKING

11. ANNEXES

ANNEX I. ETHANOL MICRODISTILLERY FINANCIAL MODULE

An easy-to-use Microsoft Excel-based financial planning module is available with this guidebook to assess the financial viability of an ethanol microdistillery (EMD) project before completing detailed financial planning for the project. Completing a sound and detailed financial plan is the first step for almost any successful project and collaboration with banks, investors, and development partners.

This annex includes a visual presentation of what the module will do, using two project cases, one for a 2,500-litre per day (LPD) sugarcane-based distillery and one for a 1,000-LPD sugarcane distillery. Distilleries of other sizes, using other feedstocks, can be modelled as well. You may request the Microsoft Excel module from the publisher of this guidebook or from the module developer.

The financial module has five sheets. The first sheet provides the contents of the financial module. The second sheet provides the instructions for its use. The third sheet contains the input assumptions of the module. This is where you, as the user, will describe your project.

Users are required to be careful when inserting assumptions into the model. The details of your project must be well thought out. For example, in setting the daily production capacity of your EMD, the capital cost for equipment purchases, staffing and other parameters must be consistent with the size of the distillery. It is recommended to consult an experienced distillery engineer to ensure that your equipment, staffing, feedstock and other input requirements match your plant capacity. There is a 15 per cent tolerance built into this model between plant capacity and required inputs, but to have reliable results, accurate input values are essential.

The fourth and fifth sheets of the module do not require any interaction by the user, since they are automatically generated by the mathematical models that are built into the module. They make their calculations and projections based on the inputs on the Assumptions page. The fourth sheet provides the investment required and possible financing strategy. The fifth sheet provides financial analysis and projections that will show to you and your lenders and partners the financial desirability of the project.

In the two cases shown here, the 2,500-LPD and the 1,000-LPD sugarcane distilleries, the difference between these two cases are the inputs in the Assumptions page that directly relate to plant capacity. The capital required, staffing, and daily inputs all depend on capacity. However, some investments such as land cost remain fixed since the size difference in the two cases does not significantly affect the land requirement. The financial projections in the last page of each case show better results for the 2,500-LPD EMD, suggesting it is optimal compared to the 1,000-LPD one. However, the capital requirement and essential inputs for the 1,000-LPD EMD are more manageable.

Better financial performance for EMDs up to a size of about 5,000 LPD is to be expected. For EMDs with a capacity higher than 5,000 LPD, the initial investment requirements, skilled labour needs, logistics and environmental costs (effluent treatment and use, etc.) may surpass the gains of having a bigger distillery and more ethanol to sell. This may be especially true for EMDs that are to be built and run by community groups or local companies with less technical capacity, less land under direct control, limited access to finance and limited know-how to mechanize feedstock production and supply chains. As a result, the optimal target may be an EMD sized in the mid-range at about 2,500 LPD.

If there is sufficient land and capital for a larger plant, or if there is not capacity and land for the mid-sized plant, then larger or smaller EMD may be chosen. This financial module enables the user to test this question of size —how big a project should be— by running the module with different assumptions until the results —Worksheets 3 and 4 of the Microsoft Excel module— show that the ideal size has been ascertained. Once this has been done, it is time to turn back to the guidebook to consider the other suggested evaluation criteria.

EMD Financial Module – Table of Contents

I. Preliminary Statements

A. Instructions .... Worksheet 1

B. Assumptions .... Worksheet 2

II. Investment Costs, Financing and Loan Repayment .... Worksheet 3

A. Investment Costs

B. Financing

C. Working Capital Requirement

D. Loan Repayment Schedule

II. Return on Investment, Projected Costs and Revenue .... Worksheet 4

A. Discounted Cash Flow, Total Capital Invested

B. Return on Investment (ROI) and Internal Rate of Return (IRR)

C. Sensitivity Analysis

1. Impact from decrease/increase in factory gate selling price

2. Impact from decrease/increase in feedstock cost

D. Projected Cash Flow Statement

E. Projected Income Statement

F. Projected Balance Sheet

G. Ethanol Production and Cost

H. General and Administrative Expenses

I. Salaries and Benefits

J. Sales Revenue

INSTRUCTIONS FOR USING THE FINANCIAL MODULE

1. Entering Information into the Module

- Enter all inputs & assumptions into the Assumptions worksheet.
- Input cells are shaded blue.
- All cells not shaded in blue have underlying formulas and should not be altered. Altering them will corrupt the model.

2. Viewing the Results:

- Click on the Assumptions tab (tab 3) to view all inputs and underlying assumptions for the financial modelling.
- Click on the Investments costs, Financing and Loan tab (tab 4) to view the breakdown and per cent of total initial investment cost, sources of financing and loan repayment schedule.
- Click on the Costs and Revenue tab (tab 5) to view the production costs, general and administration costs and growth in revenues over the 15-year projection period.
- Scroll in this tab to find the Cash Flow Statement, Income Statement, and Balance Sheet for the 15-year projection.
- Data for these reports are drawn automatically from the Assumptions worksheet. You do not need to add anything to these sheets. They are automatically generated using the underlying formulae.

3. Customizing the Financial Module:

- To protect the sheets, choose Protection and select Protect Worksheet.
- The variable inputs in the Assumptions worksheet are designed to accommodate most business models; however, the financial model can be tailored to suit specific business needs or operating procedures (such as the addition of a farm operation).
- Structural changes to the module require modifications of the underlying formulas. To make such changes, please contact UNIDO or the developer of this module.

4. Printing Financial Statements:

- To print all of the reports in the module, choose Print from the FILE menu and select "Entire Workbook". Click OK.
- To print an individual worksheet (such as the Assumptions sheet) click on the tab of the worksheet you would like to print, choose Print from the FILE menu, and select "Selected Sheet". Click OK.

Ethanol Micro Distillery Financial Model: Input Assumptions 2,500 LPD Plant

Company name to be used on all statements	Company name
Project title to be used on all statements	Project title
Date project implementation first begins	1 January 2023
Project implementation period	1.0 year(s)
Date project operation first begins	1 January 2024
End of first operation year	2 January 2025

General Assumptions:	
Project life* *(in years)*:	15 years
Exchange rate: local currency units per $1:	
Plant capacity *(in LPD)*:	2,500 litres/day
Average ethanol production *(in LPD)*:	2,500 litres/day
Number of working days *(in days per year)*:	300 days/year
Sugar cane feedstock price *(in $ per tonne)*:	$15/tonne
Ethanol yield *(in litres per tonne of feedstock input)*:	70 litres/tonne
Ethanol factory gate price *(in $ per litre)*:	$0.70/litre
Corporate profit tax *(as per cent of annual profit)*:	20.00%

Investments	
Initial Investment (including taxes, if any):	
Land cost	$10,000.00
Civil works and buildings	$20,000.00
Plant machinery, equipment, commissioning	
Sugarcane milling, fermentation, distillation, Boiler & storage unit	$475,000.00
Generator, 50 KVA diesel generator	$20,000.00
Vinasse treatment	$125,000.00
Laboratory equipment	$5,000.00
Transport of plant machinery, equipment to site	$10,000.00
Plant commissioning and staff training	$25,000.00
Office equipment and furniture	$10,000.00
Vehicles	$0.00
Pre-operative expenses	$10,000.00
Import duty and VAT	$0.00
Total	$710,000.00

Financing:

Loan(s) amount	$419,500.00
Grace period (in years)	2 years
Loan repayment period (in years)	5 years
Long-term loan borrowing interest rate (in percentage per year)	10.00%

Depreciation/amortization rate:

Land cost	10.00%
Civil works and buildings (in percentage):	5.00%
Plant machinery, equipment and commissioning (in percentage):	6.67%
Office equipment and furniture (in percentage):	20.00%
Vehicle and other fixed assets (in percentage):	20.00%
Pre-operating expenses (in percentage):	20.00%

Working capital requirements

Sugarcane feedstock	90 days
Diesel fuel	90 days
Chemicals	3 months
Salaries and wages	3 months

O&M Costs

Diesel consumption	50 litres/day
Purchase price of diesel fuel	$0.80/litre
Chemical inputs	$5,145 per month
Water bill	$250 per month
Other costs	$500 per month
Repair & maintenance (as per cent of plant machinery cost)	1.00%

Explainer: *Only blue-shaded cells are to be completed. Note that the "Project life" cell is fixed at 15 years. Do not alter cells not shaded in blue.*

Salaries and benefits

Position	Number	Salary
General Manager	1 number	$400/month
Process Engineer	1 number	$350/month
Boiler Operators	3 number	$175/month
Fermentation & Distillation	6 number	$175/month
Feedstock preparation	3 number	$150/month
Administration & General Service	1 number	$175/month
Accountant	1 number	$200/month
Cashier	1 number	$150/month
Marketing	1 number	$150/month
Driver	0 number	$120/month
Cleaning	1 number	$100/month
Guards	3 number	$100/month
Other		
Other		

Provident Fund (as a percentage of salaries)	2.50%
Salary Increases (as an annual percentage):	2.00%

Staff uniforms	$500 year
Telecom & Posts	$600 year
Marketing Expenses	$5,000 year
Office Supplies	$600 year
Legal & Audit fees	$1,000 year
Fuel and Lubricants	$3,000 year
Miscellaneous expenses	$2,000 year

Personnel Insurance (as a percentage of salaries)	2.00%
Plant Insurance (as a percentage of investment cost)	1.00%

Chemical Inputs and Costs Worksheet			
Input requirement for 30 days for 2500 litres/day plant capacity			
Description	**Unit**	**Quantity**	**Price $**
Active Dry Yeast (saccharomyces cerevisiae)	kg	25	250
Urea	kg	250	250
$ZnSO_4$ and $MgSO_4$	kg	125	1,250
Phosphoric Acid (H_3PO_4)	litres	125	1,625
Sulfuric Acid (H_2SO_4)	litres	125	500
Polybion Injection of Vitamin B-complex (2 ml)	vials	38	275
Detergent for fermenter cleaning (1 Kg)	kg	50	175
Cleaning material (brush)	piece	10	75
Lime (powder)	kg	375	175
Antibiotic (oxytetracycline)		750	75
Penicillin (1 million units/vial)	vials	188	250
DAP (Disodium Ammonium Phosphate)	kg	38	20
Antifoam agent	litres	125	100
Water softener (NaCl)	kg	125	50
Cooling tower cleaner (anti-scaling, anti-algae, anti-bacteria)	litres	125	75
Total cost			5,145
Chemical cost, per litre of ethanol			0.07

Note: *Enter the total cost value from this worksheet into the Assumptions table under O&M Costs – Chemical Inputs.*

Automatically generated reports

Note: *The following tables are automatically generated output tables derived from the assumption entered into the blue-shaded cells in the Assumptions tables.*

Investment Costs, Financing and Loan Repayment

Initial Investment Cost	Amount ($)	%
Land cost	10,000	1.3
Civil works and buildings	20,000	2.5
Plant machinery, equipment, commissioning	660,000	83.6
Office equipment and furniture	10,000	1.3
Vehicles	-	-
Pre-operative expenses	10,000	1.3
Import duty and VAT	-	
Working capital requirement	79,088	10.0
Total initial investment	**789,088**	100.0
Financed by:		
Loan amount	419,500	53.2
Equity contribution	369,588	46.8

Working Capital Requirement	
Sugarcane feedstock	48,214
Diesel fuel	3,600
Chemicals	15,435
Salaries and wages	11,839
Total working capital requirements	**79,088**

Automatically generated reports: Loan Repayment Schedule

Loan Repayment Schedule

		Grace period		Loan Payment period				
	Jan 23	Jan 24	Jan 25	Jan 26	Jan 27	Jan 28	Jan 29	Jan 30
Loan amount	419,500							
Interest due	-	41,950	46,145	50,760	42,445	33,300	23,239	12,173
Cumulative interest due	-	41,950	88,095	138,855	181,300	214,599	237,838	250,011
Interest Payment	-	-	-	65,189	58,318	50,760	42,445	33,300
Cumulative interest payment	-	-	-	65,189	123,507	174,267	216,712	250,011
Interest on loan balance	-	41,950	88,095	73,665	57,793	40,333	21,127	-
Principal repayment	-	-	-	68,713	75,584	83,143	91,457	100,603
Cumulative principal payment	-	-	-	68,713	144,297	227,440	318,897	419,500
Loan balance	419,500	419,500	419,500	350,787	275,203	192,060	100,603	-

	Year	Balance beginning of year	Interest due	Interest payment	Principal payment	Total loan payment	Balance year end
Loan receipt	Jan 23	419,500		-	-	-	419,500
Grace period	Jan 24	419,500	41,950	-	-	-	461,450
Grace period	Jan 25	461,450	46,145	-	-	-	507,595
1	Jan 26	507,595	50,760	65,189	68,713	133,902	424,452
2	Jan 27	424,452	42,445	58,318	75,584	133,902	332,995
3	Jan 28	332,995	33,300	50,760	83,143	133,902	232,392
4	Jan 29	232,392	23,239	42,445	91,457	133,902	121,729
5	Jan 30	121,729	12,173	33,300	100,603	133,902	-

Explainer: *The loan calculation is based on the loan amount, interest rate and payback period that are inserted on the Assumptions page. A two-year grace period has been requested. Loan payback begins in the third year and must be repaid in five years. Interest on each year's balance and accumulated interest are shown. The tables show what is to be paid each year to repay the loan principal and interest to complete payment in five years. The Worksheet automatically calculates what must be paid each year for the loan asked for on the Assumptions page. These values are calculated automatically.*

Automatically generated reports: Costs, Revenue, ROI

Cash Outflow	Jan 23	Jan 25	Jan 26	Jan 27	Jan 28	Jan 29	Jan 30	Jan 31
Fixed investment								
Land cost	10,000	-	-	-	-	-	-	-
Civil works and buildings	20,000	-	-	-	-	-	-	-
Plant machinery, equipment, commissioning	660,000	-	-	-	-	-	-	-
Office equipment and furniture	10,000	-	-	-	-	10,000	-	-
Vehicles	-	-	-	-	-	-	-	-
Pre-operative expenses	10,000	-	-	-	-	-	-	-
Interest payment on long-term loan	-	-	-	65,189	58,318	50,760	42,445	33,300
Repayment of Long-term Loan	-	-	-	68,713	75,584	83,143	91,457	100,603
Profit tax	-	-	23,919	22,890	21,774	23,240	24,868	26,675
Total Cash Outflow	710,000	-	23,919	156,793	155,676	167,142	158,770	160,577
Cash inflow	-	-						
Operating Income before depreciation	-	209,544	208,597	207,630	206,645	205,640	204,615	203,569
Total Cash inflow	-	209,544	208,597	207,630	206,645	205,640	204,615	203,569
Net cash flow	**(710,000)**	**209,544**	**184,678**	**50,838**	**50,969**	**38,498**	**45,844**	**42,992**

Discounted Cash Flow - Total Capital Invested

Automatically generated reports: Costs, Revenue, ROI

% Change in Ethanol Factory Price	Ethanol retail price $/litre	IRR	NPV at borrowing interest rate	NPV at 5% discount rate	NPV at 7.5% discount rate
		15.4%	$215,243	$577,744	$369,807
30%	0.91	37.1%	$1,112,518	$1,851,875	$1,431,685
25%	0.88	33.5%	$962,972	$1,639,520	$1,254,706
20%	0.84	29.9%	$813,426	$1,427,165	$1,077,726
15%	0.81	26.3%	$663,881	$1,214,810	$900,746
10%	0.77	22.6%	$514,335	$1,002,454	$723,766
5%	0.74	19.0%	$364,789	$790,099	$546,787
0%	0.70	15.4%	$215,243	$577,744	$369,807
-10%	0.63	7.8%	($83,848)	$153,034	$15,847
-15%	0.60	3.9%	($233,394)	($59,321)	($161,132)
-20%	0.56	-0.4%	($382,940)	($271,676)	($338,112)
-25%	0.53	-5.4%	($541,719)	($495,544)	($525,385)
-30%	0.49	-12.0%	($713,411)	($737,792)	($727,980)

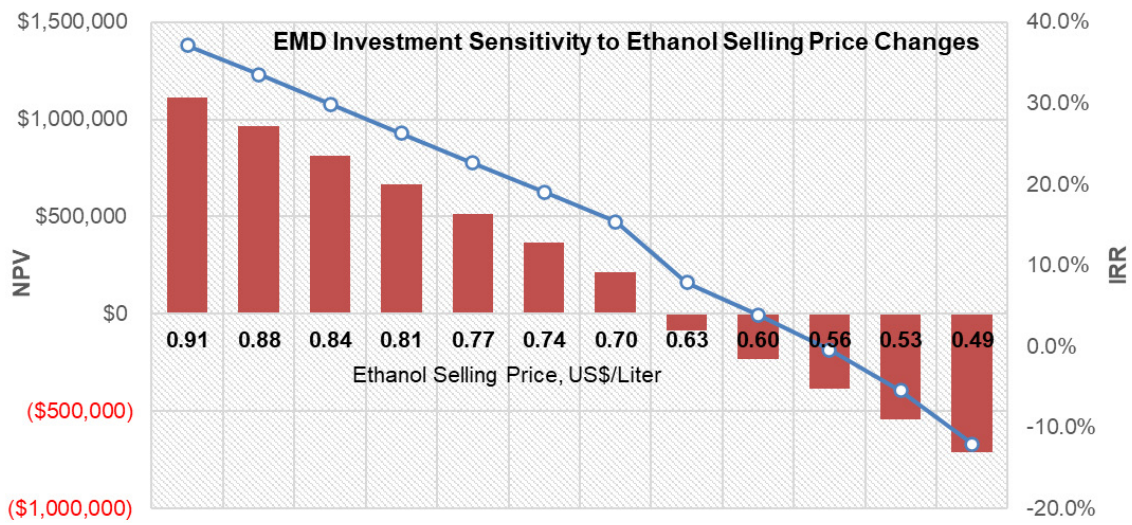
ROI

NPV at long-term loan borrowing interest rate	$215,243.21
NPV at 5% discount rate	$577,744.33
NPV at 7.5% discount rate	$369,806.80
IRR on Equity	15.4%

Explainer: *The NPV is calculated at the borrowing rate entered in the Assumptions page. In this case, 10% has been entered. NPV at 5% and 7.5% are shown to demonstrate the impact of borrowing rate on the investment.*

Automatically generated reports: Costs, Revenue, ROI

Cash Outflow	Jan 32	Jan 33	Jan 34	Jan 35	Jan 36	Jan 37	Jan 38	Jan 39
Fixed investment								
Land cost	-	-	-	-	-	-	-	-
Civil works and buildings	-	-	-	-	-	-	-	-
Plant machinery, equipment, commissioning	-	-	-	-	-	-	-	-
Office equipment and furniture	-	-	10,000	-	-	-	-	-
Vehicles	-	-	-	-	-	-	-	-
Pre-operative expenses	-	-	-	-	-	-	-	-
Interest payment on long-term loan	-	-	-	-	-	-	-	-
Repayment of Long-term Loan	-	-	-	-	-	-	-	-
Profit tax	28,679	30,901	30,683	30,461	30,435	30,204	29,968	29,728
Total Cash Outflow	28,679	30,901	40,683	30,461	30,435	30,204	29,968	29,728
Cash inflow								
Operating Income before depreciation	202,503	201,415	200,305	199,173	198,019	196,841	195,640	194,415
Total Cash inflow	202,503	201,415	200,305	199,173	198,019	196,841	195,640	194,415
Net cash flow	**173,823**	**170,514**	**159,622**	**168,712**	**167,584**	**166,637**	**165,672**	**164,687**



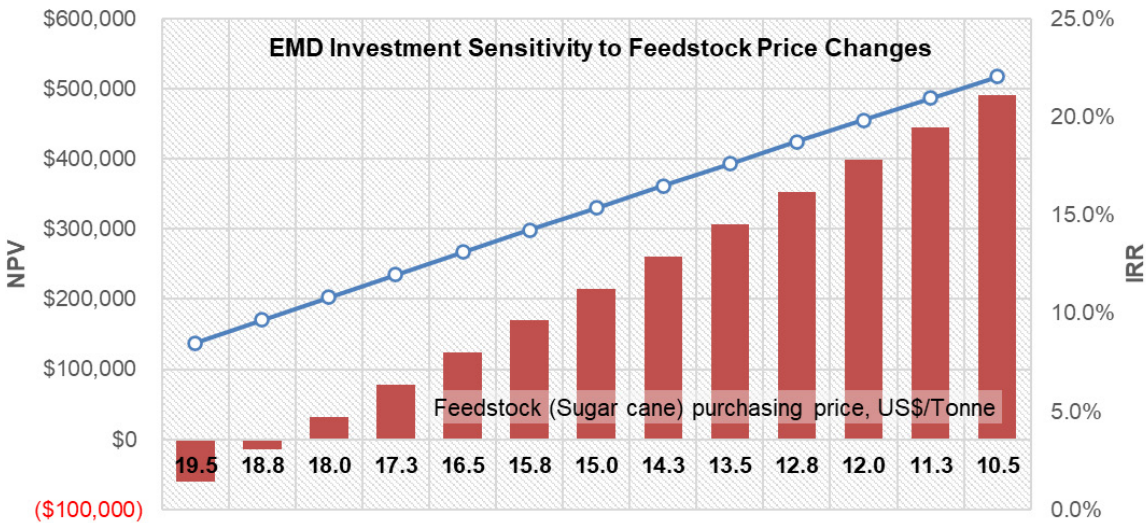
Automatically generated reports: ROI, Sensitivity Analysis

% Change in Sugarcane Cost	Sugarcane Cost $/tonne	IRR	NPV at borrowing interest rate	NPV at 5% discount rate	NPV at 7.5% discount rate
		15.4%	$215,243	$577,744	$369,807
30%	19.5	8.5%	($59,433)	$187,704	$44,742
25%	18.8	9.7%	($13,653)	$252,711	$98,919
20%	18.0	10.8%	$32,126	$317,718	$153,097
15%	17.3	12.0%	$77,905	$382,724	$207,274
10%	16.5	13.1%	$123,685	$447,731	$261,452
5%	15.8	14.2%	$169,464	$512,738	$315,629
0%	15.0	15.4%	$215,243	$577,744	$369,807
-5%	14.3	16.5%	$261,023	$642,751	$423,984
-10%	13.5	17.6%	$306,802	$707,758	$478,162
-15%	12.8	18.7%	$352,581	$772,764	$532,339
-20%	12.0	19.8%	$398,361	$837,771	$586,517
-25%	11.3	20.9%	$444,140	$902,778	$640,694
-30%	10.5	22.0%	$489,919	$967,784	$694,872

Explainer: Sensitivity Analysis

Feedstock cost and ethanol selling price have the most impact on EMD investment return. The financial model includes two sensitivity analyses, one analysing feedstock cost and the other analysing ethanol selling price, while other assumptions remain the same.

The first sensitivity analysis looks at price increase and decrease from the base ethanol selling price of $0.70. The graph shows the impact on IRR and NPV of the distillery investment. An increase in selling price brings a higher investment return. A decrease to $0.63/litre results in an investment loss.



The second sensitivity analysis *analyses cost changes to purchase feedstock. A decrease in feedstock cost brings a better ROI. An increase in feedstock cost by 30% (in this case to $19.5/tonne) results in a decreased return, lowering the IRR to 8.5%.*

These results are true for the case presented here and will vary with input assumptions.

Automatically generated reports: Cash Flow, Income Statement, Balance Sheet

Projected Cash flow Statement

Inflow of funds	Jan 23	Jan 25	Jan 26	Jan 27	Jan 28	Jan 29	Jan 30	Jan 31
Increase in equity capital	369,588							
Long-term loans received	419,500							
Operating income before depreciation	-	209,544	208,597	207,630	206,645	205,640	204,615	203,569
Total cash inflow	789,088	209,544	208,597	207,630	206,645	205,640	204,615	203,569
Outflow of funds								
Increase/ decrease in Fixed Assets								
Land cost	10,000		-	-	-	-	-	-
Civil works and buildings	20,000		-	-	-	-	-	-
Plant machinery, equipment, commissioning	660,000		-	-	-	-	-	-
Office equipment and furniture	10,000		-	-	-	10,000	-	-
Vehicles	-		-	-	-	-	-	-
Pre-operative expenses	10,000							
Interest payment on long-term loan	-	-	-	65,189	58,318	50,760	42,445	33,300
Repayment of long-term loan	-	-	-	68,713	75,584	83,143	91,457	100,603
Profit tax paid		-	23,919	22,890	21,774	23,240	24,868	26,675
Dividends paid			-	64,093	60,968	65,072	69,631	74,690
Total cash outflow	710,000	-	23,919	220,885	216,644	232,214	228,401	235,268
Cash surplus/ deficit	89,088	209,544	184,678	(13,255)	(9,999)	(26,574)	(23,786)	(31,699)
Cumulative cash balance	89,088	298,632	483,309	470,054	460,055	433,481	409,695	377,996

Inflow of funds	Jan 32	Jan 33	Jan 34	Jan 35	Jan 36	Jan 37	Jan 38	Jan 39
Increase in equity capital								
Long-term loans received								
Operating income before depreciation	202,503	201,415	200,305	199,173	198,019	196,841	195,640	194,415
Total cash inflow	202,503	201,415	200,305	199,173	198,019	196,841	195,640	194,415
Outflow of funds								
Increase/ decrease in Fixed Assets								
Land cost	-	-	-	-	-	-	-	-
Civil works and buildings	-	-	-	-	-	-	-	-
Plant machinery, equipment, commissioning	-	-	-	-	-	-	-	-
Office equipment and furniture	-	-	10,000	-	-	-	-	-
Vehicles	-	-	-	-	-	-	-	-
Pre-operative expenses								
Interest payment on long-term loan	-	-	-	-	-	-	-	-
Repayment of long-term loan	-	-	-	-	-	-	-	-
Profit tax paid	28,679	30,901	30,683	30,461	30,435	30,204	29,968	29,728
Dividends paid	80,302	86,521	85,912	85,291	85,217	84,570	83,911	83,238
Total cash outflow	108,981	117,422	126,595	115,752	115,652	114,774	113,879	112,966
Cash surplus/ deficit	93,521	83,993	73,710	83,421	82,367	82,067	81,761	81,448
Cumulative cash balance	471,518	555,511	629,220	712,642	795,009	877,076	958,836	1,040,285

Projected Income Statement

Revenue	Jan 23	Jan 25	Jan 26	Jan 27	Jan 28	Jan 29	Jan 30	Jan 31
Ethanol Sales		525,000	525,000	525,000	525,000	525,000	525,000	525,000
By-product sales		-	-	-	-	-	-	-
Total Revenue		525,000	525,000	525,000	525,000	525,000	525,000	525,000
Cost of sales		249,704	249,704	249,704	249,704	249,704	249,704	249,704
Gross profit		275,296	275,296	275,296	275,296	275,296	275,296	275,296
General Administrative and Sales								
Salaries		47,355	48,302	49,268	50,254	51,259	52,284	53,329
Staff uniforms		500	500	500	500	500	500	500
Telecom & Posts		600	600	600	600	600	600	600
Marketing Expenses		5,000	5,000	5,000	5,000	5,000	5,000	5,000
Office Supplies		600	600	600	600	600	600	600
Legal & Audit fees		1,000	1,000	1,000	1,000	1,000	1,000	1,000
Fuel and Lubricants		3,000	3,000	3,000	3,000	3,000	3,000	3,000
Miscellaneous expenses		2,000	2,000	2,000	2,000	2,000	2,000	2,000
Personnel Insurance		947	947	947	947	947	947	947
Plant Insurance		4,750	4,750	4,750	4,750	4,750	4,750	4,750
Depreciation		48,000	48,000	48,000	48,000	48,000	48,000	48,000
Sub-total		113,752	114,699	115,665	116,651	117,656	118,681	119,727
Operating Profit		161,544	160,597	159,630	158,645	157,640	156,615	155,569
Interest on long-term borrowing		41,950	46,145	50,760	42,445	33,300	23,239	12,173
Profit before taxes		119,594	114,452	108,871	116,200	124,341	133,376	143,396
Profit tax		23,919	22,890	21,774	23,240	24,868	26,675	28,679
Net profit after tax		95,675	91,561	87,097	92,960	99,472	106,701	114,717
Dividends payable			64,093	60,968	65,072	69,631	74,690	80,302
Retained Profit		95,675	27,468	26,129	27,888	29,842	32,010	34,415

Revenue	Jan 32	Jan 33	Jan 34	Jan 35	Jan 36	Jan 37	Jan 38	Jan 39
Ethanol Sales	525,000	525,000	525,000	525,000	525,000	525,000	525,000	525,000
By-product sales	-	-	-	-	-	-	-	-
Total Revenue	525,000	525,000	525,000	525,000	525,000	525,000	525,000	525,000
Cost of sales	249,704	249,704	249,704	249,704	249,704	249,704	249,704	249,704
Gross profit	275,296	275,296	275,296	275,296	275,296	275,296	275,296	275,296
General Administrative and Sales								
Salaries	54,396	55,484	56,594	57,725	58,880	60,058	61,259	62,484
Staff uniforms	500	500	500	500	500	500	500	500
Telecom & Posts	600	600	600	600	600	600	600	600
Marketing Expenses	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Office Supplies	600	600	600	600	600	600	600	600
Legal & Audit fees	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Fuel and Lubricants	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
Miscellaneous expenses	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000
Personnel Insurance	947	947	947	947	947	947	947	947
Plant Insurance	4,750	4,750	4,750	4,750	4,750	4,750	4,750	4,750
Depreciation	48,000	48,000	48,000	47,000	47,000	47,000	47,000	47,000
Sub-total	120,793	121,881	122,991	123,123	124,277	125,455	126,656	127,881
Operating Profit	154,503	153,415	152,305	152,173	151,019	149,841	148,640	147,415
Interest on long-term borrowing	-	-	-	-	-	-	-	-
Profit before taxes	154,503	153,415	152,305	152,173	151,019	149,841	148,640	147,415
Profit tax	30,901	30,683	30,461	30,435	30,204	29,968	29,728	29,483
Net profit after tax	123,602	122,732	121,844	121,739	120,815	119,873	118,912	117,932
Dividends payable	86,521	85,912	85,291	85,217	84,570	83,911	83,238	82,552
Retained Profit	37,081	36,820	36,553	36,522	36,244	35,962	35,674	35,380

Projected Balance Sheet

Assets	Jan 23	Jan 25	Jan 26	Jan 27	Jan 28	Jan 29	Jan 30	Jan 31
Current assets								
Cash	89,088	298,632	483,309	470,054	460,055	433,481	409,695	377,996
Inventory								
Total current assets	89,088	298,632	483,309	470,054	460,055	433,481	409,695	377,996
Fixed assets **a**/								
Land cost	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Civil works and buildings	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
Plant machinery, equipment, commissioning	660,000	660,000	660,000	660,000	660,000	660,000	660,000	660,000
Office equipment and furniture	10,000	10,000	10,000	10,000	10,000	20,000	20,000	20,000
Vehicles	-	-	-	-	-	-	-	-
Sub-total	700,000	700,000	700,000	700,000	700,000	710,000	710,000	710,000
Less: accumulated depreciation **b**/	-	48,000	96,000	144,000	192,000	240,000	288,000	336,000
Net Fixed assets	700,000	652,000	604,000	556,000	508,000	470,000	422,000	374,000
Total Assets	**789,088**	**950,632**	**1,087,309**	**1,026,054**	**968,055**	**903,481**	**831,695**	**751,996**
Liabilities and Equity								
Liabilities								
Long-term Loans	419,500	419,500	419,500	350,787	275,203	192,060	100,603	-
Interest payable	-	41,950	88,095	73,665	57,793	40,333	21,127	-
Tax payable		23,919	22,890	21,774	23,240	24,868	26,675	28,679
Dividends payable		-	64,093	60,968	65,072	69,631	74,690	80,302
Total Liabilities	419,500	485,369	594,578	507,194	421,307	326,891	223,095	108,981
Equity								
Share capital	369,588	369,588	369,588	369,588	369,588	369,588	369,588	369,588
Accumulated Retained earnings	-	95,675	123,143	149,272	177,160	207,002	239,012	273,427
Total equity	369,588	465,263	492,731	518,860	546,748	576,590	608,600	643,015
Total Liabilities and equity	**789,088**	**950,632**	**1,087,309**	**1,026,054**	**968,055**	**903,481**	**831,695**	**751,996**

a/ Fixed assets							
Land cost	10,000						
Civil works and buildings	20,000						
Plant machinery, equipment, commissioning	660,000						
Office equipment and furniture	10,000				10,000		
Vehicles	-						
Sub-total	700,000						
Total investment on fixed assets	700,000	-	-	-	-	10,000	-	-
Cumulative balance	700,000	700,000	700,000	700,000	700,000	710,000	710,000	710,000
b/ Accumulated Depreciation							
Depreciation expenses							
Land cost		1,000	1,000	1,000	1,000	1,000	1,000	1,000
Civil works and buildings		1,000	1,000	1,000	1,000	1,000	1,000	1,000
Plant machinery, equipment, commissioning		44,000	44,000	44,000	44,000	44,000	44,000	44,000
Office equipment and furniture		2,000	2,000	2,000	2,000	2,000	2,000	2,000
Vehicles		-	-	-	-	-	-	-
Sub-total		48,000	48,000	48,000	48,000	48,000	48,000	48,000
Less: accumulated depreciation b/							
Depreciation charge		48,000	48,000	48,000	48,000	48,000	48,000	48,000
Accumulated depreciation		48,000	96,000	144,000	192,000	240,000	288,000	336,000
Book value of Fixed assets End of Year		652,000	604,000	556,000	508,000	470,000	422,000	374,000

Explainer: *Worksheet 4 of the financial module also provides the following reports, which have not been included here.*

- ✓ ***Ethanol Production and Cost:*** *This table shows ethanol production cost, sugarcane price, ethanol yield, sugarcane feedstock input, sugarcane feedstock cost, chemical inputs, diesel fuel, water, repairs and maintenance, other costs and total production cost.*
- ✓ ***General and Administrative Expenses:*** *This table summarizes salaries, staff uniforms, telecom & mail costs, marketing expenses, office supplies, legal and audit fees, fuel and lubricants, miscellaneous expenses, and insurance for plants and employees.*
- ✓ ***Salaries and Benefits:*** *This report summarizes monthly and annual salaries, by individual and category.*
- ✓ ***Sales Revenue:*** *This report reviews selling price, sales volume and sales revenue, of ethanol and by-products.*

Ethanol Micro Distillery Financial Model: Input Assumptions 1,000 LPD Plant

Company name to be used on all statements	Company name
Project title to be used on all statements	Project title
Date project implementation first begins	1 January 2024
Project implementation period	10 years
Date project operation first begins	1 January 2024
End of first operation year	2 January 2025
General Assumptions:	
Project life* *(in years)*:	15 years
Exchange rate: local currency units per $1:	
Plant capacity *(in LPD)*:	1,000 litres/day
Average ethanol production (in LPD):	1,000 litres/day
Number of working days (in days per year):	300 days/year
Sugarcane feedstock price (in $ per tonne):	$15/tonne
Ethanol yield (in litres per tonne of feedstock input):	70 litres/tonne
Ethanol factory gate price (in $ per litre):	$0.95/litre
Corporate profit tax (as per cent of annual profit):	20.00%
Investments	
Initial Investment (including taxes, if any):	
Land cost	$10,000.00
Civil works and buildings	$15,000.00
Plant machinery, equipment, commissioning	
Sugarcane milling, fermentation, distillation, Boiler & storage unit	$300,000.00
Generator, 50 KVA diesel generator	$20,000.00
Vinasses treatment	$100,000.00
Laboratory Equipment	$5,000.00
Transport of plant machinery, equipment to site	$10,000.00
Plant commissioning and staff training	$25,000.00
Office equipment and furniture	$10,000.00
Vehicles	$0.00
Pre-operative expenses	$10,000.00
Import duty and VAT	$0.00
Total	$505,000.00

Explainer: *Only blue-shaded cells are to be completed.*
Note that the project life cell is fixed at 15 years. Do not alter non-shaded cells.

Financing:	
Loan(s) amount	$250,000.00
Grace period (in years)	2 years
Loan repayment period (in years)	5 years
Long-term Lan Borrowing interest rate (in percentage per year)	10.00%
Depreciation/amortization rate:	
Land cost	10.00%
Civil works and buildings (in percentage):	5.00%
Plant machinery, equipment and commissioning (in percentage):	6.67%
Office equipment and furniture (in percentage):	20.00%
Vehicle and other fixed assets (in percentage):	20.00%
Pre-operating expenses (in percentage):	20.00%
Working capital requirements	
Sugarcane feedstock	90 days
Diesel fuel	90 days
Chemicals	3 months
Salaries and wages	3 months
O&M Costs	
Diesel consumption	40 litres/day
Purchase price of diesel fuel	$0.80/litre
Chemical inputs	$2,058/month
Water bill	$200/month
Other costs	$350/month
Repair & Maintenance (as a percentage of plant machinery cost)	1.00%

Salaries and benefits

Position	Number	Salary
General Manager	1 number	$300/month
Process Engineer	1 number	$300/month
Boiler Operators/Feedstock preparation	3 number	$150/month
Fermentation & Distillation	3 number	$150/month
Administration & General Service	1 number	$175/month
Accountant	1 number	$200/month
Cashier	1 number	$150/month
Marketing	1 number	$150/month
Driver	0 number	$120/month
Cleaning	1 number	$100/month
Guards	3 number	$100/month
Other		
Other		

Provident Fund (as a percentage of salaries)	2.50%
Salary Increases (as an annual percentage):	2.00%

Staff uniforms	$500 year
Telecom & Posts	$600 year
Marketing Expenses	$3,000 year
Office Supplies	$500 year
Legal & Audit fees	$1,000 year
Fuel and Lubricants	$2,000 year
Miscellaneous expenses	$1,500 year
Personnel Insurance (as a percentage of salaries)	2.00%
Plant Insurance (as a percentage of investment cost)	1.00%

Chemical Input and Costs Worksheet

Input requirement for 30 Days for 1000 litres/day plant capacity

Description	**Unit**	**Quantity**	**Price, $**
Active-Dry Yeast (saccharomyces cerevisiae)	kg	10	100
Urea	kg	100	100
$ZnSO_4$ and $MgSO_4$	kg	50	500
Phosphoric Acid (H_3PO_4)	litres	50	650
Sulfuric Acid (H_2SO_4)	litres	50	200
Polybion Injection of Vitamin B-complex (2ml)	vials	15	110
Detergent for fermenter cleaning (1 Kg)	kg	20	70
Cleaning material (brush)	piece	4	30
Lime (powder)	kg	150	70
Antibiotic (oxytetracycline)		300	30
Penicillin (1 million units per vial)	vials	75	100
DAP (Disodium Ammonium Phosphate)	kg	15	8
Antifoam Agent	litres	50	40
Water softener (NaCl)	kg	50	20
Cooling tower cleaner (anti scaling, anti-algae, anti-bacteria)	litres	50	30
Total cost			2,058
Chemical cost, per litre of ethanol			0.03

Note: *Enter the total cost value from this worksheet into the Assumptions tables under O&M Costs – Chemical Inputs.*

Explainer: *Above are the input assumptions for the 1,000-LPD distillery. Following are the three most important financial statements: the balance sheet, the income statement, and the cash flow statement. These three statements together show the assets and liabilities of a business, its revenues, and costs, as well as its cash flows from operating, investing, and financing activities.*

Initial Investment Cost	Amount ($)	%
Land cost	10,000	1.8
Civil works and buildings	15,000	2.8
Plant machinery, equipment, commissioning	460,000	85.0
Office equipment and furniture	10,000	1.8
Vehicles	-	-
Pre-operative expenses	10,000	1.8
Working capital requirement	36,258	
Import duty and VAT	-	
Total initial investment	**541,258**	**93.3**
Financed by:		
Loan amount	250,000	46.2
Equity contribution	291,258	53.8

Working Capital Requirement	
Sugarcane feedstock	19,286
Diesel fuel	2,880
Chemicals	6,174
Salaries and wages	7,918
Total working capital requirements	**36,258**

EMD 1,000 LPD Key Financial Reports: Cash Flow, Income Statement, Balance Sheet

Loan Repayment Schedule

		Grace period		Loan Payment period				
	Jan 24	Jan 25	Jan 26	Jan 27	Jan 28	Jan 29	Jan 30	Jan 31
Loan amount	250,000							
Interest due	-	25,000	27,500	30,250	25,295	19,845	13,849	7,254
Cumulative interest due	-	25,000	52,500	82,750	108,045	127,890	141,739	148,994
Interest payment	-	-	-	38,849	34,754	30,250	25,295	19,845
Cumulative interest payment	-	-	-	38,849	73,604	103,854	129,149	148,994
Interest on loan balance	-	25,000	52,500	43,901	34,441	24,036	12,590	-
Principal repayment	-	-	-	40,949	45,044	49,549	54,504	59,954
Cumulative principal payment	-	-	-	40,949	85,994	135,542	190,046	250,000
Loan balance	250,000	250,000	250,000	209,051	164,006	114,458	59,954	-

Projected Cash Flow Statement

Inflow of funds	Jan 24	Jan 25	Jan 26	Jan 27	Jan 28	Jan 29	Jan 30	Jan 31
Increase in equity capital	291,258							
Long-term loans received	250,000							
Operating income before depreciation	-	131,162	130,529	129,883	129,224	128,552	127,866	127,166
Total cash inflow	**541,258**	**131,162**	**130,529**	**129,883**	**129,224**	**128,552**	**127,866**	**127,166**
Outflow of funds								
Increase/decrease in Fixed Assets								
Land cost	10,000		-	-	-	-	-	-
Civil works and buildings	15,000		-	-	-	-	-	-
Plant machinery, equipment, commissioning	460,000		-	-	-	-	-	-
Office equipment and furniture	10,000		-	-	-	10,000	-	-
Vehicles	-		-	-	-	-	-	-
Pre-operative expenses	10,000							

Inflow of funds	Jan 24	Jan 25	Jan 26	Jan 27	Jan 28	Jan 29	Jan 30	Jan 31
Interest payment on long-term loan	-	-	-	38,849	34,754	30,250	25,295	19,845
Repayment of long-term loan	-	-	-	40,949	45,044	49,549	54,504	59,954
Profit tax paid		-	14,349	13,722	13,043	13,902	14,858	15,920
Dividends paid			-	38,423	36,521	38,927	41,602	44,576
Total cash outflow	**505,000**	**-**	**14,349**	**131,944**	**129,363**	**142,628**	**136,259**	**140,295**
Cash surplus/deficit	46,258	131,162	116,180	(2,061)	(139)	(14,076)	(8,393)	(13,128)
Cumulative cash balance	46,258	177,420	293,600	291,539	291,399	277,323	268,930	255,802

Inflow of funds	Jan 32	Jan 33	Jan 34	Jan 35	Jan 36	Jan 37	Jan 38	Jan 39
Increase in equity capital								
Long-term loans received								
Operating income before depreciation	126,453	125,725	124,983	124,226	123,454	122,666	121,863	121,044
Total cash inflow	**126,453**	**125,725**	**124,983**	**124,226**	**123,454**	**122,666**	**121,863**	**121,044**
Outflow of funds								
Increase/decrease in Fixed Assets								
Land cost	-	-	-	-	-	-	-	-
Civil works and buildings	-	-	-	-	-	-	-	-
Plant machinery, equipment, commissioning	-	-	-	-	-	-	-	-
Office equipment and furniture	-	-	10,000	-	-	-	-	-
Vehicles	-	-	-	-	-	-	-	-
Pre-operative expenses								
Interest payment on long-term loan	-	-	-	-	-	-	-	-
Repayment of long-term loan	-	-	-	-	-	-	-	-
Profit tax paid	17,099	18,407	18,262	18,113	18,162	18,007	17,850	17,689
Dividends paid	47,877	51,540	51,133	50,717	50,853	50,421	49,980	49,530
Total cash outflow	64,976	69,948	79,395	68,831	69,015	68,428	67,830	67,219
Cash surplus/deficit	61,477	55,778	45,589	55,396	54,439	54,238	54,033	53,824
Cumulative cash balance	317,278	373,056	418,645	474,040	528,479	582,717	636,750	690,575

Projected Income Statement

Revenue	Jan 24	Jan 25	Jan 26	Jan 27	Jan 28	Jan 29	Jan 30	Jan 31
Ethanol Sales		285,000	285,000	285,000	285,000	285,000	285,000	285,000
By-product sales		-	-	-	-	-	-	-
Total Revenue		285,000	285,000	285,000	285,000	285,000	285,000	285,000
Cost of sales		109,432	109,432	109,432	109,432	109,432	109,432	109,432
Gross profit		175,568	175,568	175,568	175,568	175,568	175,568	175,568
General Administrative and Sales								
Salaries		31,673	32,306	32,952	33,611	34,283	34,969	35,668
Staff uniforms		500	500	500	500	500	500	500
Telecom & Posts		600	600	600	600	600	600	600
Marketing Expenses		3,000	3,000	3,000	3,000	3,000	3,000	3,000
Office Supplies		500	500	500	500	500	500	500
Legal & Audit fees		1,000	1,000	1,000	1,000	1,000	1,000	1,000
Fuel and Lubricants		2,000	2,000	2,000	2,000	2,000	2,000	2,000
Miscellaneous expenses		1,500	1,500	1,500	1,500	1,500	1,500	1,500
Personnel Insurance		633	633	633	633	633	633	633
Plant Insurance		3,000	3,000	3,000	3,000	3,000	3,000	3,000
Depreciation		34,417	34,417	34,417	34,417	34,417	34,417	34,417
Sub-total		78,823	79,456	80,102	80,761	81,433	82,119	82,818
Operating Profit		96,746	96,112	95,466	94,807	94,135	93,449	92,750
Interest on long-term borrowing		25,000	27,500	30,250	25,295	19,845	13,849	7,254
Profit before taxes		**71,746**	**68,612**	**65,216**	**69,512**	**74,290**	**79,600**	**85,495**
Profit tax		14,349	13,722	13,043	13,902	14,858	15,920	17,099
Net profit after tax		**57,397**	**54,890**	**52,173**	**55,610**	**59,432**	**63,680**	**68,396**
Dividends payable			38,423	36,521	38,927	41,602	44,576	47,877
Retained Profit		57,397	16,467	15,652	16,683	17,830	19,104	20,519

Revenue	Jan 32	Jan 33	Jan 34	Jan 35	Jan 36	Jan 37	Jan 38	Jan 39
Ethanol Sales	285,000	285,000	285,000	285,000	285,000	285,000	285,000	285,000
By-product sales	-	-	-	-	-	-	-	-
Total Revenue	285,000	285,000	285,000	285,000	285,000	285,000	285,000	285,000
Cost of sales	109,432	109,432	109,432	109,432	109,432	109,432	109,432	109,432
Gross profit	175,568	175,568	175,568	175,568	175,568	175,568	175,568	175,568
General Administrative and Sales								
Salaries	36,382	37,109	37,852	38,609	39,381	40,168	40,972	41,791
Staff uniforms	500	500	500	500	500	500	500	500
Telecom & Posts	600	600	600	600	600	600	600	600
Marketing Expenses	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
Office Supplies	500	500	500	500	500	500	500	500
Legal & Audit fees	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Fuel and Lubricants	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000
Miscellaneous expenses	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500
Personnel Insurance	633	633	633	633	633	633	633	633
Plant Insurance	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
Depreciation	34,417	34,417	34,417	33,417	33,417	33,417	33,417	33,417
Sub-total	83,532	84,259	85,002	84,759	85,531	86,319	87,122	87,941
Operating Profit	92,036	91,309	90,567	90,810	90,037	89,250	88,446	87,627
Interest on long-term borrowing	-	-	-	-	-	-	-	-
Profit before taxes	**92,036**	**91,309**	**90,567**	**90,810**	**90,037**	**89,250**	**88,446**	**87,627**
Profit tax	18,407	18,262	18,113	18,162	18,007	17,850	17,689	17,525
Net profit after tax	**73,629**	**73,047**	**72,453**	**72,648**	**72,030**	**71,400**	**70,757**	**70,102**
Dividends payable	51,540	51,133	50,717	50,853	50,421	49,980	49,530	49,071
Retained Profit	22,089	21,914	21,736	21,794	21,609	21,420	21,227	21,030

Projected Balance Sheet

Assets	Jan 24	Jan 25	Jan 26	Jan 27	Jan 28	Jan 29	Jan 30	Jan 31
Current assets								
Cash	46,258	177,420	293,600	291,539	291,399	277,323	268,930	255,802
Inventory								
Total current assets	46,258	177,420	293,600	291,539	291,399	277,323	268,930	255,802
Fixed assets a/								
Land cost	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000

Assets	Jan 24	Jan 25	Jan 26	Jan 27	Jan 28	Jan 29	Jan 30	Jan 31
Civil works and buildings	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000
Plant machinery, equipment, commissioning	460,000	460,000	460,000	460,000	460,000	460,000	460,000	460,000
Office equipment and furniture	10,000	10,000	10,000	10,000	10,000	20,000	20,000	20,000
Vehicles	-	-	-	-	-	-	-	-
Sub-total	495,000	495,000	495,000	495,000	495,000	505,000	505,000	505,000
Less: accumulated depreciation b/	-	34,417	68,833	103,250	137,667	172,083	206,500	240,917
Net Fixed assets	495,000	460,583	426,167	391,750	357,333	332,917	298,500	264,083
Total Assets	**541,258**	**638,004**	**719,767**	**683,289**	**648,733**	**610,240**	**567,430**	**519,885**
Liabilities and Equity								
Liabilities								
Long-term Loans	250,000	250,000	250,000	209,051	164,006	114,458	59,954	-
Interest payable	-	25,000	52,500	43,901	34,441	24,036	12,590	-
Tax payable		14,349	13,722	13,043	13,902	14,858	15,920	17,099
Dividends payable		-	38,423	36,521	38,927	41,602	44,576	47,877
Total Liabilities	250,000	289,349	354,645	302,515	251,277	194,954	133,040	64,976
Equity								
Share capital	291,258	291,258	291,258	291,258	291,258	291,258	291,258	291,258
Accumulated Retained earnings	-	57,397	73,863	89,515	106,198	124,028	143,132	163,651
Total equity	291,258	348,654	365,121	380,773	397,456	415,286	434,390	454,908
Total Liabilities and equity	**541,258**	**638,004**	**719,767**	**683,289**	**648,733**	**610,240**	**567,430**	**519,885**
a/ Fixed assets								
Land cost	10,000							
Civil works and buildings	15,000							
Plant machinery, equipment, commissioning	460,000							
Office equipment and furniture	10,000					10,000		
Vehicles	-							
Sub-total	495,000							
Total investment on fixed assets	495,000	-	-	-	-	10,000	-	-
Cumulative balance	495,000	495,000	495,000	495,000	495,000	505,000	505,000	505,000

Assets	Jan 24	Jan 25	Jan 26	Jan 27	Jan 28	Jan 29	Jan 30	Jan 31
b/ Accumulated Depreciation								
Depreciation expenses								
Land cost		1,000	1,000	1,000	1,000	1,000	1,000	1,000
Civil works and buildings		750	750	750	750	750	750	750
Plant machinery, equipment, commissioning		30,667	30,667	30,667	30,667	30,667	30,667	30,667
Office equipment and furniture		2,000	2,000	2,000	2,000	2,000	2,000	2,000
Vehicles		-	-	-	-	-	-	-
Sub-total		34,417	34,417	34,417	34,417	34,417	34,417	34,417
Less: accumulated depreciation b/								
Depreciation charge		34,417	34,417	34,417	34,417	34,417	34,417	34,417
Accumulated depreciation		34,417	68,833	103,250	137,667	172,083	206,500	240,917
Book value of Fixed assets End of Year		460,583	426,167	391,750	357,333	332,917	298,500	264,083

Assets	Jan 32	Jan 33	Jan 34	Jan 35	Jan 36	Jan 37	Jan 38	Jan 39
Current assets								
Cash	317,278	373,056	418,645	474,040	528,479	582,717	636,750	690,575
Inventory								
Total current assets	317,278	373,056	418,645	474,040	528,479	582,717	636,750	690,575
Fixed assets a/								
Land cost	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Civil works and buildings	15,000	15,000	15,000	15,000	15,000	15,000	15,000	15,000
Plant machinery, equipment, commissioning	460,000	460,000	460,000	460,000	460,000	460,000	460,000	460,000
Office equipment and furniture	20,000	20,000	30,000	30,000	30,000	30,000	30,000	30,000
Vehicles	-	-	-	-	-	-	-	-
Sub-total	505,000	505,000	515,000	515,000	515,000	515,000	515,000	515,000
Less: accumulated depreciation b/	275,333	309,750	344,167	377,583	411,000	444,417	477,833	511,250
Net Fixed assets	229,667	195,250	170,833	137,417	104,000	70,583	37,167	3,750
Total Assets	**546,945**	**568,306**	**589,478**	**611,457**	**632,479**	**653,300**	**673,917**	**694,325**

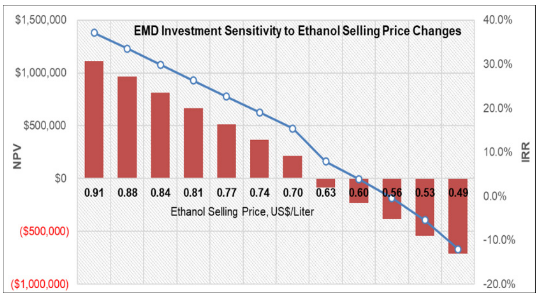
Assets	Jan 32	Jan 33	Jan 34	Jan 35	Jan 36	Jan 37	Jan 38	Jan 39
Liabilities and Equity								
Liabilities								
Long-term Loans	-	-	-	-	-	-	-	-
Interest payable	-	-	-	-	-	-	-	-
Tax payable	18,407	18,262	18,113	18,162	18,007	17,850	17,689	17,525
Dividends payable	51,540	51,133	50,717	50,853	50,421	49,980	49,530	49,071
Total Liabilities	69,948	69,395	68,831	69,015	68,428	67,830	67,219	66,597
Equity								
Share capital	291,258	291,258	291,258	291,258	291,258	291,258	291,258	291,258
Accumulated Retained earnings	185,739	207,654	229,389	251,184	272,793	294,213	315,440	336,470
Total equity	476,997	498,911	520,647	542,442	564,051	585,471	606,698	627,728
Total Liabilities and equity	**546,945**	**568,306**	**589,478**	**611,457**	**632,479**	**653,300**	**673,917**	**694,325**
a/ Fixed assets								
Land cost								
Civil works and buildings								
Plant machinery, equipment, commissioning								
Office equipment and furniture			10,000					
Vehicles								
Sub-total								
Total investment on fixed assets	-	-	10,000	-	-	-	-	-
Cumulative balance	505,000	505,000	515,000	515,000	515,000	515,000	515,000	515,000

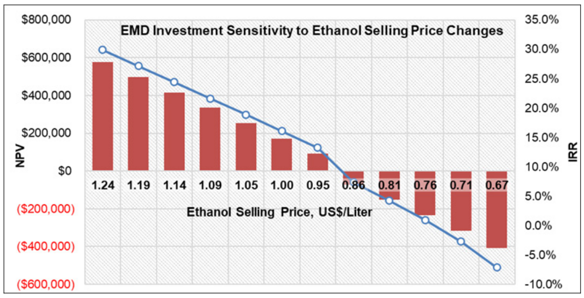
Assets	Jan 32	Jan 33	Jan 34	Jan 35	Jan 36	Jan 37	Jan 38	Jan 39
b/ Accumulated Depreciation								
Depreciation expenses								
Land cost	1,000	1,000	1,000					
Civil works and buildings	750	750	750	750	750	750	750	750
Plant machinery, equipment, commissioning	30,667	30,667	30,667	30,667	30,667	30,667	30,667	30,667
Office equipment and furniture	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000
Vehicles	-	-	-	-	-	-	-	-
Sub-total	34,417	34,417	34,417	33,417	33,417	33,417	33,417	33,417
Less: accumulated depreciation b/								
Depreciation charge	34,417	34,417	34,417	33,417	33,417	33,417	33,417	33,417
Accumulated depreciation	275,333	309,750	344,167	377,583	411,000	444,417	477,833	511,250
Book value of Fixed assets End of Year	229,667	195,250	170,833	137,417	104,000	70,583	37,167	3,750

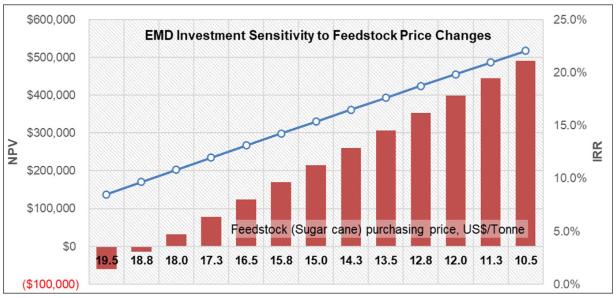
EMD 1,000 LPD Key Financial Reports: Cash Flow, Income Statement, Balance Sheet

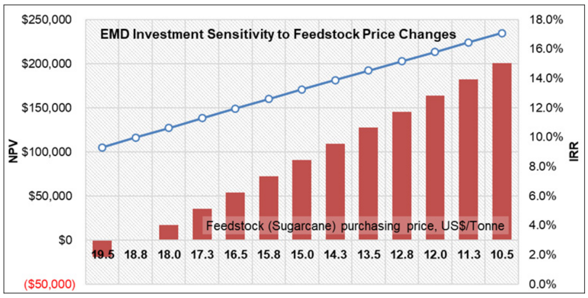
2,500-LPD EMD Sensitivity Analysis

1,000-LPD EMD Sensitivity Analysis









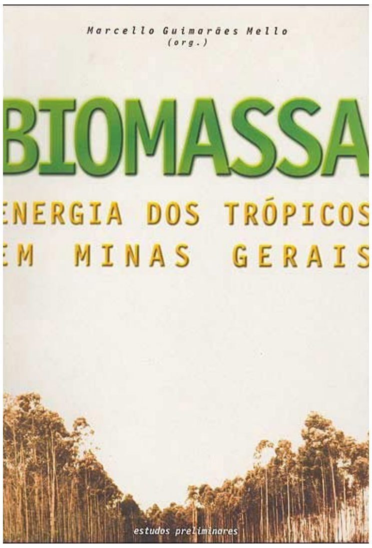
Are you planning an ethanol fuel project? Please reach out to Mr. Jossy Thomas, Industrial Development Officer, Climate Technologies Innovation Unit, Decarbonization and Sustainable Energy Division, UNIDO, j.thomas@unido.org, to the CECC, or to Project Gaia, Inc., to get the Microsoft Excel workbook that will allow you to produce a financial plan and financial statements for your EMD project.

ANNEX II. FURTHER READING: TECHNICAL GUIDES TO BUILDING FARM-BASED ETHANOL MICRODISTILLERIES

Early interest was shown in farm-based microdistilleries by farmers in Brazil, the U.S. and other countries, including several in Southern Africa. Here is some further reading in the work that was done in the U.S. and Brazil on farm-based distilleries, beginning about 1980. The interest in fuel made on the farm peaked after the oil shocks of 1973-74 and 1979. Today's climate crisis and renewed interest in low carbon fuels has helped to revive this interest. While some of these publications are interesting mostly from a historical perspective, several remain valuable business, financial and technical guidebooks for today's practitioner.

Of particular interest are the Blume, Freudenberger, and Souza e Silva books and the U.S. Department of Energy (USDOE) Fuel from Farms: A Guide to Small Scale Ethanol Production. These books are highly recommended to the user of this UNIDO Council on Ethanol Clean Cooking (CECC) guidebook and will provide valuable supplementary information to what has been made available in this guidebook. In most but not all cases, these books are available online.

Biomassa
Energia Dos Trópicos Em Minas Gerais



By Marcello Guimarães Mello
Published 2001 by LabMídia/FAFICH, Universidade Federal de Minas Gerais (UFMG). In Portuguese.

This book is a foundational work of the Brazilian microdistillery movement, written by a pioneer of Brazilian small-scale ethanol production. It describes a small-scale farming strategy built around a distillery that provides fuel, feed, fertilizer and other co-products for a farm with milking cows, other farm animals, 6 ha of sugarcane to provide feedstock to the distillery, row crops, a fast-growing fuelwood plantation, and some natural lands left as part of the farm. Marcello Mello's concept of small self-sufficient farms, using limited mechanization, first developed in the 1980s, created a vision for small-holder Brazilian farmers that is still powerful today.

This important book is available only in Portuguese, but several academic research and industry articles have been written about Marcello Mello's work. Three are recommended here:

- Ortega, E., Watanabe, M., and Cavalett, O. (2008). Production of Ethanol in Micro and Mini Distilleries. Laboratory of Ecological Engineering, Faculty of Food Engineering (FEA), State University of Campinas (Unicamp). Accessed at: https://www.researchgate.net/publication/268300757_PRODUCTION_OF_ETHANOL_I N_MICRO_AND_MINI-DISTILLERIES. Also available here: https://www.scribd.com/document/53894897/Micro-Distillery-Ecounit-Brazil.
- Scholtes, F. (2009). Status quo and prospects of smallholders in the Brazilian sugarcane and ethanol sector: Lessons for development and poverty reduction. ZEF Working Paper Series 43 on Sustainable Energy and Rural Development. Center for Development Research, Department of Political and Cultural Change, University of Bonn. Accessed at: https://www.econstor.eu/dspace/bitstream/10419/88388/1/772418969.pdf. Also here: https://www.zef.de/uploads/tx_zefportal/Publications/wp43.pdf.

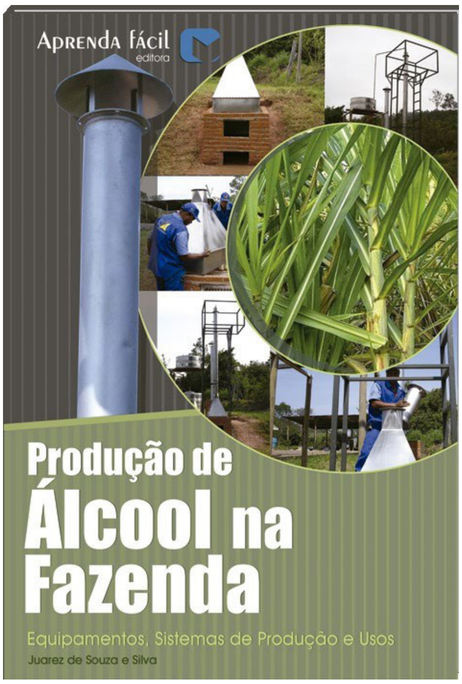
- Maroun, M. and La Rovere, E. (2014). Ethanol and food production by family smallholdings in rural Brazil: Economic and socio-environmental analysis of micro distilleries in the State of Rio Grande do Sul. Biomass and Bioenergy 63 (2014) 140 – 155. Accessed at: http://centroclima.coppe.ufrj.br/index.php/en/producao-academica-3/2014- 1/140-ethanol-and-food-production-by-family-smallholdings-in-rural-brazil-economic- and-socio-environmental-analysis-of-micro-distilleries-in-the-state-of-rio-grande-do- sul/file.

Produção de Álcool Combustível na Fazenda e em Sistema Cooperativo

By Juarez de Sousa e Silva, editor
(Production of fuel alcohol on the farm in a cooperative system).
Published 2007 by Universidade Federal de Viçosa (UFV). Viçosa-MG, Brazil. (In Portuguese.)

The work of Marcello Guimarães Mello inspired a generation of researchers and practitioners and gave definition to the movement in Brazil promoting the idea of the intrinsic sustainability of small-scale farmers and landholders, as an alternative to large, industrial farming. One of the most prominent researchers is Professor Silva of UFV, now retired. His first book detailed the design, development and operation of a small, on-farm distillery ideal for the small-scale dairy industry. This book details the design of the distillery, how to operate it and the economics of the operation. A second book has turned this knowledge into a course of learning that teaches microscale distillery development in a step-by-step fashion and goes into greater detail on the experience of operating the distillery as a business.

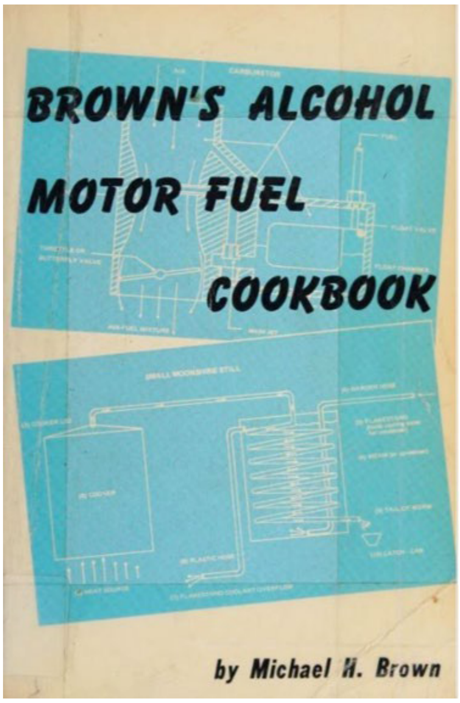
Produção de Álcool na Fazenda - Equipamentos, Sistemas de Produção e Usos



(Production of Alcohol on the Farm—Equipment, Production Systems and Uses)
Published 2011 by *Aprenda Fácil*, Viçosa-MG, Brazil, 2011 (In Portuguese).

This book is available for sale in Portuguese either in hardcopy or as an e-book at the Aprenda Fácil website, here. Silva's original book has been translated to English and is available at Project Gaia, here.

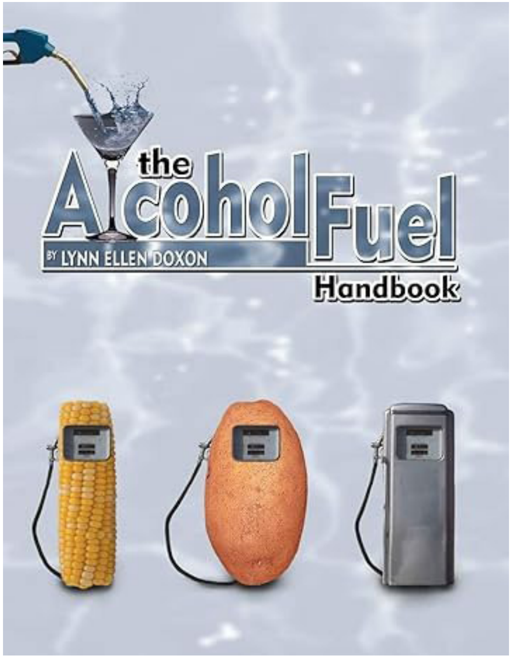
Brown's Alcohol Motor Fuel Cookbook



By Michael H. Brown
Published 1979 by Desert Publications, California

The first half of the book is a well-documented step-by-step guide on converting spark engines to use alcohol fuel. The second half of the book covers alcohol production in an easy and understandable way. It covers batch production, column design, stripper plates and solar stills. There are numerous pages of photographs and technical drawings.

The Alcohol Fuel Handbook

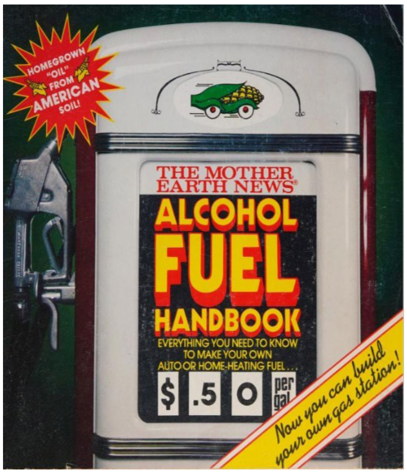


By Lynn Ellen Doxon

First published in 1980, reissued in 2013. Lynn Ellen Doxon was associated with work done by distillery designer Robert Brautigam and the Tallgrass Research Center, which was active in the early 1980s. Reissued in 2013 by Infinity Publishing (now defunct) This book is only available on the aftermarket.

Additional information can be found here.

Mother Earth News Alcohol Fuel Handbook

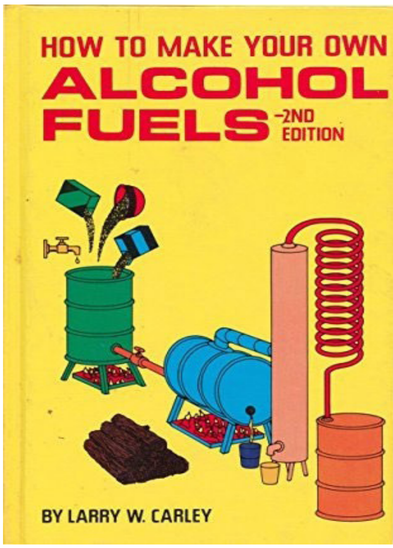


By Michael R. Kerley

Published in 1980 by Mother Earth News This is a comprehensive overview to making alcohol fuel and contains several plans for making small scale distilleries. Distillery plans are contained in Chapter 9 and are available here.

For the Alcohol Fuel Handbook, see: https://journeytoforever.org/bflpics/AlcFuelMEN.pdf. Mother Earth News continues to be published. Their archive on ethanol fuel is here.

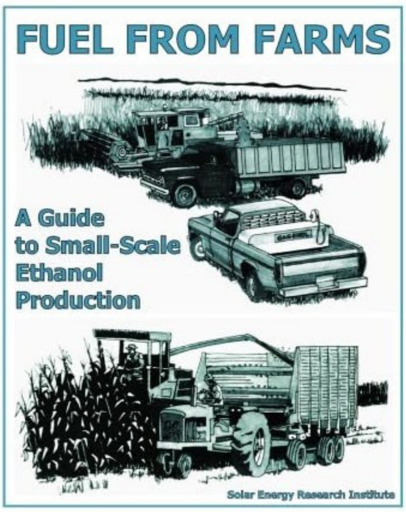
How to Make Your Own Alcohol Fuels



By Larry W. Carley
Published in 1981 by Tab Books

This is a basic but comprehensive book on the reasons for ethanol, and on fermentation, feedstocks, making mash, distillation, basic distillery design, several distillery models, planning, supplies, and engine conversion.

Fuel from Farms: A Guide to Small Scale Ethanol Production

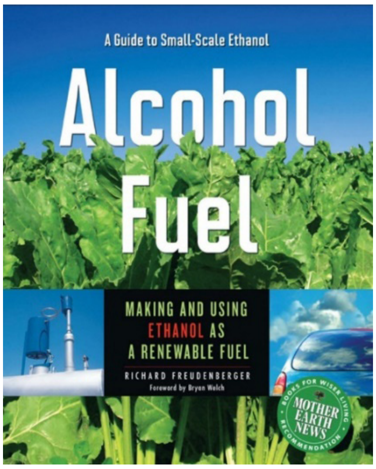


Published in 1980 and reprinted in 1982 by the Solar Energy Research Institute, operated for the U.S. Department of Energy by the Midwest Research Institute.

This work was sponsored by the U.S. Department of Agriculture and the Office of Alcohol Fuels, U.S. Department of Energy. It was republished in 2010 by the Solar Energy Research Institute and is available for purchase. This comprehensive guide for farmers covers all aspects of the planning and decision-making to produce ethanol on the farm. Topics covered include an introduction and perspective setting, the decision to produce, market assessment, production potential, basic ethanol production, feedstocks, co-products, agronomics, plant design with technical drawings, a representative ethanol plant, maintenance checklist, business planning, analysis of financial requirements, financing, and a project case study. The guide includes an appendix on environmental considerations, a glossary, and additional reference and technical information.

This publication was seminal in the development of the American farm distillery movement. This publication can be purchased in soft cover for about $20.00 or it can be found online or on GoogleBooks.

A Guide to Small-Scale Ethanol Alcohol Fuel – Making and Using Ethanol as a Renewable Fuel



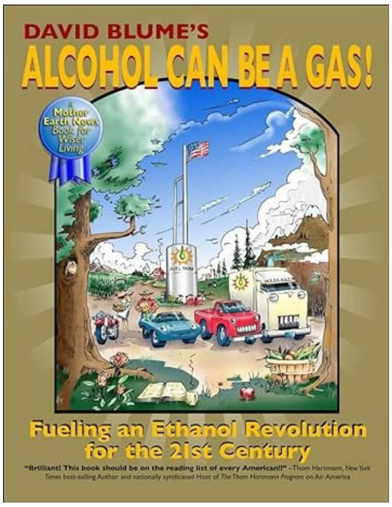
By Richard Freudenberger
Published in 2009 by New Society Publishers

This builds on the work first published in The Mother Earth News in the 1980s.

A presentation on the Freudenberger book is available on YouTube. A series of six videos with Richard Freudenberger is available on YouTube. Part I is here.

For the series, search "Freudenberger Alcohol Fuel" or click here.

Alcohol Can Be a Gas! Fueling an Ethanol Revolution for the 21st Century



By David Blume
Published in 2007 by the International Institute for Ecological Agriculture (IIEA)

This is a definitive reference work on alcohol fuel. It is a very comprehensive guide on how to produce alcohol fuel on the farm or at a small and micro scale. It is written simply but is technically detailed, with photographs and drawings. In addition to distillery design and construction, this book provides instruction on how to convert spark-ignition internal combustion engines to run on alcohol fuel.

The book's contents include: a history of alcohol fuel, the politics of alcohol fuel, sustainable agriculture (permaculture) and the production of alcohol fuel feedstocks, feedstock preparation and fermentation, information about a range of feedstocks, a primer on distillation, designing a distillery, co-products from distilleries, a model farm based around a microdistillery, how to use ethanol in engines, spark engine conversions, government policy to promote alcohol fuel production and use, ethanol microdistillery case studies, engineering and conversion tables, a glossary and an index. Excerpts from the book are available to read online, here and here.

The book can only be purchased in hard copy, paper back or as a Kindle book, and has been written for the non-scientific reader but is replete with technical detail and instruction. The book can be purchased here.

More resources and a bibliography of research and technical work on microdistilleries is available at: https://projectgaia.com/our-approach/resources/.

ANNEX III. MICRODISTILLERY EFFLUENT HANDLING STRATEGY – BIOGAS PRODUCTION

Effluent from an ethanol distillery must be treated before it is discharged to the environment. Biogas generation presents an opportunity to both treat the wastes from the distillery and use energy generated from the biogas in the boiler or for other purposes.

Biogas is well understood as a renewable and clean-burning source of energy that is generated by the anaerobic digestion, or biodigestion, of organic materials, such as the effluent from an ethanol microdistillery. Biodigestion is also an effective way to solve pollution problems arising from the release of effluent from a microdistillery (Kharayat, 2012). It may be combined with other strategies, including retention or settling ponds, drying beds, artificial wetlands, algae and fishponds, spray irrigation and aerobic composting to create a multistep process for cleaning up effluent and making it safe for release into the environment (Kharayat, 2012). This annex provides an example of a relatively simple and low-cost method of anaerobic digestion using Linear Low-Density Polyethylene (LLDPE) bags rather than tanks constructed from steel or masonry. For information on EMD waste disposal requirements, please see Chapter 4 of the Guidebook.

Biogas can play a significant role in reducing dependency on biomass and fossil fuels. It can be used in the distillery boiler (contributing up to 64 per cent of boiler fuel) to produce steam for distillation (O'Shea, et al., 2020). Or it can be used to fuel a generator to produce electricity for the distillery's pumps, motors, electronic controls and lighting (Reis and Hu, 2017). Any excess supply of biogas can be used to meet local needs in the community, whether for power generation or directly as fuel for cooking. The liquid and solid residues of the anaerobic digester are suitable for fertilizer use, provided the digestate has been thoroughly reacted. An installed digester at a distillery could even accept organic wastes from the community, particularly animal manure from neighbouring farms, if controlled for quantity and quality (Sistema.bio, 2024).

The digestate from biogas is enriched in organic matter and can be used as an agricultural fertilizer to supplement or substitute for chemical fertilizers (Kharayat, 2012). Biogas has other economic and environmental benefits as well. It is a step toward the "circular economy" and can contribute to mitigating GHG emissions, improving soil carbon and balancing crop nutrients (Balakrishnan, 2024).

Biogas can be produced from a wide range of raw materials and thus can be customized for different conditions and settings. Wastewater and sludges from a distillery are efficient feedstocks for biogas production. Anaerobic digestion typically has been incorporated with other treatment steps to minimize the environmental impact of a distillery. The relatively small size of a microdistillery makes it much easier to develop backend processing for beneficial waste handling and the reuse of nutrients.

The characteristics of vinasse, or stillage, the final residue from the distillation of fermentation juice (called beer or wine) used to produce ethanol, are determined by the raw material used, the variety of sugarcane or cassava, or other feedstock, the type of soil in which the feedstock is grown, harvesting methods, industrial processes used to prepare the feedstock, and efficiency of the distillation column. Therefore, the characteristics of stillage will differ among distilleries.

Although rates are variable, generally, for every litre of alcohol produced in a distillery, about 8 to 12 litres of stillage will be generated. The stillage is high in COD and BOD due to the presence of organic compounds, such as polysaccharides, proteins, polyphenols, waxes, and melanoidin in the stillage. Distillery stillage contains about 2 per cent natural products of sugar and amino acids (known as melanoidins) which have a dark brown colour. These substances are strong antioxidants and may pollute if released untreated into the environment.

Typical characteristics of sugarcane and cassava vinasse:

- Light brown liquid. Contains ~92 per cent water and ~8 per cent organic solids and minerals.
- High organic content (organic compounds such as acetic acid, lactic acid, glycerol and various reducing sugars)
- High ash content and concentration of mineral salts
- Low pH (4 – 5)
- High BOD (20,000 – 75,000 mg/L)
- High COD (40,000 – 100,000 mg/L)

Characteristics of cassava vinasse

Cassava vinasse characteristics	
pH	**4 – 5**
COD	**40,000 – 70,000 mg/L**
BOD	20,000 – 35,000 mg/L
SS	25,000 – 45,000 mg/L
Total N	800 – 900 mg/L
Total P	200 – 400 mg/L

Note. Yang and Li (2013) and Luo et al. (2009)

Characteristics of sugarcane and molasses vinasse

Sugarcane vinasse characteristics (molasses, juice or mix)	
pH	3.5 – 5.0
COD	9,200 – 97,000 mg/L
BOD	7,000 – 75,000 mg/L
SS	10,000 – 38,000
Total N	90 – 885
Total P	18 – 200

Note. After Rabelo, et al. (2015)

Distillery stillage, with its high content of nitrogen, phosphorus and organics, can be used for direct soil fertilization (spreading on the fields with or without plowing). As an example, vinasse generated from sugarcane juice fermentation is widely used as a fertilizer in Brazil. However, at high doses (> 250 m^3/ha), the use of distillery stillage is harmful to plant growth and soil properties, while its application at lower doses (125 m^3/ha) can be beneficial to yields, improving sprouting, growth, and yield, due to its content of nutrients, P, N, K, and Ca (Biswas, et al., 2009). To ensure correct nutrient balances, the vinasse should be tested, and annual soil tests should be done. The combined application of distillery stillage with natural organic compounds such as cattle manure, green leaf manure, and bio-compost helps to assure good nutrient balance (Biswas, et al., 2009).

Over-application of distillery stillage can lead to the build-up of phosphorus, potassium and nitrogen, imbalance among these nutrients, and the accumulation of mineral salts to toxic levels. Excess nutrients in the soil cause eutrophication of waterways from nutrient runoff. Nutrient runoff can result in fish kills, algae blooms, and other environmental problems.

For distillery effluent to be discharged into the environment, BOD should be reduced to about 80 ppm (or ~80 mg/L) and COD to 200 ppm (or ~200 mg/L) according to standards set by WHO (WHO, 2013).

The technological methods used for the treatment of distillery stillage are biological (aerobic and anaerobic), physico-chemical (coagulation or flocculation, electrocoagulation, adsorption, advanced oxidation, and membrane processes), and thermal (evaporation or combustion). The choice of treatment method depends on its efficiency and cost, the type of land where the distillery stillage will be used after treatment, regulatory constraints, and public acceptance of the treatment.

The simple and affordable waste treatment options realistically available to a microdistillery operator, in addition to field application, include settling ponds, anaerobic and aerobic treatment, artificial wetlands and ponds for further treatment, drying beds, and a mix of these methods.

Anaerobic digestion of stillage can generally reduce stillage BOD and COD by 80 to 90 per cent. Further reduction is achieved with aerobic treatment, for example, mixing digestate from the anaerobic process with organics, such as crop residues, to produce compost for field application.

Stillage can be used to keep piles or windrows of compost moist, in an aerobic composting process, which accelerates the composting process. Stillage can also be mixed with roughage for animal feed. In a sugarcane distillery this roughage could include cane tops, bagasse, and filter mud.

Biological Treatment of Wastes

Biological treatment of distillery stillage relies on the natural growth and selection of microorganisms. During this process, the microorganisms use pollutants for food and convert the organic material into simpler substances in the presence or absence of oxygen. Aerobic or anaerobic methods can be used separately for the treatment of distillery stillage. But a combination of both methods is best used for wastewater that is high in organic pollutants.

Aerobic and Anaerobic Treatment

Biological treatment is the most efficient and cost-effective way to treat ethanol microdistillery stillage. Both aerobic and anaerobic treatment rely on processes of microbial decomposition to treat wastewater. The key difference between anaerobic and aerobic treatment is that aerobic systems require oxygen, while anaerobic systems do not. This is a function of the types of microbes active in each system. Although both anaerobic and aerobic systems can treat many of the same biological constituents, there are some differences that make each technology better suited for specific contaminants, concentration levels, temperatures, and other wastewater stream characteristics.

In general, aerobic treatment systems are best suited for streams with relatively low BOD or COD and are also used for removal of nitrogen and phosphorus. Anaerobic systems are typically used for treatment of waste streams with high concentrations of organic contaminants and for warm wastewater streams (Kharayat, 2012).

Therefore, aerobic treatment is more suitable for low-strength wastewaters while anaerobic treatment is more suitable for high-strength wastewaters. Aerobic treatment is used as both a pre- and final treatment. Many microorganisms (bacteria, cyanobacteria, yeast, fungi, etc.) can be used to treat distillery stillage in aerobic conditions. The efficiency of treatment depends on the following factors: temperature, pH, COD, and nutrients (ammonia nitrogen and phosphate phosphorus) (Mikucka and Zielińska, 2020). Aerobic treatment systems include settlement ponds, aerated lagoons, artificial wetlands, trickle and spray irrigation and composting.

Anaerobic treatment results in less sludge production than settlement ponds and lagoons and generates valuable by-products—biogas, but also digestate, the liquid and solid material left behind after anaerobic digestion has been completed, acted upon by the anaerobic bacteria. This material is stable and safe for use as fertilizer, especially when finished with aerobic composting.

Digestate is nutrient-rich and contains all the recycled nutrients that were present in the original organic material, plus what have been added by the bacteria, in a form more readily available to plants and soil. The composition and nutrient content of the digestate depends on the feedstock added to the digester. Liquid digestate can be easily spray-applied to farms as fertilizer, reducing the need to purchase synthetic fertilizers. Solid digestate can be used as livestock bedding or composted with minimal additional processing (Tanigawa, 2017).

Anaerobic and aerobic systems are often paired for treatment of streams with high concentration of organic contaminants. For these setups, anaerobic treatment is used for initial reduction of organic contaminant levels, while aerobic treatment is used as a secondary polishing step to further reduce BOD and suspended solids (SS). In general, using both technologies together result in more efficient treatment than if an aerobic system were used alone, as well as more complete contaminant removal than if anaerobic treatment were used alone (Tanigawa, 2017). The decision to use both technologies will require more capital investment but will facilitate permitting from the environmental authorities and lower operational and waste discharge costs.

Adding anaerobic treatment to a waste processing strategy offers several benefits:

- Anaerobic treatment requires less energy for its operation than aerobic treatment alone.
- Biomass generation in anaerobic processing is six- to eight-fold less than in aerobic processing. Therefore, the cost of sludge treatment and application (or disposal) is reduced.
- Anaerobic treatment requires fewer nutrients because less biomass is produced. Therefore, the cost for nutrient supplementation, if required, will be less in anaerobic treatment.
- Anaerobic processing requires a smaller reactor volume as it can handle higher volumetric loading rates.
- Anaerobic processing produces methane, which is an easy-to-use source of energy.
- Anaerobic processing responds to substrate addition rapidly after a long shut down period (i.e., the process is resilient).

The following is a representative technical design calculation using the effluent flow from a 1,000-LPD microdistillery (values from Metcalf and Eddy, 5th ed., 2013):

1. Assume 0.40 m3 of biogas is produced per kg of COD removed.
2. Assume 12.5 per cent of reacted COD is not involved in biogas production, Therefore, 0.35 m3 of biogas is produced per kg of COD.
3. Daily COD production from 12,000 L of effluent (assuming COD of 100,000 mg/L for a molasses feedstock distillery) is 1,200 kg COD.
4. Assuming the biodigester efficiency for COD removal is 90 per cent.
5. Total COD removed = 90 per cent of incoming load of 1,200 kg.
   a. = 0.90 x 1200 kg per day = 1,080 kg COD/day
   b. = 0.35 m3 biogas kg COD x 1,080 kg COD/day = 378 m3/day
   c. 378 m3/day biogas is 378,000 L/day biogas.
6. Dividing biogas yield by 12,000 L effluent input shows that 31.5 L of biogas is produced from one L of treated effluent.
7. If 55 per cent of the biogas is methane =

0.55 x 378 m3/day = 207 m3/day.[3]

8. 207 m3/day methane is 207,000 L/day methane.
9. Dividing methane yield by 12,000 L of effluent shows that 17.3 L of methane is produced from one L of treated effluent.

Here is a sample calculation for sizing the digester(s):

10. Distillery produces 12,000 L of effluent per day. Assume 4,000 L used for fertigation; 8,000 L available for digester.
11. Converting litres to cubic meters, effluent will require 8 m3 of biodigester volume, with 25 per cent additional for biogas generation. 8 m3/75 per cent = 10.7 m3 of digester volume required.
12. Assuming 50 days retention time in digester, 50 days x 10.7 m3 = 535 m3 total digester volume is required. (Warmer climates require less retention time, and cooler climates, more)
13. If low-cost, plastic bag or geomembrane digesters are to be used, and if a standard size in width is known for the digester bag, the length (L) of the digester can be computed as follows: L = V/πr2 or, as an example, assuming a 4-meter diameter bag, 535 m^3 V/π (32) = ~40 m in length.
14. Therefore, in this example, one or several bags in series, 4 m in diameter and a total of 40 m in length, would be required to process the distillery effluent directed to the digester. From the first calculation, above, approximately 378 m^3 biogas would be produced per day.

Low-Cost Digesters

To reduce biodigester cost, a plastic or geomembrane bag biodigester, or a series of such bag biodigesters, rather than steel or masonry tanks, can be used. Linear Low-Density Polyethylene (LLDPE) digesters are the preferred option, according to Sistema.bio. LLDPE is a flexible and durable choice of plastic sheeting (Sistema.bio, 2022). Other materials used are HDPE and PVC.

Sheet plastics used for bag digesters

Polymer	Flexibility	Impact Strength	Stress Crack	Impact Resistance	Density
LLDPE	☆☆☆☆	☆☆☆	☆☆☆☆	☆☆☆☆	0.93
HDPE	☆☆	☆☆☆	☆☆☆	☆	0.96
PVC	☆☆	☆	☆☆	☆	1.35

Note. Sistema.bio, 2022

[3] Raw biogas typically consists of methane (50–75%), carbon dioxide (25–50%), and smaller amounts of nitrogen (2–8%) (Li, et al., 2019).

The system components include the anaerobic bag reactors, which can be installed in various sizes and in series, a feeding tank, a biologic (inoculation) tank, an H2S filter, a pressure release valve, HDPE gas lines, water traps, and geotextile ground protectors. Site preparation is required prior to digester installation. Site preparation work includes drainage, excavation of trenches to receive the biodigesters and piping, backfilling, construction of structures and protective roofing, fencing and civil works for above and underground piping (Sistema.bio, 2022). While there are many variables to be considered, the likely cost of the bag biodigester waste treatment system should approximate about 10 per cent of the distillery capital cost, based on analysis by Project Gaia using pricing from Sistema.bio (Sistema.bio, 2022).

Sistema.bio has 11 standard sizes of reactors, from 4 m^3 to 40 m^3 in liquid phase. Their design allows the interconnection of reactors to increase the system's treatment capacity volume up to 240 m^3 in liquid phase. Using the computations above showing the need for 535 m^3 of reactor volume, this would require two digester series of 240 m^3 each plus an additional digester series of 55 m^3 (Sistema.bio, 2024). This could be accommodated on a plot of land as small as 0.5 h.

In cooler climates, it may be necessary to enclose the biodigesters in greenhouses to raise their operating temperature. Galvanized-steel-framed hoop-style greenhouses (hoop houses) with UV-resistant 6-mil clear polyethylene sheeting can be used. UV resistance is essential for the plastic sheeting to last (in any case, it will have to be replaced every several years). Hoop houses can be easily made on site with galvanized steel tubing (Bootstrapfarmer.com, 2024).[4]

If the biodigesters are installed in hoop houses, the pressure relief valve and biofertilizer tank must be installed outside the greenhouse. Moreover, the greenhouse must be well-ventilated before entering.

The biodigester is part of an integrated EMD backend strategy. The biodigester requires pre- and post-treatment steps. Settlement ponds should be constructed ahead of the biodigester to receive the stillage from the distillery. Digestate from the biodigester should be aerobically finished after the digester, for example, with aerobic composting with crop residues or other available chopped biomass, prior to field application. If there is too much liquid to be absorbed in the composting operation, construction of a pond or an artificial wetland for additional cleanup is an option, provided enough land is available.

[4] A helpful video on building hoop houses is here: https://youtu.be/TVaOiHUzvZU.

Microdistillery developers can build their own bag digester system, and many such systems have been built and are successfully operating. Instructions are available online for building these systems and one is here (Ortega, 2009). However, there are small and medium-sized bag digester technology providers available, such as Sistema.bio, which is based in Kenya and has installed bag digesters in a number of African countries —as many as 95,000 bag digesters world-wide (Sistema.bio, 2024).[5] Construction, operation and maintenance of bag digesters —as is true for any biodigester system— is not uncomplicated and requires attention to detail (This is also true for pond and wetland systems.) Therefore, EMD developers should consider working with a company experienced with bag digesters that can design and build the digester for the EMD and train the EMD staff in its operation. The bag digester company would then be available to help the EMD operator maintain and troubleshoot the biodigester system to assure that it works well for the distillery.

An EMD developer should work with a biodigester expert to evaluate feasibility of biogas generation and the treatment of effluent with anaerobic digestion. This requires careful analysis of effluent characteristics, energy cost, capital investment and operational costs. A pilot study with one or two smaller bag digesters can be conducted prior to building a larger system to handle all or a sizeable proportion of the distillery effluent. The expected lifetime of a Sistema.bio installation is 20 years. A summary of the commissioning and operation of a bag digester system is available by downloading the Sistema.bio user manual, here (Sistema.bio, 2024).

A low-cost biodigester design by Sistema.bio

Note. Sistema.bio, 2022

A series of 10 Sistema 40 reactors, each 16 m in length, installed at a pig farm

Note. BM Editores, 2023

[5] Sistema.bio is a social enterprise and certified B corporation that provides biodigester technology, training and financing. Sistema.bio manufactures and distributes high-quality, affordable biodigesters and provides flexible interest-free repayment plans as well as monitoring services for the systems they install (bcorporation.net, 2024).

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Vienna International Centre
Wagramerstr. 2, P.O. Box 300,
A-1400 Vienna, Austria

+43 1 26026-0

www.unido.org | www.cleancookingcouncil.org

ceccsecretariat@unido.org

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