SUSTAINABLE DEVELOPMENT OF BIOMASS ENERGY FOR RURAL ELECTRIFICATION

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ABSTRACT
Energy is one of the essential requirements to alleviate poverty and socioeconomic advancement and development. Most of the rural areas are not under the national grid; therefore, electrification in rural area is one of the important factors to develop power and energy by using biomass. Environmental pollution is another important issue. Green energy is current demand for the existence of future world. For that reason, reducing carbon emission and meeting energy demands are the main topologies to plan energy systems. The biomass itself is derived from three principal sources: forestry, agricultural products and biogenic waste. Biomass can be converted into useful energy (heat or electricity) or energy carriers by direct combustion, thermo-chemical and biochemical conversion technologies. Biomass energy is used to generate biogas (methane) used for cooking in household purpose and also electricity generation. As Ethiopia is an agricultural and forestry based country, plenty of biomass resources are available here and using proper biomass resources for development of power and energy for rural remote villages. In this paper, a sustainable development of biomass energy system is proposed for electrification of rural areas.

Keywords:
Biomass, Biomass power generation system, Biofuels, Biomass conversion methods, rural electrification system, opportunities and challenges in rural electrification

INTRODUCTION

It is estimated that 85 percent of the 1.2 billion people in the world living without access to electricity reside in rural areas, which is attributable to the marginalization of the poor as well as their long distance from established electrical grids. Ethiopia with landmass of 1.1million square kilometres is third giant and second populous nation in the Sub-Saharan Africa with estimated population of about 95.5 million according to 2016 index. Currently, Ethiopia has around 4500MW of installed power generating capacity, out of which 3750MW is generated from hydropower plants. The remaining 350MW and 120MW comes from the solar, wind, geothermal sources respectively. Ethiopia's biomass energy resource potential is considerable. According to estimates by Woody Biomass Inventory and Strategic Planning Project (WBISPP), national woody biomass stock was 2149 million tons with annual yield of 70 million tons in the year 2015. These figures exclude biomass fuels such branches/leaves/twigs (BLT), dead wood and homestead tree yields. In response to these challenges, the energy policy of the country focuses on: i) Rapid development of all forms of energy, both conventional and non-conventional (renewable). ii).Promoting energy conservation and efficient management of demand iii) Environment conservation and sustainable development iv) Development of decentralized energy systems based on renewable sources especially for use in rural areas.

II) Biomass: Biomass is renewable source of energy produced in nature through photosynthesis achieved by solar energy conversion and it play dual role in greenhouse gas mitigation both as an energy source and as a carbon sink. It is available in the form of wood, agricultural residues, and food grains. Solid biomass is commonly used as fuel for cooking and other thermal process in small industries, fuel for boilers, but it can be transformed into gaseous and liquid fuel in the form of ethanol and biodiesel**.**

Table1: Summary of Ethiopian biomass resource potential (biomass feedstock)

1. Agricultural biomass residue 1.1. Coffee Residues a) 214,299tonnes/year b) Production of briquettes charcoal.	1.2. Bamboo a) Largest bamboo growing area in Africa 469,664ha b) Charcoal briquettes & multiple goods.
1.3. Enset a) Indigenous drought resistant staple food b) multifold purposes residue (fuel, fed for cattle,).	1.4. Banana a) biomass residue for fuel.
1.5. Cotton Stalk residue a)Potential 400,301.5tonnes b) Yield 89,000 tonnes per year	1.6. Sawmill residue a) 25,000tonnes per year b) Production of substitutable fuel industries.
1.7. Chat (cash crop) a) Yield 6,608 tonnes/year (826 charcoal tonnes/year b) One of the exportable good c) Charcoal production or directly used.	1.8. Energy plants (Jatropha, Castor bean, palm tree etc.) a) Suited to agro ecology b) cheap cost of factors c) land for Jatropha investment 23.3million ha.
1.9. Crop residues a) Multiple uses (fertilizer, fodder, building material, etc.) b) Potential supply presented in table2.	1.10. Animal residue a) Multi-uses (fertilizer/compost, fuel, house decoration, utensil production etc.) Potential supply presented in table2.
1.11. Woody biomass resources 2.1. Forest (Natural and planted) a) Forest coverage 12.2 million ha (11% of total land mass) .b) Timber & non-timber products	1.12. Other woody biomass resources a) Coverage 44.65milion ha (41%) 2.3. Grasses b) production of bio fuels c) Used as fodder & other purposes.
1.13. Waste industries 3.1. Municipal solid wastes a) clean urban environment b) data unavailable on potentialities.	1.14. Agro-industrial by products a) for biogases and ethanol production b) 700,000ha suitable land for sugarcane(MWE) c) 1billion ethanol potential(MWE).

III) Technology:

The paper addresses a power generation system for rural Ethiopia using biomass

Biomass conversion methods: 1) Direct combustion method 2) Thermo chemical conversion (gasification and liquefaction) method 3) Bio chemical conversion (anaerobic digestion and fermentation) method.

1) **Direct combustion method**: Biomass can be burned to produce electricity and CHP via a steam turbine in dedicated power plants. The typical size of these plants is ten times smaller (from 1 to100 MW) than coal-fired plants because of the scarce availability of local feedstock and the high transportation cost. A few large-scale such plants are in operation. The small size roughly doubles the investment cost per kW and results in lower electrical efficiency compared to coal plants. Plant efficiency is around 30% depending on plant size. This technology is used to dispose of large amounts of residues and wastes (e.g bagasse). Using high-quality wood chips in modern CHP plants with maximum steam temperature of 540°C, electrical efficiency can reach 33%-34% (LHV), and up to 40% if operated in electricity-only mode. Fossil energy consumed for bio-power production using forestry and agriculture products can be as low as 2%-5% of the final energy produced. Based on life-cycle assessment, net carbon emissions per unit of electricity are below 10% of the emissions from fossil fuel-based electricity. When using MSW, corrosion problems limit the steam temperature and reduce electrical efficiency to around 22%. New CHP plant designs using MSW are expected to reach 28%-30% electrical efficiency, and above 85%-90% overall efficiency in CHP mode if good matching is achieved between heat production and demand. Incineration of MSW is a mature technology. Emissions of pollutants and dioxin can be effectively controlled, but in many countries, incinerators face public acceptance issues and are seen as competing with waste recycling. Municipal solid waste (MSW) also offers net reduction of CO2 emissions. MSW can generate some 600 kWh of electricity per tonne and emit net 220-440 kg CO2 from the combustion of the fossil-derived materials (20-40% of MSW). The CO2 emitted to generate 600 kWh from coal would be some 590 kg. Methane emissions from MSW in modern landfills would be between 50-100 kg/t (equivalent to 1150-2300 kg CO2), 50% of which is collected and 50% is released in the atmosphere. Thus, electricity production from MSW offers a net emission saving between 725 and 1520 kg CO2/t MSW. Saving is even higher for CHP.
2) **Thermo chemical conversion method**: Biomass conversion into biogas can be either from fast thermo-chemical processes (e.g., pyrolysis1) which can produce biogas and other fuels, with only 2%-4% of ash, or from slow anaerobic fermentation - which converts only a fraction (50%60%) of feedstock but produces soil conditioners as a by-product. The biogas can be used in combustion engines (10 kW to 10 MW) with efficiency of some 30%-35%; in gas turbines at higher efficiencies or in highly-efficient combined cycles. Biomass integrated gasification gas turbines (BIG/GT) are not yet in commercial use, but their economics is expected to improve. The first integrated gasification combined cycle (IGCC) running on 100% biomass (straw) has been successfully operated in Sweden. Technical issues appear to have been overcome. IGCC plants are already economically competitive in CHP mode using black-liquor from the pulp and paper industry as a feedstock. Other developments have brought Stirling engines2 and organic Rankine cycles3 (ORC) closer to the market whereas integrated gasification fuel cell plants (IGFC) still need significantly more R&D.
   Gasifier Complete gasification stages i) Drying of feedstock (~1200C) ii) Pyrolysis (Two Zones) (200~6000C) iii) Combustion (900~12000C) iv) Reduction (900~6000C)
3) **Bio-chemical conversion method**: Anaerobic digestion, landfill gas - In the absence of air, organic matter such as animal manures, organic wastes and green energy crops (e.g. grass) can be converted by bacteria-induced fermentation into biogas (a 40%-75% methane-rich gas with CO2 and a small amount of hydrogen sulphide and ammonia). Anaerobic digestion is also the basic process for landfill gas production from municipal green waste. It has significant potential, but it is characterised by relatively small plant size. Anaerobic digestion is increasingly used in small-size, rural and off-grid applications at the domestic
   And farm-scale. The rising cost of waste disposal may improve its economic attractiveness. In modern landfills, methane production ranges between 50 and 100 kg per tonne of MSW. In general, some 50% of such gas can be recovered and used for power and heat generation. After purification and upgrading, biogas can be used in heat plants, stationary engines, fed into the natural gas grid, or used as a transport fuel (compressed natural gas). Large-size plants using MSW, agricultural wastes and industrial organic wastes (large-scale co-digestion) need some 8000-9000 tonne MSW per year per MW of installed capacity. Some 200 such plants are in operation or under construction worldwide using more than 5 million tonnes of MSW

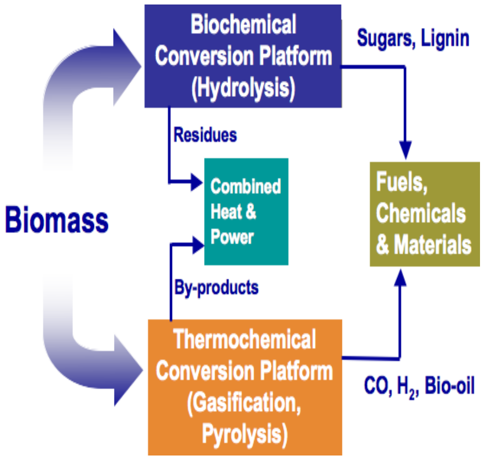

Figure: 1 Biomass conversion process

IV) **TYPICAL COSTS** Unlike wind, solar and hydro biomass electricity generation requires a feedstock that must be produced, collected, transported and stored. The economics of biomass power generation are critically dependent upon the availability of a secure, long term supply of an appropriate biomass feedstock at a competitive cost. Feedstock costs can represent 40% to 50% of the total cost of electricity produced. The lowest cost feedstock is typically agricultural residues like straw and bagasse from sugar cane, as these can be collected at harvest (ECF, 2010). For forest arising, the cost is dominated by the collection and transportation costs. The density of the forestry arising has a direct impact on the radius of transport required to deliver a given energy requirement for a plant. The low energy density of biomass feedstocks tends to limit the transport distance from a biomass power plant that it is economical to transport the feedstock. This can place a limit on the scale of the biomass power plant, meaning that biomass struggles to take advantage of economies of scale in the generating plant because large quantities of low-cost feedstock are not available. The prices of pellets and woodchips are quoted regularly in Europe by ENDEX and PIX (Table 5.1). The prices are for delivery to Rotterdam or North/Baltic Sea ports and do not include inland transport to other areas. Prices for biomass sourced and consumed locally are difficult to obtain and no time series data on a comparable basis are available. Prices paid will depend on the energy content of the fuel, its moisture content and other properties that will impact the costs of handling or processing at the power plant and their impact on the efficiency of generation. Table 5.2 presents price estimates for biomass feedstocks in the United States. The 2011 “U.S. Billion-ton Update: Biomass Supply for a Bio energy and Bio products Industry” provides very detailed estimates of the amount of biomass feedstock’s available at different prices in the United States. Figure 5.1 presents the results of this analysis for forest and wood wastes, agricultural biomass and wastes, and dedicated energy crops, respectively.

TABLE: 2: BIOMASS FEEDSTOCK PRICES AND CHARACTERISTICS IN EAST AFRICA

	TYPICAL MOISTURE CONTENT	HEATING VALUE MJ/KG(LHV)	PRICE(USD/GJ)	PRICE(USD/TONNE)	COST STRUCTURE
FOREST RESIDUES	30% – 40%	11.5	1.30 – 2.61	15 – 30	**COLLECTING, HARVESTING, CHIPPING, LOADING, TRANSPORTATION AND UNLOADING. STUMPAGE FEE AND RETURN FOR PROFIT AND RISK.**
WOOD WASTE	5% – 15%	19.9	0.50 – 2.51	10 – 50	**COST CAN VARY FROM ZERO, WHERE THERE WOULD OTHERWISE BE DISPOSAL COSTS, TO QUITE HIGH, WHERE THERE IS AN ESTABLISHED MARKET FOR THEIR USE IN THE REGION**
AGRICULTURAL RESIDUE	20% – 35%	11.35 – 11.55	1.73 – 4.33	20 – 50	**COLLECTING, PREMIUM PAID TO FARMERS, TRANSPORTATION.**
ENERGY CROPS	10% – 30%	14.25 – 18.25	4.51 – 6.94	39 – 60	NOT DISCLOSED.
LANDFILL GAS		18.6 – 29.8	0.94 – 2.84	0.017 – 0.051	GAS COLLECTION AND FLARE.

This analysis for the Africa is based on detailed geographic simulations and includes supply curves for the different biomass feedstocks by region. Detailed analysis of this nature helps to give policy-makers confidence in resource availability and costs when developing support policies for biomass. Significant quantities of bio energy feedstocks are available from forestry arising and other residues while significant residues and wastes from corn production are available at USD 55/tonne and above. Dedicated energy crop availability is strongly related to cost, representing the important impact that the best crop, land and climate conditions can have on feedstock costs. Other important cost considerations for biomass feedstocks include

The preparation the biomass requires before it can be used to fuel the power plant. “The challenge when talking about biomass power generation is to convey the idea that we are actually talking about a series of technologies,” Taylor says. “The simple combustion of biomass to generate steam requires a very different technology than that required to gasify wood chips and then burn that gas to provide steam to power a turbine, and these technologies vary substantially in technology terms and cost. The situation is also complicated by the fact that some technologies are more mature than others."For example, the total installed costs of stoker boilers ranged between $1,880 and $4,260 per kilowatt (kW) in 2010, while those of circulating fluidized bed boilers were between $2,170 and $4,500 per kW. Anaerobic digester power systems had a significantly wide range of capital costs from $2,570 up to $6,100 per kW, and gasification technologies had total installed capital costs of between $2,140 and $5,700 per kW. While IRENA's report recognizes that there are many possible influences on cost, its modelling is based off of three key drivers: equipment cost from factory gate to site delivery; total installed project cost, including fixed financing costs; and the levelized cost of electricity (LCOE), a calculation of the cost of generating electricity at the point of connection to a load or electricity grid.

There are four major components that largely determine the LCOE for biomass-fired power generation technologies, according to Taylor: feedstock cost and quality, equipment cost and performance, the balance of project costs and the cost of capital. "The feedstock costs and capital costs, including the cost of finance, primarily determine the LCOE for biomass-fired power generation," he says. "Feedstock costs typically account for between 20 percent and 50 percent of the LCOE, but they can be even higher." Operations and maintenance (OM) costs can make a significant contribution to the levelized cost of electricity as well, accounting for 9 to 20 percent of the LCOE for biomass power plants. IRENA's data indicates that it can be lower than this in the case of co- firing, but greater for plants with extensive fuel preparation or handling and conversion needs. Fixed OM costs typically range from 2 to 7 percent of installed costs per year for most biomass technologies, with variable OM costs of around one-half a cent per kW hour (kWh). Landfill gas systems have much higher fixed OM costs, which can be 10 to 20 percent of initial capital costs per year. To bring down the cost of biomass power technologies over time, Taylor has some
insight. "Part of the answer to this question lies in the fact that different technologies are at different stages of maturity," he says. "Although we don't expect significant cost reductions for mature technologies like stoker boilers, the opportunities for cost reductions from many of the gasification technologies are much better."

On feedstock, Taylor says the use of agricultural or forestry residues at the site where they are processed often results in the lowest electricity costs, given the noted importance of feedstock costs relative to overall electricity generation costs from bio energy. Current data shows that the most competitive projects using these feedstocks produce electricity for as low as 6 cents per kWh. Technology and cost specifics aside, some countries are clearly trailblazing the renewable energy path, and there are a few stand-outs and up-and-comers.

V) **Biomass power generation system**

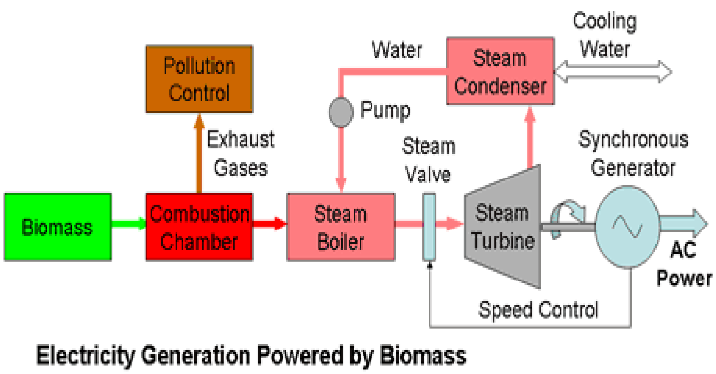

Figure: 2 Biomass power generation system.

This paper examines biomass power generation technologies but also touches on the technical and economic characterisation of biomass resources, preparation and storage. There can be many advantages to using biomass instead of fossil fuels for power generation, including lower greenhouse gas (GHG) emissions, energy cost savings, improved security of supply, waste management/reduction opportunities and local economic development opportunities. However, whether these benefits are realised, and to what extent, depends critically on the source and nature of the biomass feedstock. In order to analyse the use of biomass for power generation, it is important to consider three critical components of the process: » Biomass feedstock: These come in a variety of forms and have different properties that impact their use for power generation. » Biomass conversion: This is the process by which biomass feedstocks are transformed into the energy form that will be used to generate heat and/or electricity. » Power generation technologies: There is a wide range of commercially proven

power generation technologies available that can use biomass as a fuel input. Biomass is used for facility heating, electric power generation, and combined heat and power. The term biomass encompasses a large variety of materials, including wood from various sources, agricultural residues, and animal and human waste.
Biomass can be converted into electric power through several methods. The most common is direct combustion of biomass
material, such as agricultural waste or woody materials. Other options include gasification, pyrolysis, and anaerobic digestion. Gasification produces a synthesis gas with usable energy content by heating the biomass with less oxygen than needed for complete combustion. Pyrolysis yields bio-oil by rapidly heating the biomass in the absence of oxygen. Anaerobic digestion produces a renewable natural gas when organic matter is decomposed by bacteria in the absence of oxygen.Different methods work bet with different types of biomass. Typically, woody biomass such as wood chips, pellets, and sawdust are combusted or gasified to generate electricity. Corn Stover and wheat straw residues are baled for combustion or converted into a gas using an anaerobic digester. Very wet wastes, like animal and human wastes, are converted into a medium-energy content gas in an anaerobic digester. In addition, most other types of biomass can be converted into bio-oil through pyrolysis, which can then be used in boilers and furnaces.
VI) Biomass Estimation at the Power Plant design stage:
At this stage, a detailed biomass assessment is carried both at regional (block or district) and village level.
The objectives of the assessment at this stage are to:
• Forecast availability of its supply for next five years
• Estimate pricing of biomass for the next five years
• Streamline biomass supply chain for next five years
•Validate biomass based gasification technology in terms of capacity and type. 30 Kw gasifier running for 10 hours daily for 350 days a year will require 210 MT biomass (30 X 10 X 350 X 2= 2, 10,000 Kg= 210 MT).

I.)Biomass Estimation at the Power Plant recommissioning Stage:

Under the re-commissioning stage, a detailed biomass estimation and assessment is conducted both at regional and village level to meet the following objectives: • Estimate available biomass supply • Streamline biomass supply chain for assuring continuous supply of raw material (biomass) to the power plant. • Estimate/ analyze the price at which the biomass would be available considering seasonal variation and availability. • Adopt alternative methods for facilitating continuous biomass supply by community participative alternatives such a
a) Energy plantation on waste land,
b) Integrative energy plantation with forest departments in case of Jointρ Forest Management scenarios.

METHODOLOGY

As indicated above, while the objectives of assessment at the two stages are different, the methodologies remain the same. Accordingly, this section details the overall methodology being used in the two stages. Biomass estimation and assessment is conducted in the following step-wise manner:
• Conducting surveys: a) Biomass availability survey (quantifying and qualifying available
b) biomasses Biomass based consumption survey (identifying bona-fide andρ competitive users)
• Analyzing Data:
a) Characterization of Biomass
b) Biomass Utility
c) Biomass Pricingρ
• Recommending/ assessing Outputs/ Results: a) Resource Map
b) Biomass Management Plan/ Strategy

VII) BIOMASS POWER CALCULATION:

Biomass required for power production Annual biomass requirement = Biomass consumption/hr*Working hr/day) * days/yr) The above calculation is based on following assumptions: The hours of running are decided by the load planned (or power demand) among the targeted population. A usual case for gasifier based system is 5 hrs loads. Running a small gasifier for 10 hrs a day is an optimistic scenario. Allgasifiers need maintenance once a week. Practically, all biomass power plants are shut down for at least a month every year. Thus, assuming a biomass power operating for 350 days a year is again an optimistic scenario. The underlying assumption in the above case is that biomass supply chain is in place for providing continuous supply of biomass to power plant.
i) Biomass Pricing: The cost of biomass is calculated based on following parameters:

• Calorific value of biomass: If calorific value of biomass is high, he cost of biomass is high.
• Availability of biomass: If the biomass is available in bulk throughout the year, the cost of biomass is low. However, if biomass is affected by seasonality, the cost of biomass increases.
• Consumption pattern of biomass: If the biotic pressure in terms of consumption on particular biomass is high, the cost of biomass increases.
• Logistical cost of biomass: If the biomass is bulky, the following costs increase.
Loading cost of biomass: Bulky biomass is heavy and thus the cost of loading and de-loading goes up Transportation cost of biomass: It's more expensive to transport bulky biomass, as compared to the one that is less bulky

VIII) BIOMASS POWER GENERATION GRID CONNECTED:

Biomass gasification is the conversion of biomass into a combustible gaseous mixture. In a reactor, commonly known as the gasifier, biomass undergoes chemical reactionsinacontrolledairsupply.
First, drying of biomass takes place in the uppermost part of the gasifier. Biomass is heated at 90°C to 100°C to remove its moisture. Then pyrolysis takes place, where dried biomass gets heated from 300°C to 400°C and volatile combustible matter is released. This leaves behind a carbon residue called char. The volatile combustible matter contains non-condensable gases andcondensableoilsliketar
In the third step of oxidation, controlled oxygen is provided which burns the volatile matter and char. When all the oxygen is consumed, a reducing atmosphereiscreated.
In the reduction zone, the carbon dioxide and water vapour produced in the oxidation process get reduced to carbon monoxide, hydrogen and methane which essentially from the producer gas
Water is used to cool and clean the producer gas. Cleaning takes place through condensation. The gas is further cleaned through filters. Finally, the gas is fed into a gas engine which converts it into electrical energy

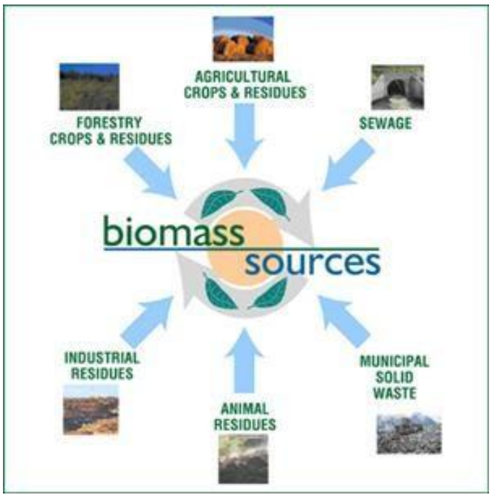

Figure: 3 Biomass different power resources

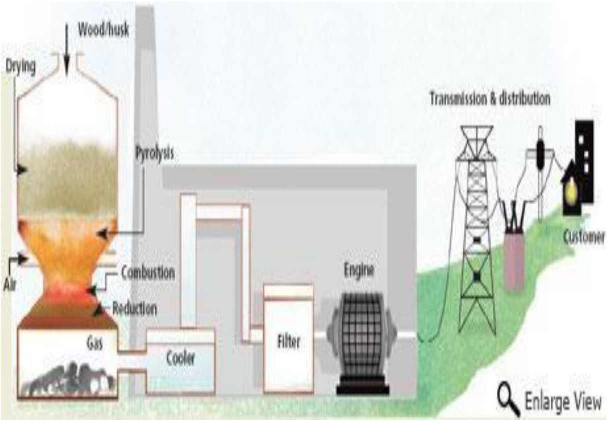

Figure: 4 Biomass power connected to grid

Figure: 5 Gasification of liquid biomass technology

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