Overview of agriculture sector, prevalent disposal methods and technologies to generate energy from crop residue

September 2020

Abhijit Lohakarey
Associate Director, Power & Utilities, PwC India

pwc

Contents

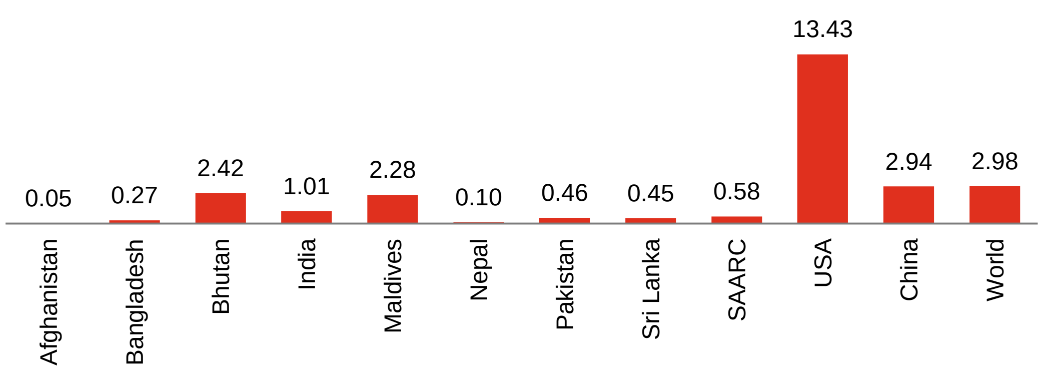
Background

Background

The SAARC Member States are agrarian countries where agriculture contribute to over 20% of their GDP and is a source of subsistence to over 60% of the population

- SAARC region is one of the most energy intensive regions in the world, owing to increasing economic activity and growing population.
- The GDP growth in SAARC nations is pegged at 5-8% per annum up to 2040. This growth is massively driven by a spike in productivity, pulling people out of the low-income status.
- SAARC region has a low per capita electricity consumption of 576 kWh/year, which is lower than the global average of 2,977 kWh and also lower than the developed countries like the US and EU but this is likely to change with the improving energy scenario.
- **The region is heavily dependent of agriculture, due to which an enormous amount of agricultural residue is produced each year of which around 80% - 85% is burnt in the fields**.

Per Capita Electricity Consumption (MWh/Capita)

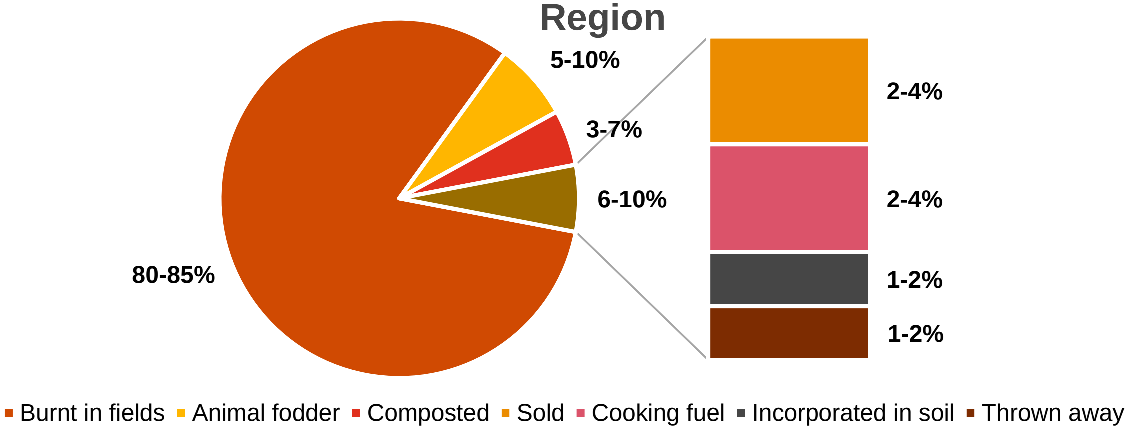


Country	Total installed Capacity (MW)	Installed RE Capacity (MW)
Afghanistan	1,341	355
Bangladesh	21,400	568
Bhutan	1,614	1,615
India	363,369	117,919
Maldives	-	11
Nepal	765	1,112
Pakistan	25,374	13,049
Sri Lanka	4,086	2,091
SAARC	**393,192**	**136,720**

Overview and Effects of Crop Residue Burning

The surplus residue production is burnt each year in the SAARC countries and CO_2 and CH_4 are released in the atmosphere

Disposal Methods of Crop Residue in SAARC Region



Pros and Cons of Crop Residue burning

Advantages

- Cheap
- Reduced manpower
- Easy and quick
- May assist insect, weed and disease control
- Reduced nitrogen tie-up

Disadvantages

- Loss of nutrients
- Loss of carbon
- Soil microbes and fauna are impacted
- Aggregate stability of soil reduces
- Soil erosion through wind and water increases

Country	Crop wise residue burnt in SAARC countries in 2016 (tonnes)
Afghanistan	1,138,300
Bangladesh	6,839,181
Bhutan	35,067
India	49,140,239
Maldives	32
Nepal	1,992,117
Pakistan	7,247,329
Sri Lanka	661,555
SAARC	**67,053,820**

Health and Environmental Effects of Crop Burning

Bangladesh, India, and Pakistan, which have larger populations, have more people exposed to toxic emissions and many people are being affected by chronic diseases

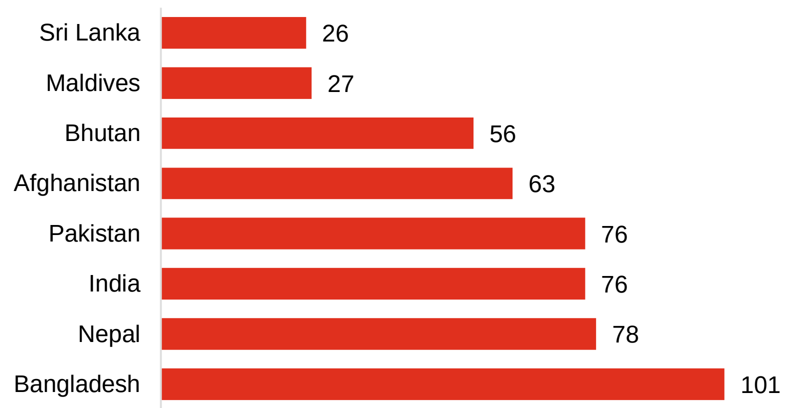
The transboundary transport of air pollution in the South Asian region has become an issue of increasing importance over the past several decades. There are two major ways in which biomass burning contributes to climate change:

1. Long-term global warming effect linked primarily to CO_2 emissions and release of GHGs from deforestation/other forms of land conversion during which biomass is burnt and not fully replaced;

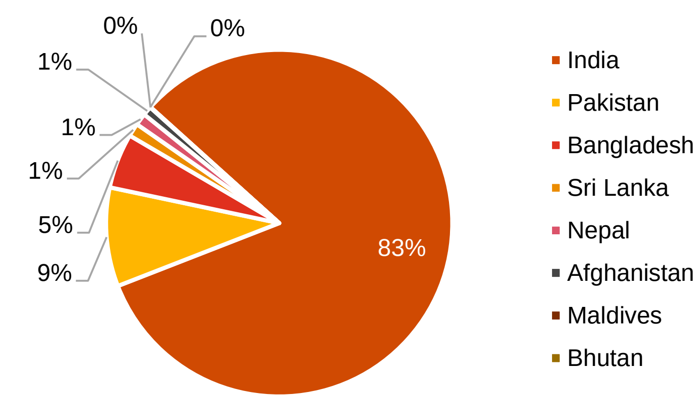
2. Short-term warming effect, which is attributed to the emission of black carbon from the burning of biomass near snow and ice-covered regions.

Particulate matter, PM2.5, affect the respiratory and cardiovascular systems of living beings along with its other environmental effects. The black carbon aerosols have a large impact on the heating, regional circulation and rainfall patterns over the emission regions.

Particulate Matter (PM 2.5) Air Pollution in SAARC States (μg/m³)



CO_2 Emissions (Mt) in SAARC Member States



Effects of Crop Burning

Crop burning has adverse effects on SAARC Member States

Environment

- In the cold winter months, the cities get blanketed by a toxic haze of particulate matter, small and often invisible particles of dust and soot (smog) which reduces visibility.
- Air gets polluted due to crop residue burning.
- The air pollution reaches "Hazardous" levels.
- Rise in the sea level due to Greenhouse gases which leads to rampant floods and cyclones.

Health

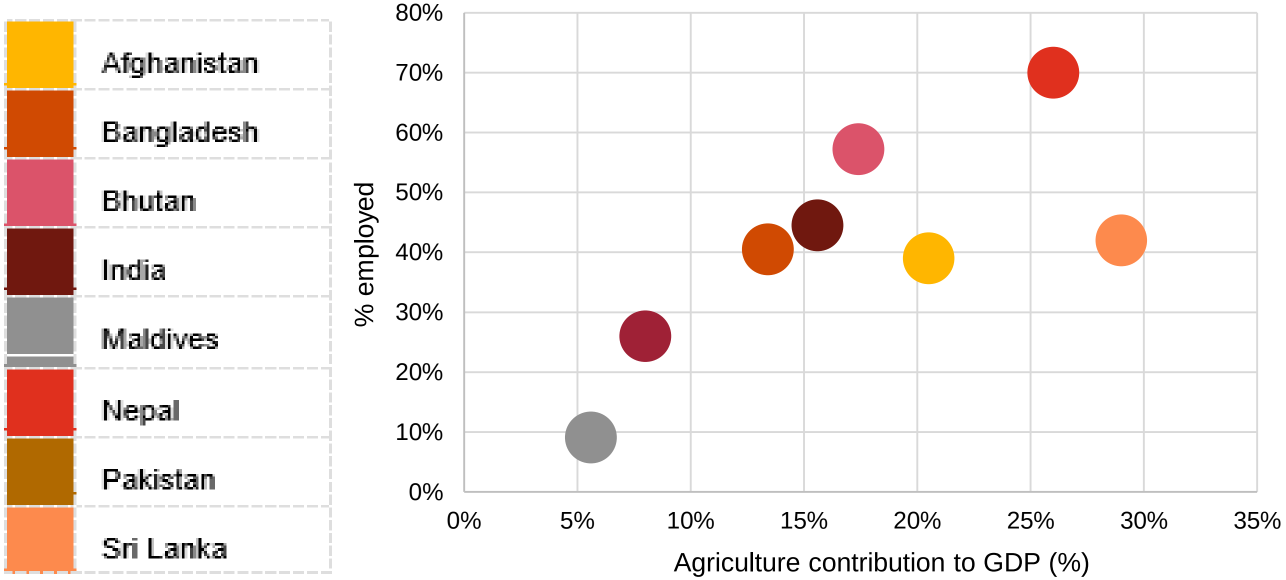
- The most common health effects experienced by the citizens are difficulties in breathing, skin problems, irritations to their eyes, nose, and throat.
- Short-term symptoms include Itchy eyes, nose and throat, coughing, shortness of breath, chest pain, headaches, nausea, Upper respiratory infections, etc.
- Long-term effects include lung cancer, cardiovascular disease, chronic respiratory illness, and developing allergies.

Prevalent Disposal Methods of Crop Residue and Alternate Uses

Overview of Agriculture Sector

In SAARC member states, 40-80% of workforce is into agriculture

Agricultural GDP and Employment in SAARC Member States



Over 65% is the rural population in the SAARC region

40-80% of the workforce is into agriculture

Agriculture farming in South Asia is dominated by small fields, where average size of field is below 0.5 hectare in Bangladesh, and below 1.0 hectare in Sri Lanka and Nepal. In India, the average farm size is 1.4 hectare. Pakistan, however, endowed with land resources, fares better than others, with an average farm size of 3.0 hectare.

Major challenges in SAARC's regional agriculture are absence of infrastructure for irrigation, storage and connectivity, lack of financial support to farmers, absence of assured field inputs: seeds, fertilizers, pesticides, lack of mechanized harvesting equipment, changing energy scenario, and natural resource degradation.

Utilization of Residue and Reasons for Burning

Farmers usually rely on conventional ways for disposal of residues by using them as animal food, fertilizers, in harvesting of other crops by ploughing or burning

Present Utilization Practices adopted by SAARC Member States

Afghanistan
Animal feed, farm applications, cooking

Bangladesh
Animal feed, organic fertilizer, mulching, cooking

Bhutan
Fuel wood, animal feed

Maldives
Animal feed, cooking, compost

Nepal
Animal feed cooking, compost

Pakistan
Animal feed, cooking, compost

Sri Lanka
Compost and fertilizers, Mulching

India
Animal feed, paper and pulp production, mushroom cultivation, mulching, compost

Usually, the farmers have a 20-day window to manage the crop residues before the sowing of the next crop. Traditional as well as mechanized harvesting leaves residue in the fields in the form of stalks, stubble and straws that farmers burn to clear the field for sowing the next crop. Most farmers prefer burning of crop residue over alternate usage, as it is a quicker and cheaper option, and kill weeds and pests in the process.

Major Reasons for Burning the Residue as Disposal

- Residues, having low nutrient content, and are not suitable for cattle fodder
- High rent of rotavator for mulching; for example, in India, it is INR 1,000 per hour (~USD 14/hour)
- Lack of manpower and high labor cost for efficient straw cutting since the introduction of mechanized farming
- Lack of storage space for residue, if collected
- Lack of adequate incentives for sale of such residue
- Burning is the cheapest disposal method

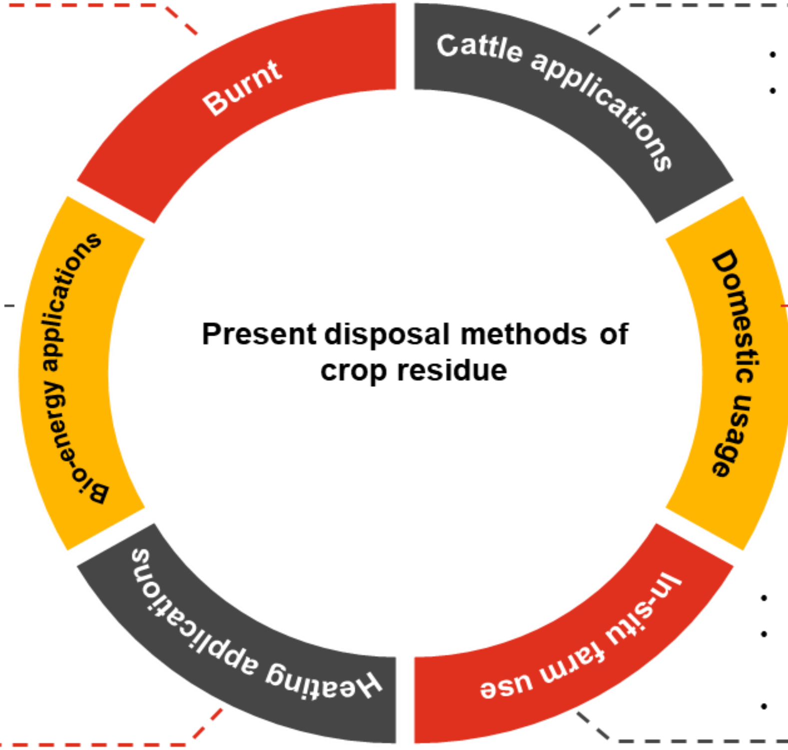
Present Disposal Methods of Crop Residue

Burning is the most prevalent method of crop residue; farmers prefer to burn the crop residue due to heavy investments needed for buying equipment

Farmers have been relying on various techniques for disposing off crop residue, which include using them as animal fodder, ploughing them back into the ground or burning them completely. Recently, newer methods of disposal are also being adopted for the utilization and disposal of these residues, like converting them into biofuels. However, this method is still in pilot stages of development and implementation. The most prevalent disposal technique is field burning of the residues.

- Burnt in-situ by farmers for quick sowing of next crop and lack of alternate usage

- Cattle fodder
- Cattle bedding



- Sold to developers for power and heat generation
- Sold to biofuel manufacturers to produce transport fuel

- Biogas production
- Cooking fuel
- Thatching of roofs

- Brick ovens and kilns
- Domestic heating
- Drying of spices
- Pottery and charcoal making

- Used to prepare compost
- Spread in the fields as mulch for next crop
- Used as fertilizer

Potential Crops for Energy Generation

Cereals have the highest residue producing potential amongst all crops like pulses, oilseeds, cotton and jute

- Most of the residues from these crops are not available throughout the year but are accessible only at the time of harvest. This makes collection convenient, but on the other hand, creates storage related problems, if the residues have to be conserved for use during lean period. Therefore, availability of crop residues is expected to be spread evenly over the year. As a result, crop residues of one kind or the other are available throughout the year.

Potential Crops for Energy generation in SAARC Member States

Country	Highest Production Crops
Afghanistan	**Rice, wheat, maize**, cotton, sugarcane, barley, potato and sugar beet
Bangladesh	**Rice**, **wheat, maize**, sugarcane and jute
Bhutan	**Rice, wheat, maize** and barley
India	**Rice, wheat, maize**, cotton, sugarcane and jute
Nepal	**Rice, wheat** and barley
Pakistan	**Rice, wheat, maize**, cotton and sugarcane
Sri Lanka	**Rice and maize**

The potential crops for energy generation are selected using a combination of factors like:

Area under cultivation

Annual production of crop

Estimated residue potential and surplus residue

Energy content of residue

Crop Residue Potential

The highest potential for energy generation can be realized in three Member States - India, Bangladesh and Pakistan

Crop residue potential: The following table provides the crop residue potential of all the SAARC Member States that can be used for energy generation through efficient harvesting, aggregation, collection and setup of energy generation equipment for heat or power generation.

Crop residue potential of SAARC Member States using rice and wheat straw residue

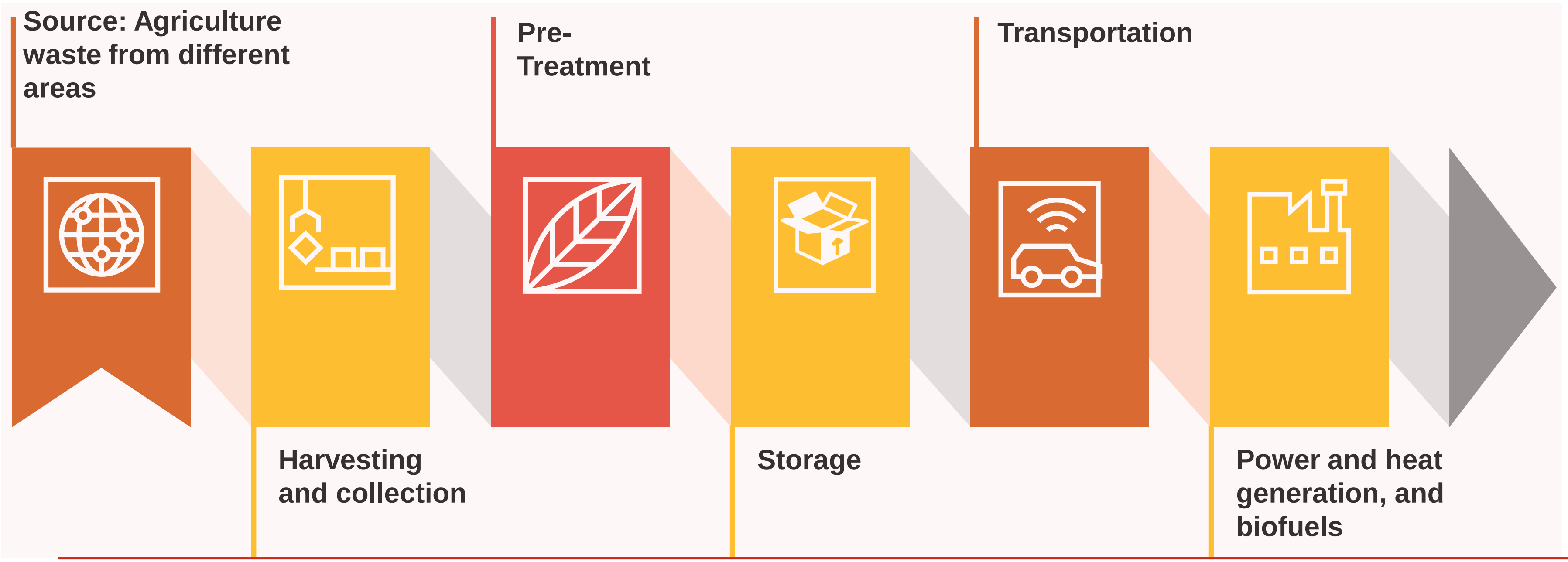
Member State	Gross Residue Production (GRP) (Million Tonnes)	Surplus Residue Production (SRP) (Million Tonnes)
Afghanistan	6.4	1.4
Bangladesh	57.2	15.6
India	319	80.3
Nepal	11.6	3
Pakistan	54.4	13
Sri Lanka	3.5	1
Total	**452**	**114**

GRP = *Yield of crop x Residue Production Ratio of the crop*
SRP = *GRP x Surplus Production Ratio of the crop*

Supply Chain Mechanism (1/2)

Overview of supply chain mechanism

The following figure is the supply chain for converting agricultural waste into more useful forms etc. in the SAARC Member States:



Briquetting process converts crop residues like straws and husks with lower bulk density (80-100 kg/m^3) to higher bulk density briquettes (900-1300 kg/m^3).

Depending on the type of residue used in these briquettes, they can be used as a fuel for cleaner burning.

Briquette machines can be operated by local entrepreneurs or farmer associations to produce products that will replace firewood in rural households, production and sales of which will aid in farmers' incomes.

Supply Chain Mechanism (2/2)

Overview of transportation of crop residue, pellets and briquettes

Transportation cost

- Transport cost- A function of type of residue, form of the residue, type of transport means (vehicle) and distance to be travelled.
- Transportation by tractor, trailer and trucks is most common, while rail is used by some large-scale operators.
- Transportation cost of USD 7-10/Tonne is charged by farmers who supply their residue to the plant site.
- Drying and densification of the residue with equipment can reduce this transportation cost significantly.
- Crop residue densification, i.e. pelletization or briquetting, is suggested for efficient transportation of biomass for long distances.

Pellets

Process of molding or compressing a residues into the shape of a pellet. A broad range of various materials are pelletized includes wood pellets that are frequently used as fuel and pellets from crop residue for animal feed.

Briquettes

Compressed block of combustible biomass material that can be used to fire in combustors for generating heat. Moisture content can be as low as 4%, yields higher energy output and emissions when combusted.

Weather effect on the residue before utilization

There is a time of only 2-3 weeks between the harvest and sowing of the next crop. The crop residue, if not burnt, is collected and stored in the form of bales till they are collected by the aggregators or by power plant owners.

There is a delay of 1-2 months by the time this residue is transported to their end usage, during which time they may be affected by moisture if not stored properly in dry locations.

An increase in the moisture content of the residue reduces the heat content of the fuel and does not ignite straightaway in the gasifiers. The wet residue also produces excessive smoke and ash when fired in the gasifier reactors, thus bringing down the efficiency of the process.

Alternate Uses of Crop Residue

Various applications of crop residues like compost and fertilizer making, mushroom cultivation and paper and pulp manufacturing are prevalent in the South Asian countries

Compost and Fertilizer making

The crop residues left behind after the harvest such as straws, stubbles, stoves and husks can be used as natural fertilizers in the fields to boost the biological and chemical properties of the soil. However, the residue needs composting before being used as fertilizer. The composting method can be of two types - pit composting and aboveground composting, depending on the availability of water, moisture content of soil and temperature of the region. The compost generated is sold to distributors at market prevailing rates.

Mushroom cultivation

Crop residue of few major crops, like rice and wheat, are used in mushroom production in tropical areas. The residues, despite their high moisture content, contain 2-3 times as much protein as common vegetables and amino acids necessary for mushroom cultivation. Wheat and rice straws are used as substrates for cultivation of button mushrooms and straw mushrooms. The straws are mixed with horse manure and hay which are maintained under controlled temperature and moisture conditions for growth of mushrooms. For maximum substrate conversion efficiency, the rice and wheat straws are mixed in equal proportions.

Paper and pulp manufacturing

Residues that are rich in fibers, like that of rice, wheat, sugarcane and cotton, are predominantly being used for manufacturing of pulp, that can be further utilized to create useful items such as paper, cups, plates, straws, etc. Depending on the morphological, anatomical and chemical structure different crops are used for generation of different paper products.

Technologies for Energy Generation

Technologies for Energy Generation (1/3)

Five technologies: combustion, gasification, pyrolysis, anaerobic digestion and co-firing are compared

Technology	Installation Cost	Tariff	Key Features, Pros and cons
Combustion	Million USD 1 – 1.07/MW	USD 0.134-0.14/Unit	The technology is well suited for all types of biomass like municipal waste, agricultural waste, animal waste, etc. with **moisture content of up to 60%.** Modern biomass combustion technologies have emerged like **fully automated pellet boilers, co-firing, and efficient combined heat and power production** for a large variety of biomass resources. **Suited for capacities beyond 5 MW** for realizing maximum efficiency. The process uses incineration of the waste resulting in large emissions of flue gases. Additional capex may have to be incurred for the treatment of these gases to meet the country's emissions standards.
Gasification	Million USD 0.63 – 0.85/MW	USD 0.12-0.13/Unit	Biomass gasification is a thermo-chemical conversion of solid biomass into a combustible gas mixture, called as **producer gas**. **This producer gas is a mixture of combustible gases consisting of Carbon Monoxide, Hydrogen and Methane.** The producer gas can be used for electrical power generation, either through dual-fuel IC Engines or through 100% gas-fired spark ignition engines. Makes use of thermal decomposition of the waste to produce heat, O&G, which can be used as end-products. **The producer gas is cleaner than the flue gases**. Can work on a wide range of waste types and sizes, requiring less pre-treatment. Governments also offer subsidies, grants and incentives for the use of biomass gasification plants, thereby reducing capital costs. **Widely used in the rural areas in smaller capacities to utilize agricultural wastes.**

Technologies for Energy Generation (2/3)

These technologies have evolved over the years

Technology	Installation Cost	Tariff	Key Features, Pros and cons
Pyrolysis	Million USD 0.85 - 1/MW	USD 0.13-0.14/Unit	Biomass pyrolysis is **a thermal decomposition of biomass occurring at very high temperatures in the absence of Oxygen.** Pyrolysis processes can be categorized as slow or fast. Slow pyrolysis takes several hours to complete and results in biochar as the main product. On the other hand, fast pyrolysis yields 60% bio-oil, 20% biochar and 20% syngas and takes seconds for complete pyrolysis. **Pyrolysis is a low-cost technology as compared to combustion**, capable of processing a wide variety of feedstock like agricultural waste, wood, municipal solid waste, etc. Typically, **pyrolysis plants work well beyond 2 MW scale.** **Like gasification**, the technology makes use of thermo-chemical combustion to produce syngas, bio-oil and char, all of which have high economic value. Works on a wide range of wastes in higher capacities. Initial capex of the equipment is quite high and is still in the R&D stages of implementation.

Technologies for Energy Generation (3/3)

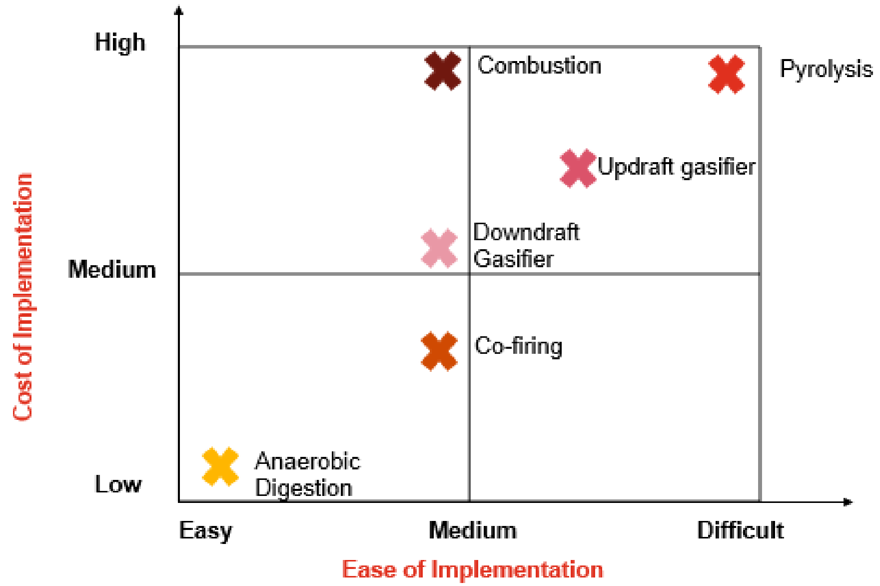
Many factors affecting choice of technology are type, quantity and quality of agriculture feedstock, desired energy form, economic aspects, etc.

Technology	Installation	Tariff	Key Features, Pros and cons
Anaerobic Digestion	USD 250-300/Unit	Not Applicable	Anaerobic digestion is **the process of producing methane rich biogas in the absence of Oxygen using bacteria-induced fermentation of organic matter** for use in cooking or heating applications. This process is best suited for wet biomass sources like manure, kitchen and animal waste, waste water, agricultural waste, municipal waste, etc. The technology is commonly used in **small size, rural and off-grid applications for cooking purposes.** Anaerobic digestion by way of using a biogas plant is being used in the SAARC countries for many decades at a household level. The technology is being commercially used in developed countries in large scales **for production of biogas using different types of wastes.** The Governments of most countries provide grants and subsidies to individuals installing a biogas plant at home.
Co-firing	Million USD 0.42-0.5/MW	USD 0.13-0.135/Unit	Co-firing is a low-cost option for efficiently converting biomass to electricity by **adding biomass as a partial fuel in high-efficiency coal fired boilers.** The technology can be directly applied to existing coal-fired power plants by making modifications to the feed intake system, resulting in lower installation costs. However, only 15-20% of the entire feedstock will be replaced by agricultural residue and will only marginally reduce the tariffs. This technology should only **be used when a coal-fired plant is in close proximity to the fields to reduce transportation costs and ensure fuel availability.**

Selection of Suitable Technology

Gasification best suits the need for energy generation owing to its ability to work with a large range of residue types and sizes and wide operational range

Impact of Technology w.r.t. Ease of Implementation



- **Anaerobic digestion and combustion**: Common and well established technologies used across all the Member States
- **Gasification**: Implemented only in India, Pakistan and Bangladesh.
- **Co-firing:** A mandate to co-fire biomass along with coal has been passed in India only, and suitable modifications to feedstock is under process.
- **Pyrolysis:** In the nascent stages of development and has been installed on pilot basis on very small scale in India and Pakistan.

It is recommended to install gasifiers in all the countries for its many advantages like adaptability to a wide range of residues, low cost, easy implementation and scalability from few hundred kW to MW capacities

Mapping of Biomass Energy Conversion Technologies

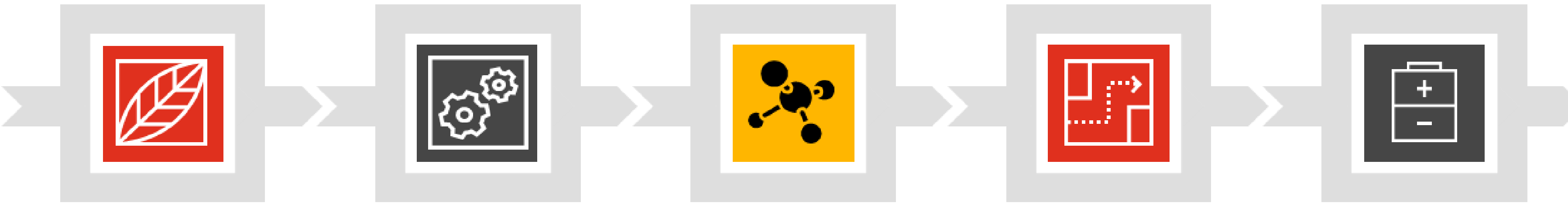
Member State	Anaerobic Digestion	Combustion	Co-firing	Gasification	Pyrolysis
Afghanistan	√	√	X	X	X
Bangladesh	√	√	X	√	X
Bhutan	√	√	X	X	X
India	√	√	√	√	√
Nepal	√	√	X	√	X
Pakistan	√	√	X	√	√
Sri Lanka	√	√	X	X	X

Gasification Process

The syngas can be used as a fuel in place of diesel in IC engines or a 100% gas-fired spark ignition engine coupled with generator to produce electricity

- Gasification is a partial oxidation process, in which a carbon source such as **biomass is broken down into Carbon Monoxide (CO) and Hydrogen (H_2), Carbon Dioxide (CO_2) and hydrocarbon molecules such as Methane (CH_4). The end products of gasification are ash and slag, char, bio-oil and producer gas, or syngas.**
- The complete gasification system consists of a gasification unit called gasifier, purification unit and energy converter, burners or internal combustion engine.

Gasification process



Drying

Agricultural biomass usually contain 10%–35% moisture. When biomass is heated to about 100 °C, the moisture is converted into steam.

Pyrolysis

The process occurs at 200-300°C. Methane and other hydrocarbons are produced from the biomass by the action of heat which leaves a reactive char.

Combustion

The volatiles and char are partially burned in air or oxygen to generate heat and carbon dioxide, which provides heat for the subsequent reactions

Reduction

In the reduction phase, carbon dioxide absorbs heat and reacts with the remaining char to produce carbon monoxide (syngas)

Gas utilization

The syngas an be used for thermal applications in drying industries, kilns and boilers It can also be used to generate power using gas-fuel engines

Preconditions for biomass for implementation: Biomass gasifiers need dry and uniform-sized fuel for smooth operations and higher efficiency. Most gasifiers operate on woody biomass or loose biomass.

Selection of Gasifier Technology (1/2)

There are 5 key gasifier types based on their construction and operation

Gasifier Type	Construction and Operation
Updraft	In an updraft gasifier, biomass is loaded at the top of the gasifier and air is blown in at the bottom; thus, the flow of elements is counter-current, wherein **the fuel flows downwards and the air flows upwards.**
Downdraft	In a downdraft gasifier, air is drawn downwards through the biomass. Thus, the flow of elements is co-current, **wherein the fuel and air both flows downwards**.
Cross draft	**The crossdraft gasifier is similar to that of the updraft one, except that the air enters from the side of the reactor, instead of the top.**
Fluidized bed	In fluidized bed gasifiers, the biomass is brought into an inert bed of fluidized material (e.g. sand, char, etc.). **The fuel is fed into the fluidized system either above-bed or directly into the bed**, depending upon the size and density of the fuel and how it is affected by the bed velocities.
Entrained-flow	In entrained-flow gasifiers, **fuel and air are introduced from the top of the reactor**, and fuel is carried by the air in the reactor. **The operating temperatures are very high in the range of 1200–1600 °C.**

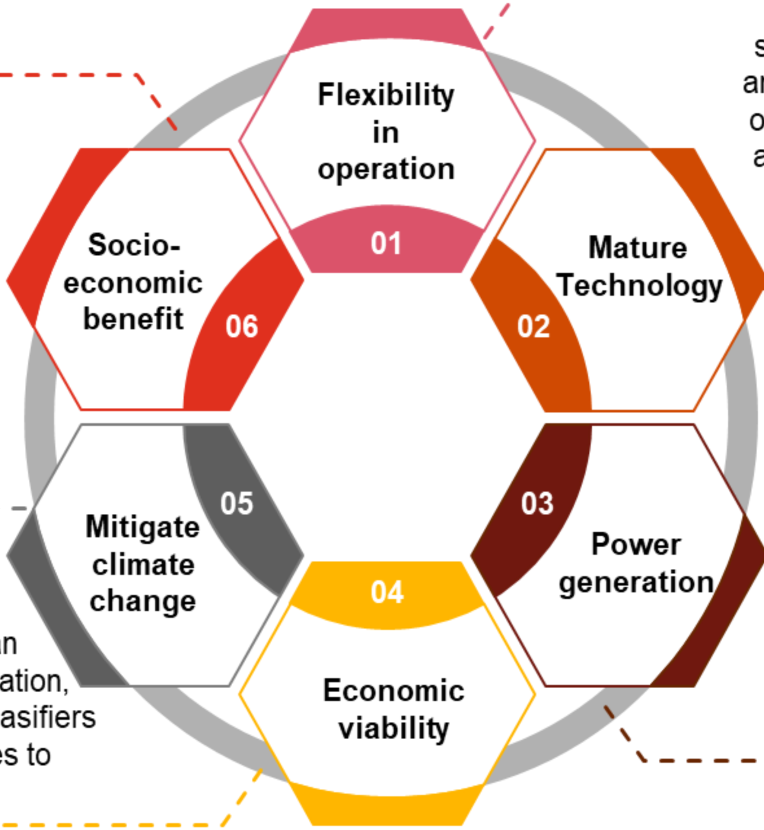
Selection of Gasifier Technology (2/2)

The downdraft type gasifier is preferred by developers as it produces cleaner gas and lower tar, thus reducing O&M costs for regular cleaning of filters

Gasifier Type	Advantages	Disadvantages
Updraft	**Simple design** High fuel to gas conversion efficiency Accepts fuels with higher moisture content Accepts fuels of different and non-uniform sizes	**High amount of tar produced** Extensive and expensive gas cleaning techniques required if used for power application
Downdraft	Low tar content **Cleaner gas produced** Gas can be used directly for power generation At lower loads, fewer particles are produced in the gas	Limited scale-up Strict fuel requirements- size, type and uniformity **High amount of ash and dust produced** At lower temperatures, more tar is produced
Cross draft	Applicable for small scale applications Due to high temperatures**, gas cleaning requirements are low**	**High amount of tar produced** Strict fuel requirements- size, type and uniformity High amount of ash and dust produced
Fluidized bed	Single reactor and compact construction Works with different feed stock sizes **No clinker formation**	**Gas stream contaminated with fine dust particles** Low biomass hold up in the fuel bed Fuel flexibility between 0.1-1 cm size biomass
Entrained-flow	Applicable for large systems **Short residence time of biomass**	**Very high temperature causes material handling and ash melting issues** Very high capital cost Strict fuel requirements

Advantages of Biomass Gasification

The biomass gasification is a mature technology and has many advantages such as flexible to operate, socio-economic benefits and can be used for power generation



01 Flexibility in operation: Unlike other renewable sources, can generate electricity when and where required using a wide range of residue. The biomass can be stored and used as per demand. Can also be set up any place with adequate agricultural residue

02 Mature Technology: Biomass gasifier technology is mature and gasifiers are available in different designs and capacities to suit types and quantities of residue availability

03 Power generation: Due to proximity to rural areas the technology can be used for cheap and decentralized electricity supply to villages

04 Economic viability: Cost of power generation is lower than conventional fuel based power generation, due to almost zero cost of fuel. The gasifiers can be designed for smaller capacities to power villages

05 Mitigate climate change: Biomass is a carbon neutral fuel and net emission of CO_2 would be zero, thus reducing GHG emissions

06 Socio-economic benefit: The gasifier plants can be used to generate local employment and capacity building in rural areas

Q&A

Thank you

pwc.com

September 2020-17853