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Renewable Energy: A New Paradigm for Growth in Agriculture

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Preface

Two key resources for development of human civilization are food and energy and their demand is increasing day by day. The human activity is the manifestation of stored solar energy as food synthesized by plants. With the advancement of food production system from agrarian to a futuristic technology-driven system, there has been rapid increase in energy use in agriculture. Share of agricultural sector in total energy consumption is about 7-8% and further increase in energy use is expected from the present consumption 1.6 kW ha^{-1} to 2.5 kW ha^{-1} to meet the production target of the country during next 20 years. The rise in energy use is imbibed with adverse effects on climate due to burning of fast depleting fossil fuels with far greater emission of greenhouse gasses. In this context, it is imperative to harness and use more renewable forms of energy. Currently, about 16% of the country's installed electricity generation capacity is contributed by renewable sources of energy like wind, solar, bio-energy, hydro power etc. The national solar mission has propelled progress to increase the renewable energy use share in different sectors including agriculture. Solar PV pumping programmes with partial financial support from Government has been in operation in different states to irrigate the field crops. Recently, *Kisan Urja Suraksha Evam Utthaan Mahaabhiyan* (KUSUM) has been launched by the Ministry of New and Renewable Energy, Govt of India to promote renewable energy use in agriculture. These developments indicate far greater possibility of shifting from conventional energy use towards renewable energy based climate resilient and green agriculture in near future.

This strategy paper based on the presentations and discussions in a workshop on "Renewable Energy: A New Paradigm for Growth in Agriculture" on September 25, 2018 deals with the current and future use of renewable energy in Indian Agriculture in the context of available technologies and their techno-economic feasibility. Academy thanks all the eminent scientists and experts for their participation in the in-depth interaction and deliberations. I especially compliment Dr O.P. Yadav, Convener for his initiative to organize the strategy consultation. The editorial support extended by Dr V.K. Bhatia and Dr Kusumakar Sharma is thankfully acknowledged.

(**Panjab Singh)**
President

Renewable Energy: A New Paradigm for Growth in Agriculture

1. INTRODUCTION

Energy is the basic necessity for human being to survive. Demand for daily energy requirements creates pressure on finite source of fossil fuel based energy, which is rapidly declining in different parts of the world. Therefore, there is need to reduce our dependency on fossil fuel based energy, which can be achieved by increasing the share of renewable sources. Solar radiation is the ultimate source of energy which can be harnessed by photosynthesis (3-4% efficiency), photovoltaic (15-30% efficiency) and futuristic bio-photo voltaic-chemical pathway of *Moorella thermoacetica* bacteria. Agriculture is one sector, which consumes about 7-8% of total energy consumption of India. Pumping of irrigation water, use of heavy machineries for different farm operations, processing and value addition of farm produces etc. are major activities by which energy is consumed in agriculture sector. With the advancement of food production system from agrarian to a futuristic technology-driven system, there has been rapid increase in energy use in agriculture. It has been expected that energy use in agriculture needs to be increased from its present value 1.6 kW ha^{-1} to 2.5 kW ha^{-1} to meet the production target of next 20 years. The rise in energy use has adverse effects on climate due to burning of fast depleting fossil fuels and thus emitting greenhouse gasses. In this context, we need to harness and use more renewable forms of energy, especially solar energy that is plentiful in most part of the country. Also, at several locations in India harnessing wind power and utilizing biomass could be effective alternatives. At present, about 16% of the country's installed electricity generation capacity is contributed by renewable sources e.g. wind, solar, biomass etc. The national solar mission has been in progress to increase the renewable energy use share at different sectors including agriculture.

There is target of installation of 100 GW grid-tied PV generations in the country by 2022. Similarly, off-grid PV generation target is 2 GW, which includes solar PV pumping system. Apart from PV generation, there is target of installing 20 million m^2 solar thermal collectors e.g. solar drier, solar cooker, solar water heater etc. Simultaneously, there is also target of 60 GW wind energy generation, 10 GW biomass power generations and 5 GW from other renewables, adding the total renewable energy target of India to 175 GW by 2022. Agriculture sector has great scope in meeting this renewable energy target of the country and can be achieved through major two ways. First is the replacement of fossil fuel based farm operations with renewable energy sources. Second is the contribution in renewable energy generation from agriculture sector. The first approach includes replacing diesel operated or grid-tied electric pumps with solar photovoltaic (PV) pumping system, use of solar devices for processing and value addition of foods, increasing use of solar PV driven tools and implements etc. The second approach is through contribution in renewable energy generation, which may be achieved through either cogeneration of food and energy using agri-voltaic and solar-wind hybrid system or utilizing biomass and agro-wastes for energy generation. All these possible options of renewable energy use and generation in agriculture sector are discussed below along with suitable policy interventions for their increased adoption in field.

2. RENEWABLE ENERGY USE IN INDIA VIS-À-VIS WORLD

At present, renewable energy share to world's global electricity production is estimated as 26.5% (by the end of 2017), out of which 16.4% is contributed by hydropower, 5.6% by wind energy, 2.2% by biomass-power and 1.9% by solar PV and rest in by other renewables (Renewables 2018 Global Status Report, REN21). In India about 16% of energy generation is met through renewable sources e.g. wind, solar, biomass, small hydropower etc. whereas coal is still the main source contributing about 60% of total generation. During last few years, a great stride has been made in renewable energy sector and 71.5 GW renewable energy systems have been installed in India by the end of July 2018. Among off-grid PV installations, about 38,687 solar PV pumps have been installed across the country by the end of 2017.

India ranks 7th in the world in total renewable energy installed capacity while China tops the list followed by USA and Germany. India ranks 5th in the world in total wind energy installation, whereas it is 10th in world among solar PV installation.

Biomass has always been an important energy source in India considering the benefits it offers. It is renewable, widely available, and carbon-neutral and therefore has the potential to provide significant employment in the rural areas. About 32% of the total primary energy use in the India is still derived from biomass and more than 70% of the country's population depends upon it for its energy needs especially for food cooking. In India, biomass materials used for power generation are mostly the agricultural residues or by products e.g. bagasse, rice husk, straw, cotton stalk, coconut shells, soya husk, de-oiled cakes, coffee waste, jute wastes, groundnut shells, saw dust etc. The cumulative biomass power generation capacity in India is about 9377.61 MW by the end of July 2018.

Indian annual gross crop residue production has been estimated as 371 million tons, of which wheat and paddy residues constitutes 27–36% and 51–57%, respectively across years. Bio-energy potential from various residual agricultural mass is estimated to be 4.15

EJ y^{-1} (1 EJ = 10^{18} Joule), equivalent to 17% of India's aggregated consumption of principal energy. The major constraints in biomass utilization is management of widely distributed biomass which makes the collection and transport difficult, time consuming and energy intensive. Another major challenge is to have transport fuel from biomass conversion.

3. SCOPE OF RENEWABLE ENERGY IN AGRICULTURE IN INDIA

India has an estimated renewable energy potential of about 900 GW from commercially exploitable sources. Among the total renewable potential, wind power potential is about 102 GW at 80 metre mast height, solar power potential of about 750 MW assuming 3% wasteland is made available, bio energy potential of 25 GW and rest is by other renewables.

3.1. Solar energy resources

The average solar irradiance on horizontal surface in India is 5.6 kWh m^{-2} day^{-1} and in western India it is 6-6.5 kWh m^{-2} day^{-1}. The solar resource map of India shows that western India receives higher amount of irradiation as compared to rest of the country. However, the cold arid region of the country located at Leh and Ladakh receives highest amount of solar irradiation, which is about 7-7.5 kWh m^{-2} day^{-1}. In western India, maximum amount of radiation in a year is received during the month of April (~6.5-7.5 kWh m^{-2} day^{-1}), whereas the minimum is in the month of December (4.5-5.5 kWh m^{-2} day^{-1}). In total, 6000-7000 kWh of solar energy is available during a year in western India. Moreover, most of the days in a year at western India are cloud free which is generally >300 days clear sunny days in a year. Available solar irradiation and utilizable energy for any location in India can also be viewed from http://mnre.gov.in/sec/solar-assmnt.htm.

3.2. Wind energy resources

Total wind power potential of the country is about 102 GW at 50 m height. Among this, on-shore potential is about 49,130 MW. Most of the wind power potential lies at the state of Gujarat, Andhra Pradesh, Tamilnadu and Karnataka with an estimated potential of 35.07, 14.49, 14.15, and 13.59 GW, respectively. In deserts of India covering western Rajasthan, the wind energy potential is about 5.05 GW.

3.3 Energy from biomass and organic fractions of domestic and industrial wastes

The current annual availability of biomass in India is estimated at about 500 million metric tons. Studies sponsored by the Ministry of New and Renewable Energy have estimated surplus biomass availability of about 120-150 million metric tons per annum covering agricultural and forestry residues corresponding to a potential of about 17,536 MW. Maximum potential of biomass based power generation lies in the state of Punjab with a potential of about 3172 MW equivalent. Apart from it, about 5000 MW additional power could be generated through bagasse based cogeneration in the country's 550 Sugar mills. Most of these bagasse based power generation potential of the country lies in Maharastra and Uttar Pradesh with a potential of 1250 MW from each state. Waste from agricultural farm e.g. cow dung can also be converted to energy and there is a potential of 2554 MW across the country with Maharastra at the top of the list.

4. AVAILABLE RENEWABLE ENERGY TECHNOLOGIES IN AGRICULTURE SECTOR

4.1. Solar technology

4.1.1. Solar photovoltaic technology

Agri-voltaic system

Agri-voltaic system produces food and also generates renewable energy from a single land unit. The concept of integrating both food production and energy generation on a single land unit has been evolved in recent times due to ever increasing demands for the land resources. Both Production of food and generation of photovoltaic based renewable energy need solar irradiation. Production of food occurs by conversion of solar energy to food through photosynthetic process with an efficiency of ~3% whereas PV based energy generation occurs through conversion of solar energy to electric energy through photovoltaic process with an efficiency of ~15%. Both these processes require land as a basic natural resource. Therefore, competition for land may arise in future for agricultural use and PV based electricity generation. There is possibility that solar PV based electricity production will be preferred over agriculture because of its higher efficiency of converting solar energy. Therefore, it is thought of producing both simultaneously from a single land unit through agri-voltaic system.

The interspaces area of agri-voltaic system, which is about 3 m to 9 m in between two PV arrays are utilized for growing suitable crops preferably short height, low water requiring and having certain degree of shade tolerance. In arid western Rajasthan and Gujarat, suitable crops for interspace area may be mung bean (*Vigna radiata*), moth bean (*Vigna aconitifolia*) and clusterbean (*Cyamopsis tetragonoloba*) during kharif season whereas cumin (*Cuminum cyminum*), isabgol (*Plantago ovata*), and chick pea (*Cicer arietinum*) during rabi season. Apart from these arable crops, medicinal plants e.g. gwarpatha (*Aloe vera*), sonamukhi (*Cassia angustifolia*) and sankhpuspi (*Convolvulus pluricaulis*) may be grown in inter space area. Areas below PV modules may also be used to grow vegetables and spices e.g. turmeric, cucurbitaceous crops, brinjal, leafy vegetables etc.

The electricity generated from PV modules in agri-voltaic system may be directly supplied to local grid through net metering system. Average PV generation from agri-voltaic system is about 4-5 kWh kW_p^{-1} day^{-1}. Through sale of the generated electricity, an income of Rs. 7.5-8.0 lakh $acre^{-1}$ can be generated.

For optimum PV generation, regular cleaning of deposited dust from PV module surface is essential and requires about 20-40 litre $month^{-1}$ kW_p^{-1} of water. The rainwater harvesting system from top surface of PV modules in agri-voltaic system has the capability to provide water for cleaning purpose and to recycle it. Apart from cleaning, harvested rainwater may provide irrigation of about 40 mm in 1 acre land.

Solar PV pumping system

Water is the primary source of life for mankind and one of the most basic necessities for crop production. The demand for water to irrigate crops is increasing for achieving the targeted food grain production of the country. For sustainable food production from agricultural farms, irrigating crops at right stages is critically important. Solar PV pumps are quite useful for irrigating the crops using solar energy. Typically, a solar PV system consists of i) PV modules (ii) mounting structure (iii) pump unit (AC/DC) and (iv) tracking system. Sizing of PV module in a solar PV pumping system depends on capacity of pump to draw water. If the suction head is about 4-5 m, which is applicable in case of a surface water reservoir, 1 HP capacity pump is sufficient which requires about 900 W_p panel in case of DC pump and 1400 W_p panel in case of AC surface pump. If the solar PV pump is to be used for drawing more deep water from wells or tube wells, panel size will be higher accordingly. If an irrigation network which requires higher operating pressure than the pump is able to generate as per its capacity and available solar irradiance, the pump will not able to provide irrigation water successfully. For this purpose, larger size PV pumping system e.g. 3 HP or 5 HP solar PV pumping system is required.

Solar PV pumps can be best used with pressurized irrigation system e.g. drippers, sprinkler etc. Small sized solar PV pumps of 1 HP capacity is best suitable to irrigate crops from surface water reservoir in to greenhouses, poly houses, shed net houses for high-value vegetable production. It has been observed in field that 1 HP capacity solar pumps with 3-4 m suction head generates a pressure of about 2-2.5 kg cm^{-2} which can operate 9 mini-sprinklers, 50 micro-sprinklers and drippers. Pressure-discharge relationship of 1 HP solar pump showed a discharge of 45-50 litres per minute when connected to 9 mini-sprinklers.

For operating pressurized irrigation systems e.g. sprinklers, drippers etc, 3 HP or 5 HP solar PV pumping system is commonly used to meet the requirement of designed irrigation network. However, to meet the irrigation demand of crops in rainfed areas or in drylands, these solar PV pumps are mostly connected to ground water table, which are at critical withdrawal stage at most places. It has been reported by the Central Ground Water Board (CGWB) that most of the wells in dryland areas of the country are in critical stage of groundwater withdrawal. Since, the dryland regions receive scarce rainfall and contribution of it to deep groundwater is very negligible, it may not be advisable to further use groundwater for irrigation purpose. Under such circumstances, use of solar PV pumps may prove fatal in future since free and abundant solar energy in the region may lead to excessive withdrawal of groundwater using solar PV pump. Apart to it, solar PV pumps are distributed to farmers in the region under heavy subsidy schemes with financial support from Government up to ~70-80% and hence farmers always show their interest to install the system in their feilds. Therefore, demand for solar PV pumps has been increased tremendously in recent years and even the demand for higher capacity pumps has been increased to withdraw groundwater as deep as 200-250 m.

Under such situation of scarce water resource but plentiful availability of solar irradiation, solar PV pumps need to be used judiciously. Available runoff water after high intensity rainfall event may be stored in farm ponds or polythene lined surface water reservoir. The arid region in India has tradition of harvesting rainwater in indigenous water harvesting structures e.g. nadi, tanka etc since long before. Harvested rainwater in the surface water reservoir may be used for irrigation through solar PV pumping system and for this purpose, small sized solar PV pumps e.g. 1 HP capacity may be sufficient. Moreover, meeting the irrigation requirement from rainwater harvesting structure coupled with solar PV pumping system may be a self-sustainable unit in remote locations.

Solar PV pumping systems has been viewed as one of the most viable options for future energy secure agriculture. Apart from lower life cycle cost, solar PV pumping system has additional advantages over other pumping systems: (i) PV panels of a solar pumping system reduce the CO_2 emission in atmosphere at a rate of about 1360 kg CO_2 yr^{-1} m^{-2} panel area; (ii) assured power supply in a solar PV pumping system enables the farmer to get an improvement in crop yield; (iii) during off time, electricity generated by the solar PV pumping system may be used for domestic needs and for operating small farm machines; (iv) solar PV pumping system may be used in far remote locations, where electric grids are not available. Considering the low life cycle cost and above said benefits, solar PV pumping system will obviously be considered as the first choice by farmers to irrigate crops.

Solar PV sprayer/duster

Approximately, 35% of the crop production is damaged if pest and diseases are not controlled at right time. Uniform spraying of liquid formulations or dusting of plant protection chemicals throughout the crop field is very important for effective control of pest and diseases. Keeping in mind these requirements, several solar PV operated equipment have been designed and developed e.g. solar PV sprayer, solar PV duster etc.

Solar PV sprayer is used for spraying of agricultural chemicals in agricultural field. To provide energy to DC pump (60 W) of the PV sprayer, 120 W_p capacity (60 $W_p \chi$2 Nos) solar PV modules are connected so that the produced energy may be directly used by DC motor.

Solar PV duster is used for application of dust formulation pesticides e.g. sulphur dust, malathion powder etc. It essentially comprises of a PV module (7.5 W_p), a metal carrier, storage battery (12 V, 7Ah) and especially designed compatible dusting unit.

4.1.2. Solar thermal technology

Different types of solar thermal devices are available for processing and value addition of agricultural produces and for improvement of rural livelihood. For example, solar drier, solar cooker, solar water heater, solar desalination device etc have great potential in contributing renewable energy use in agriculture. The basic principle of all these solar devices is to entrap solar irradiation in to an insulated enclosure and converting it to heat energy for further use in drying, cooking, heating etc. Flat glass collectors are mostly used in these solar thermal devices, which receives about 5000-6000 Wh m^{-2} day^{-1} of solar irradiation with an efficiency of 15-20%.

Solar dryer

Solar dryer is a convenient device to dehydrate fruit, vegetables and grains efficiently while eliminating the problems of open sun drying e.g. contamination of dried products with dust, insect infestation and spoilage of products due to sudden rain events. Different types of forced and natural circulation type solar dryers have been designed and developed in different parts of India. Among these type of driers, inclined solar driers are most commonly used. Other types are solar cabinet drier, solar cooker cum drier, phase change material based drier, forced convection type drier with solar air heaters and electric blowers etc. A drier of 1 m^2 glass collector can dry 10-12 kg of fruits and vegetables in 12-24 h, depending upon the initial moisture content of produce. Cost of inclined solar drier is about Rs 9000 m^{-2} collector area. The drier has been extensively tested for drying onion, okra, carrot, garlic, tomato, chilli, ber, date, spinach, coriander, salt coated aonla etc. The powdered products from some of these solar dried materials have also been tested for instant use and have a great potential in development of local entrepreneurship on processed product marketing. Typically, the efficiency of the dryer is 17.57%. Apart from the economic benefit, solar drier can save about 290-300 kWh m^{-2} y^{-1} equivalent energy. Use of solar drier can also reduce 1127 kg of CO_2 y^{-1}, if replaces the conventional electricity operated oven drier.

Animal feed solar cooker

Another important solar thermal device is animal feed solar cooker, which is generally used for boiling of animal feed. Otherwise, the feed for cattle are conventionally boiled through burning of fuel wood, cattle dung cake and agricultural wastes before feeding. The animal feed solar cooker can be fabricated using locally available materials e.g. clay, pearl millet husk and animal dung. Four aluminum pans (*tagari*) with lid can be kept inside cooking chamber for boiling of animal feed. Different types of animal feed e.g. crushed barley (*Jau Ghat*), cluster bean split (guar korma), cluster bean powder, cotton seed, and gram churi with water can be successfully boiled using the animal feed solar cooker between 9 AM and by 3 PM. Animal feed viz. cotton seed and *khal* have also been successfully boiled by the farmers using the animal feed solar cooker. The thermal efficiency of the animal feed solar cooker is about 21.8%. The animal feed solar cooker saves about 1059 kg of fuel wood per year, which is equivalent to 3611 MJ of energy. Moreover, the use of the solar cooker for animal feed would result on the reduction in emission of 1442.64 kg of CO_2 per year.

Solar cooker

In domestic life, most of the cooking energy requirement in rural areas is met by cooking gas or liquefied petroleum gas (LPG), firewood, agricultural waste and cow dung cake. To reduce the pressure on fast depleting fossil and to avoid the use of fuelwood for cooking purpose, solar cooker may be a good option. Different types of solar cooker have been developed in India e.g. solar oven, hot box solar cooker, improved hot box with tilted absorber, double reflector hot box solar cooker, non-tracking solar cooker etc. Solar cookers can be used for boiling rice, lentil, vegetables, dal, roasting of groundnut, boiling of potato, baking of vegetables and preparing *bati* and other local food like *kheech* and *kheer* etc. The overall efficiency of the solar cooker is 24.6%. To eliminate tracking completely and meet requirement of about 10 people, a non-tracking solar cooker has been designed and fabricated. By using the non-tracking solar cooker one can save about 30-40% of fuel requirement. The efficiency of the non-tracking solar cooker is 29.5%.

Solar water heater

Hot water is an essential requirement in domestic life mainly used for taking baths and washing clothes, utensils etc during winter days. Hot water is conventionally obtained through heating using conventional sources of energy e.g. fossil fuels (kerosene, LPG, coal, furnace oil), firewood, cow dung cake, electricity generated from thermal power plants etc. Whenever, these conventional sources of energy are used for water heating, significant amount of CO_2 gas is emitted in atmosphere and creates atmospheric pollution.

Alternatively, solar water heaters can be used to produce hot water using renewable form of solar energy. The most commonly used solar water heater for domestic needs is natural circulation type solar water heater and collector-cu-storage type solar water heater. Both these water heater collects the solar irradiation on flat glass collector. Recently, evacuated tube collectors (ETC) are widely used for solar water heater, which are more efficient than flat plate collector based water heater. ETC based solar water heaters are mostly available in market with a price of about Rs 150 per litre capacity.

Solar distillation unit

Water is a basic necessity for life and people are dependent either on surface water resources e.g. ponds, lakes, rivers etc or groundwater resources e.g. well, tube wells etc. In recent times, both quantity and quality of fresh waters becomes a problem due to injudicious use of water and contamination of salts, heavy metals etc. Under such situation, availability of drinking water is a major problem specifically in arid zone where water is very scarce. Under such critical situations, brackish water can be converted to distilled water using solar energy through solar distillation unit or solar still. Distillate output of solar still need to be mixed with suitable standard minerals in appropriate proportion to make it suitable for drinking purpose. Thermal efficiency of such stills was found to range from 20 to 34% from winter to summer with productivity ranging from 1.0 to 3.3 litres m^{-2} day^{-1}. The economic evaluation of the brick masonry type solar desalination device revealed high internal rate of return (IRR) (151%) and less payback period (0.65 years).

4.2. Wind energy technology

4.2.1. Horizontal axis wind turbine

Horizontal Axis Wind Turbine (HAWT) with three blades installed at the top of a tower of 60-80 m height is generally used for generating electricity from wind energy. As per Betz limit theory, maximum 59% of kinetic energy of wind can be harvested by wind turbines. Efficiency of wind turbines installed in field at a height of 80 m is observed to vary from 40 to 44%. Capacity of turbine installed in fields at different locations of India varies from 250 kW to 2 MW.

Land required to install a wind turbine in field depends on the blade length and the capacity of turbine. Although it has not been installed in regular grid, however a separation distance between wind towers is maintained which is about 4-5 times of the blade length of the turbine. Thus, approximately 4-6.25 ha land area may be required to install a 2 MW turbine, which indicates a land requirement of about 2-3 ha MW^{-1}. Therefore land used for wind turbine installation can be utilised for agricultural production to increase overall land productivity.

4.2.2. Vertical axis wind turbine

Apart from harnessing high atmospheric wind energy at about 50-80 m above ground level (agl) through HAWT, surface wind energy can also be harvested through installation of small vertical axis wind turbine (VAWT) in the form of dual purpose wind barrier. The barrier will able to control wind erosion as well as to generate electric energy from erosive winds. The sheltered distance provided by the barrier is 15 H, where H is the height of the barrier. Considering the available wind speed >10 km h^{-1} for about 10 hours in a day during summer months, 6-10 kWh electricity units may be generated in per ha per day using the developed wind barrier in field. Therefore, dual purpose wind barrier along with VAWT is capable of operating small sized irrigation pump in agricultural field.

4.3. Technology for energy production from agro wastes

About 112 million tons of crop residues are surplus or available in India after accounting for its various traditional utilities. Anaerobic digestion of these crop residues can also generate about 67 million tons of enriched and well decomposed bio-manure/slurry, 12.88 million tons of bio-CNG etc. A recent report of Confederation of Indian Industry (CII)-Niti Aayog of 2018 (Action Plan for Bio-mass Management) also reports additional financial co-benefits of Rs. 7074 $acre^{-1}$ through anaerobic digestion over in-situ management of residues. Anaerobic digestion of crop residues will also moderate pollution, climate change and associated risks in agriculture. Bio-CNG marketing infrastructure in India has also been strengthened with Rs. 75,000 crore private and public investments in August 2018. It has made anaerobic digestion plants economically, environmentally and commercially viable business model without any subsidy being offered for in-situ management. Employment of 0.5 million in the bio-gas plants at primary level and 0.7 million at the secondary level have been estimated for baling, collecting and handling the bio-mass straw. Enabling Gazette notification of Government of India dated 4th June 2018 states that it is Rs.3 to 4 trillion economy of generating biofuel and bio compost from surplus residues of crops, animal dung, sewage sludge, municipal solid, domestic and industrial wastes.

4.3.1. Cogeneration or mixed feed stock

Bio-CNG generation and its benefits can be further multiplied by cogeneration with following agro-wastes. Bio gas yield depends on C:N:P, pre-treatment to break lignin, temperature inside the digesters and many other factors. Mixing of carbon, protein and fat rich feedstocks can optimize the substrate qualities.

- Indian Institute of Technology Delhi has estimated generation of 350 million tons of bio-manure, $6.38\chi10^{10}$ m^3 of bio-gas containing 55 to 65% methane from 980 million tons of cattle dung of 300 million animals. Poultry dropping is being used in the pilot plants of India to increase bio-gas productivity of paddy straw having high C:N. Actually, a mixture of 80 per cent straw (C:N = 75:1) and 20 per cent cattle dung (C:N = 10:1) gives the highest gas productivity in comparison to straw alone or dung alone.
- An integrated system of anaerobic digestion of crop residues, other bio-mass, animal excreta, sewage, municipal solid wastes, industrial, processing and food wastes can be designed to optimize the bio-gas and manure production throughout the year. However, it has to be ensured that the bio-manure gets back to the fields for recycling of nutrients into the soil. In fact, the gasses released during in-situ decomposition and curing of dung in open heaps etc are being directed towards maximum methane production and are filled into cylinders and balloons instead of their release into the air pollution. This is in fact the additional financial co-benefit and environmental externalities in the entire game of bio-CNG production by anaerobic digestion.

4.3.2. Methods of energy generations from agro-wastes

Biomass and agro-waste can be utilized to generate renewable energy, which are of mainly three types: (i) gaseous fuels like biogas (methane), (ii) liquid fuels such as methanol, ethanol, butanol or pyrolysis oil and (iii) electricity. There are two main routes for conversion of biomass into energy i.e., thermo-chemical and bio-chemical. The process details of these two processes and end products are shown in Fig. 1 and 2,

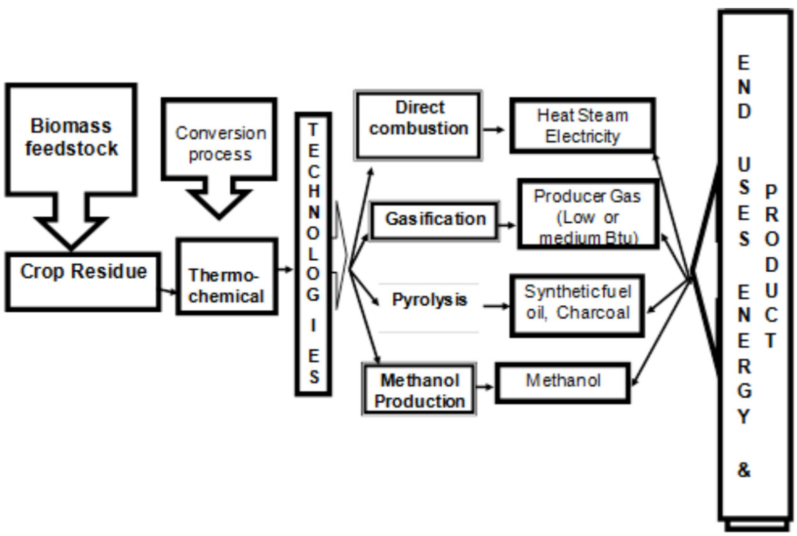

Fig. 1: Thermo-chemical conversion process

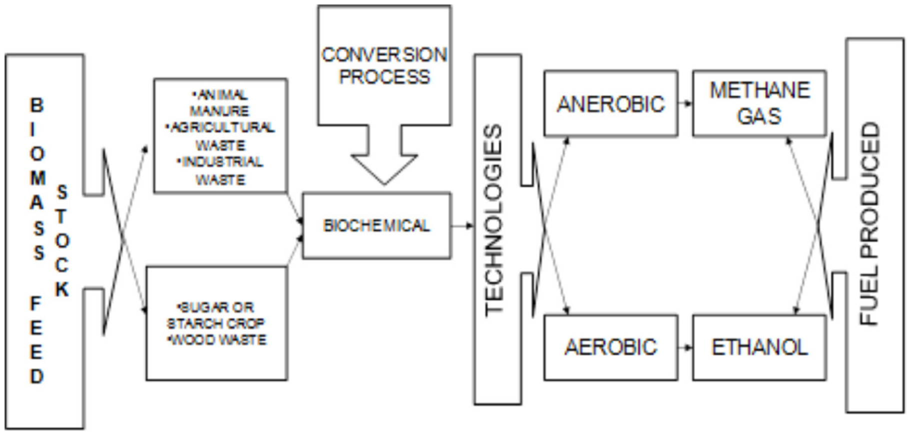

Fig. 2: Bio-chemical conversion process

respectively. The thermo-chemical processes for conversion of biomass to useful products involve heating, pyrolysis, combustion and gasification. Bio-chemical conversion involves biological and chemical agents for degradation and these processes are more suitable for green biomass having higher moisture and less lignin. Thermo-chemical processes are fast and bio-chemical processes are relatively slow. Both processes are important and use different kind of feed stocks. In context with Indian agriculture, thermo-chemical processes are implementable for woody type of crop residues which are lignocellulosic and their biological degradation takes long time. The exhaust of the steam turbine can either be fully condensed to produce power, or used partly or fully for another useful heating activity. The latter mode is called cogeneration.

4.3.3. Comprehensive policy for crop residue management

India may adopt a comprehensive policy for crop residue management. The surplus crop residues can be collected using balers, straw reapers, etc. This method can only collect the crop residues to the tune of 60-70 %. The remaining 30-40 % is to be added in-situ. The farm machines available for crop residue incorporation work well when only 30-40 % of crop biomass is left on field. These machines can handle the crop residue to the extents of 2-4 tons ha^{-1}. For heavy residue conditions above 7 tons ha^{-1}, these machines have shown operational constraints. The best way is to remove 60-70 % crop biomass from field and then use the machines for remaining crop residue for incorporation or retention in soils. Out of collected crop biomass, 50 % can be diverted to electricity production and heat generation, 25 % can be diverted to pyrolysis to generate the char and remaining 25 % can be used for Bio-CNG.

Model for complete utilization of crop residue

A model for complete utilization of crop residue was developed in which biomass is pyrolysed at 300-400 °C to obtain the char, bio-crude and fuel gas in the ratio of 3.5:3.5:3. The schematic diagram of the model is given in Fig. 3.

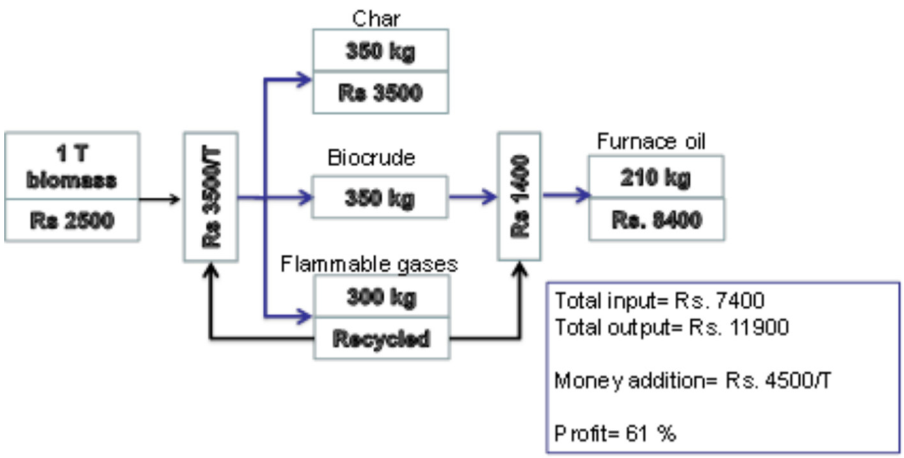

Fig. 3: Comprehensive model for utilization of crop residues

Considering the biomass availability at Rs. 2500 ton^{-1} after collection and handling at the process site, the pyrolysis process uses Rs. 3500 ton^{-1} to generate 350 kg of char, 350 kg of bio-crude and 300 kg of fuel gases. The fuel gases are recycled back to provide the heat to pyrolysis process. Bio-crude can be converted to furnace oil at process cost of Rs. 4 kg^{-1}, investing Rs 1400 for processing 350 kg of biocrude to 210 kg of furnace oil. The economic gain with respect to 350 kg char is Rs.3500 and for 210 kg of bio-crude is Rs. 8400. The total money inflow in this process is Rs. 7400 and outflow is Rs. 11900. The economic gain estimated is Rs. 4500 ton^{-1}. The economic pathway analysis yielded that the profit to the tune of 61 % could be achieved using this model with saving of 0.94-0.99 ton CO_2 per ton of biomass.

5. ROLE OF RENEWABLE ENERGY TECHNOLOGIES IN CLIMATE CHANGE MITIGATION

PV based electricity generation is the clean energy production since it does not contribute to greenhouse gas (GHG) emission. Otherwise, CO_2 emission factor of thermal power plant based electricity generation is about 0.82 kg CO_2 kWh^{-1}. It indicates that whenever we use grid electricity, we indirectly contribute to CO_2 emission in atmosphere. Therefore, all the renewable energy based technologies as discussed above whenever applied in agricultural field saves a significant amount of GHG emission and thus helps in mitigating climate change. For example, agri-voltaic system saves about 598.6 tons of CO_2 emission ha^{-1} y^{-1}. Similarly, 1 HP solar PV pumping system saves about 615 kg CO_2 emission ha^{-1} y^{-1}. Solar thermal devices for water heating also saves huge amount of CO_2 emission in atmosphere e.g. solar water heater with capacity of 100 litre per day can save up to 1.5 ton of CO_2 y^{-1} depending upon the location of installation. Therefore, it is clear that use of solar energy in agriculture either through adoption of agri-voltaic system or use of solar PV pumping system for irrigation or use of solar thermal based processing and value addition of agricultural produces will lead to climate smart agriculture. In addition to reduction in GHG emission, renewable energy technologies provide several ecosystem services. For example, adoption of agri-voltaic system will lead to improved microclimates in agricultural field, reduction in loss of soil moisture through evapo-transpiration, reduction in erosion of top fertile soil, optimum use of rain water by harvesting it and recycling it etc, which ultimate reduces the risk of crop failure during aberrant weather situations. Similarly, solar PV pumping system may help farmers to earn income by selling additional electricity generated through PV systems when it is not used for irrigation purpose.

6. TECHNO-ECONOMIC ANALYSIS OF RENEWABLE ENERGY TECHNOLOGIES

Economics of renewable energy technologies can be calculated through life cycle cost (LCC) analysis. Total life cycle cost of a renewable energy technology is comprised of capital cost, maintenance cost, replacement costs for damaged components and operational cost. Before adding these above costs, all future costs (C) are converted to present worth considering the relative rate of inflation and discount rate.

$$PW = C \times \left[(1+i) / (1+d)\right]^{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, PW is the present worth of any future cost, *i* is the relative rate of inflation and *d* is the discount rate per year and *n* is the time period in years. Relative rate of inflation accounts for the escalated increase or decrease in prices of a commodity in comparison to general inflation rate. For any commodity, if the price escalation is expected as per the general inflation rate then relative rate of inflation was considered zero. Discount rate accounts the real value of money in future and in most of the economies of the world it is about 8-12%, and therefore 10% is considered in general. A discount rate of 10 % per year would mean that in real terms it makes no difference to a farmer whether he has Rs 100 now or Rs 110 in one year's time. Conversely, a cost of Rs 110 one year from now has a present worth of Rs 100. For a future single cost in n^{th} year, the present worth of that cost is calculated using Eq (1). However, for future multiple payments, costs are to be converted to present worth for each year and then needs to be cumulated.

Here, as an example, LCC of solar PV pumping system is discussed. Since the PV panel works for 25 years after its installation, the life cycle of solar PV pumping system was considered 25 years. After conversion of all future costs during its life cycle and summing them up to its present value, total life cycle cost for 3 HP solar PV pumping system is about Rs. 3,51,286 whereas for 5 HP system it is Rs. 5,14,111. The annualized life cycle cost (ALCC) for 3 HP and 5 HP solar PV pumping systems are Rs 38,688 y^{-1} and Rs 56,620 y^{-1}, respectively.

Another approach to calculate the economics is to calculate the payback period. Under such cases all future cost and future benefits are converted to present worth and net present value is calculated. Time period at which the cumulated net present value becomes positive is considered as the payback period.

7. FUTURE OF RENEWABLE ENERGY BASED AGRICULTURE IN INDIA

In spite of significant progress made in renewable energy generation and utilization in agriculture during last few years, there are several opportunities to contribute largely to 175 GW renewable energy target by 2022. Although, there are several advantages of renewable energy technologies whether it is utilization or generation in agricultural field, adoption of these technologies in farmers' field and rural hinterland is far from satisfactory. Therefore, suitable policy interventions need to be formulated in addition to addressing some researchable issues so that future Indian agriculture becomes renewable energy driven. Some of the issues for wider utilization and generation of renewable energy in agriculture are discussed below.

Solar PV pumping systems are being installed across the country with 70-80% support from Government because of high cost of installation. For example, 3 HP and 5 HP solar PV pumping systems costs about Rs 3 lakhs and Rs 5 lakhs, respectively for installation in farmers' field. Beneficiary farmers are satisfactorily using these pumps for irrigation to mostly horticultural crops. Although there is high demand from farmers to install the system in their field, but the number of allotted beneficiaries under Government subsidy scheme is much lesser than expected. For example, only 38,687 solar PV pumps have been installed in the country till 2017, whereas there is scope of replacing about 17 million irrigation pumps across the country, which are presently being operated either through diesel or grid connected electricity. To get maximum benefits from solar PV pumping system, bidirectional energy metre or net metre may be attached to solar PV pumping system. Although solar PV pumps provide assured power supply to farmers for providing irrigation at critical crop growth stages, provision should be made so that farmers can apply irrigation even during cloudy days and night also. Lastly, the size of solar PV modules in a solar PV pumping unit increases as the depth of ground water becomes high. Since, the major cost of a solar PV pumping system is contributed by PV modules, overall cost of pumping groundwater becomes high when the groundwater is deep. On contrary, if the initial cost is met, a solar PV pump indiscriminately withdraws deep groundwater, which is again a concern for groundwater management. Therefore, present subsidy schemes of Government allows for installation of solar PV pumps only up to 5 HP capacity, which can withdraws groundwater from a depth of about 200-250 ft with satisfactory discharge. Whereas, most of the present grid tied electric pumps in the country are in operation with wells or bore wells, deeper than 200-250 ft. Therefore, there is need for promotion of solar PV pump based irrigation from farm ponds specifically in dryland areas where ground water depth is high.

Agri-voltaic system provides opportunity to generate electricity from farmers' field and thus can increase farmers' income. However, the cost of its installation is quite high. For example, Rs 50-60 lakhs investment is required for establishing agri-voltaic system on 1 acre land. To overcome this problem, Public-Private Partnership (PPP) model may be developed. In the PPP model private party will take lead role in PV installation and generation whereas the land owner or farmers will take lead role in farming. The accrued benefits from the system may be shared between private party and farmer. Ministry of New and Renewable Energy has recently launched the scheme KUSUM (*Kisan Urja Suraksha Evam Utthaan Mahaabhiyan*), in which it is planned to install 10,000 MW capacity solar farming system across the country. It is to be ensured that agri voltaic system is a part of the KUSUM scheme. Moreover, performance of suitable crops for agri voltaic system needs to be tested in different agro-ecological regions of the country. Even, the installation of rainwater harvesting system facility to all land-based solar PV installations across the country may be made mandatory.

A major limitation of any PV system is its inability to produce electricity during night. PV system generally produces electricity effectively for 4-5 hours a day. On the other hand, wind turbines can generate electricity 24 hours a day depending on the diurnal variation of wind speed. Thus, solar-wind hybrid may be a good option to generate energy during 24x7 hours in a week. However, research efforts are required to resolve few technical issues of solar-wind hybrid system including designing of solar-wind hybrid system so that effect of wind turbine shade on PV generation can be minimized, and developing smart inverters to combine PV and wind turbine generated energy together of supplying it to grid. Even, further ahead of it, 'four-in-one' land use system may be thought of where wind energy generation at higher atmosphere, solar energy generation near to ground surface, rainwater harvesting from top of PV surface and crop cultivation on ground surface can be done together.

Soil erosion by wind action and deposition of eroded dust on PV module is a major problem for maintaining higher performance ratio (PR) factor of solar PV plants specifically in arid region. Even, the loss of finer particles from top surface of agricultural field makes the soil poor that affects adversely plant growth. Under such situation, dual purpose wind barrier can be used surrounding field boundaries to generate renewable energy from wind resources which can be further used on farm for different purposes. Design of such barrier has been developed. However it needs further field evaluation at different locations of arid region in the country.

Solar PV driven tools and implements can share a large portion of renewable energy utilization in agriculture. Therefore, research efforts are required to develop PV driven tractors, tools and implements etc. Solar fencing can be a viable option to protect crop damage by wild animals and can be promoted for installations in farmers' field. Policy guidelines may be formulated to make it mandatory to cover a portion of polyhouse cultivation system with PV modules.

Solar thermal devices e.g. solar drier, solar cooker, solar water heater etc. are most proven technology since long time but adoption of these in farmers field is comparatively less. Although, there is demand of the devices in the rural areas, however, availability of the devices in market is less. Major limitations of its adoption are: (i) lack of entrepreneurs for fabrication of the devices, (ii) lack of awareness to farmers about the operations of solar thermal devices, (iii) lack of business model for marketing process based products. To address the issue, it is required to promote entrepreneurship for fabrication of the devices and to develop business models to attract investors.

Use of agro-waste or biomass residue for thermal power generation is often debated because of its unviable high tariff rates leading to heavy subsidies; it also liberates gases into the air and does not provide compost to maintain soil health, fertility, productivity and profitability of the farmers. Recently, second generation (2G) bio-fuel technologies have been announced during 2018-19 annual budget, in which biogas and bio-CNG will be produced from wastes through anaerobic digestion. Unlike solar and wind power, liquid and gaseous bio fuels can be stored economically Bio-refineries being set up in India for liquid and gaseous bio fuels production provide compost and minimize greenhouse gas liberation. The anaerobic digestion also provides compost, liquid manure and other bye products. Entrepreneurship development for densification (bailing, briquetting and pelleting) of agro-residues may be promoted for utilization of surplus crop residues for meeting domestic and industrial needs and also to be used as fuel for electricity generation. Production of biochar is upcoming technology for efficient management of crop residues which needs support for field level demonstration and utilization of biomass as soil amendment, liquid fuel (by-product) as furnace oil and feed stalk for value added solid and liquid products. There is need for a National level e-database of biomass availability, utilization pattern and surplus quantities. Database also needs to be generated considering economic environment impact of in-situ and ex-situ management of straw being burned in the field.

8. RECOMMENDATIONS

- Bidirectional energy meter or net meter may be attached to solar PV pumping system so that farmers can sell additional PV generated electricity to local grid when pump is not used for irrigation purpose and thus will provide extra income to farmers. Indian Council of Agricultural Research (ICAR), local DISCOMs and Solar Energy Corporation of India (SECI) under MNRE may come together to implement the system at different states of the country.
- Additional battery backup facility may be included in solar PV pumping system scheme so that farmers can apply irrigation water in their field even during cloudy days and night also. ICAR, MNRE and state agricultural department may come together to provide the facility to farmers of the country.
- There is need for promotion of developing surface water storage of rain water and runoff either through farm ponds or water storage tanks and irrigating with the stored water through solar PV pumping system. The system can be developed through linking of Pradhan Mantri Krishi Sinchay Yojana (PMKSY), National Solar Mission (NSM) and KUSUM.
- Renewable Energy Service Company (RESCO) model can be formulated for installation of agri-voltaic system in farmers' field for food production and PV based electricity generation from a single land unit. SECI may formulate and implement the model in collaboration with Ministry of Agriculture and Farmers' Welfare similar to the RESCO model for roof top solar system.
- Agri-voltaic system needs to be tested in different agro-ecological regions of the country with different crops, for which research efforts need to be strengthened. ICAR may take a lead role to develop the network on agri-voltaic system in India.
- Rainwater harvesting system facility along with cultivation of high-value medicinal crops at interspace area may be made mandatory for land-based solar PV installations across the country so that stored rainwater may be recycled for cleaning of PV modules and for providing supplemental irrigation to crops. National Institute of Solar Energy (NISE), SECI and other concerned organizations in India working on medicinal plants may formulate the necessary guidelines for this purpose.
- Solar-wind hybrid may be a good option to generate energy throughout the day and night and therefore needs to be promoted on agricultural land so that overall land

productivity may be improved. National Institute of Solar Energy (NISE), National Institute of Wind Energy (NIWE) and ICAR may work together to develop such model and implement at suitable locations in the country.

- Small Vertical Axis Wind Turbine (VAWT) based hybrid barrier may be used on farm boundaries to reduce wind erosion as well as to generate electric energy, which may be further used for pumping irrigation water. Design of such barrier has been developed, though it needs further field evaluation at different suitable locations of the country and ICAR may take lead role on this aspect.
- Suitable solar PV/thermal tools, implements and devices may be included in package of practices for agriculture in different states of the country. State agricultural departments and Krishi Vigyan Kendras (KVKs) in collaboration with ICAR institutes may take initiatives for promotion of these solar PV/thermal devices.
- Solar PV covered polyhouses need to be promoted for protected cultivation of horticultural crops so that energy requirement for operationalization of polyhouses can be met from renewable energy sources. National Horticulture Mission (NHM), SECI and ICAR Institutes working on protected cultivations may come together to develop and implement such system in farmers' field.
- Entrepreneurship for fabrication of solar devices may be promoted so that small scale industries on solar based food processing units may be developed. MNRE and ICAR Institutes working on agricultural engineering may take lead role on this aspect.
- There is need for formulation of policy guidelines on proper management of residues for renewable energy generation, compost preparation and providing it as feed to livestock. ICAR institutes working on Agricultural Engineering and National Institute of Bio-Energy (NIBE) may take the lead to develop suitable model for this purpose in consultation with other departments and stakeholders.

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