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SMART VILLAGES – A SUSTAINABLE APPROACH FOR PEOPLE, PLANET AND PROSPERITY

Anju Vijayan Nair

Mississippi State University

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Abstract

To stay competitive in an ever-growing manufacturing sector, a high-tech global manufacturing enterprise must emphasize on over-all development that focuses on meeting the needs of present generation without compromising the needs of future generation. Sustainable development is the key to meet these needs without adversely affecting social, economic and environmental entities. For this to be successful, sustainable development should start from under-developed, remote areas and off-grid villages worldwide. Finding ways to improve the lives of people in villages with their participation is the key to self-sustaining socio-economic development. By establishing a healthy and self-sufficient village, we are able to provide hope and happiness to the people living there. Food-Energy-Water (FEW) nexus is central to sustainable development in these off-grid villages. In this essay, a dilemma triangle approach to identify the major focuses and issues for sustainable development from the perspective of Food, Energy and Water for people, planet and prosperity is presented in the context of an off-grid Indian village. A possible comprehensive solution is proposed for attaining self-sustainability in off-grid villages addressing the FEW needs. The proposed solution includes sustainable and environment-friendly technologies that can be adopted by a high-tech global manufacturing enterprise for implementing in such villages. The advent of Industry 4.0 technologies and the Fourth Wave of environmental innovation gives businesses the power to scale these solutions making socio-economic and environmental partnerships more productive, measurable, open and collaborative.

Introduction

Engineering has created a huge wave of industrialization and urbanization in the past few decades. As a result, the world that we live in has been transformed and shaped into a better and technologically-efficient society with improved systems for communication, transportation, manufacturing and economy. At the same time, use of machineries and sophisticated technologies has led to the increased depletion of natural resources. As the population increased, demand for better facilities, food, energy and other technologies also increased, which further resulted in exploitation of nature and its resources. If this exploitation continues in this scale, by 2035, there will not be any resources left for the future generations. Therefore, it is high time that the industries, manufacturing enterprises and governments across the world give priority and emphasis on "***sustainability***".

Sustainability can be defined as the practice of maintaining processes of productivity indefinitely - natural or human made - by replacing resources used with resources of equal or greater value without degrading or endangering natural biotic systems [1]. Industries and manufacturing enterprises must consider ways to achieve world-wide development which is anchored on sustainability. Sustainable development is the organizing principle for meeting human development goals while simultaneously sustaining the ability of natural systems to provide the natural resources and ecosystem services upon which the economy and society depend [2]. According to the UN Agenda 2030, sustainable development is of comprehensive and universal nature and aims at being transformative. "Comprehensive" means that sustainable development includes the economic, social and environmental dimensions. "Universal" implies that sustainable development not only complies with economic, social and environmental goals at the local scale, but global challenges also must be addressed by national governments and institutions, to enable suitable "transformative" changes in our ways of life [3].

Most of the social, economic and industrial developments are concentrated in and around urban areas. At the same time, a large majority of rural communities are deprived off the facilities enjoyed by the urban communities. Rural development is essential to accelerate overall development of any country. In order to keep a healthy competition in the coming years, large manufacturing enterprises must focus on overall sustainable development which includes social and economic upliftment of rural communities. Finding ways to improve the lives of people in villages with their participation is the key to a self-sustaining socio-economic development. By establishing a healthy and self-sufficient village, we are able to provide hope and happiness to the people living there. Education, entrepreneurship, physical infrastructure, and social infrastructure play an important role in developing rural regions. The development must be sustainable as the resources available are limited and human needs are always growing.

Challenges in Rural Development - Context of Indian Off-grid Villages

India is one of the fastest growing economies in the world and is emerging as a major player in global platform. According to the 2011 Census of India, about 68% of people in India lives in villages. Majority of people in villages depend on agriculture as their main source of living. Many off-grid villages are situated at remote locations, which makes it difficult for the people to have access to basic facilities and technologies. They have limited or no access to basic facilities like water supply, electricity, schools, hospitals and toilets. The people in such off-grid villages depend on water from wells or tube wells for drinking, household and agricultural purposes. Sometimes, people have to walk long distances carrying water from far away sources. Due to illiteracy and lack of awareness, unhygienic practices are prevalent in such villages, which adversely affects the health and quality of lives of people.

Food, energy and water are the three central factors necessary for the well-being, poverty eradication, and social and economic prosperity of people. Food-Energy-Water (FEW) nexus is the central for sustainable development. Demand for these three is increasing due to increased population, economic instabilities, social discriminations etc. Unscientific agricultural practice is one of the main reasons for over-exploitation of water thereby causing water scarcity. Improper agricultural practices pollute groundwater and nearby surface water sources. Different processes involved in food production like land preparation, fertilizer production, irrigation, sowing, harvesting and transportation of crops demands energy which is limited/unavailable in off-grid villages. Also, a considerable amount of solid waste and waste water are generated as a result of agriculture. Improper management of these wastes will eventually cause soil erosion, land and water pollution and outbreak of epidemics. Continuous growing of same type of crops without proper replenishment of soil using organic fertilizers will lead to decrease in fertility of soil resulting in low productivity.

Smart Village to Address the Challenges

The concept of smart villages is to provide access to basic facilities like energy, water, food security, education, sanitation etc. to off-grid villages. A Smart Village enables its inhabitants to make use of the contemporary technological and social achievements and offers an opportunity to efficiently deal with future of energy security and issues of local and circular economies [4]. Among the key characteristics expected in smart villages are connections to towns and cities both through physical infrastructure and through information and communications technologies (ICT) enabled by energy access [5]. ICT can enhance education and health services, providing access to the world's knowledge base and opportunities for distance learning [5]. Smart village also refers to a bundle of services delivered to its residents through community participatory approach in an effective and efficient manner [6]. The basic framework of a smart village proposed by Ramachandra and co-authors is shown in Figure 1. The various services that can be provided include affordable clean water, basic education, shelter and food, communication and transportation, job for the youths, farms and grazing fields for cattle and a proper market for agriculture produce [6].

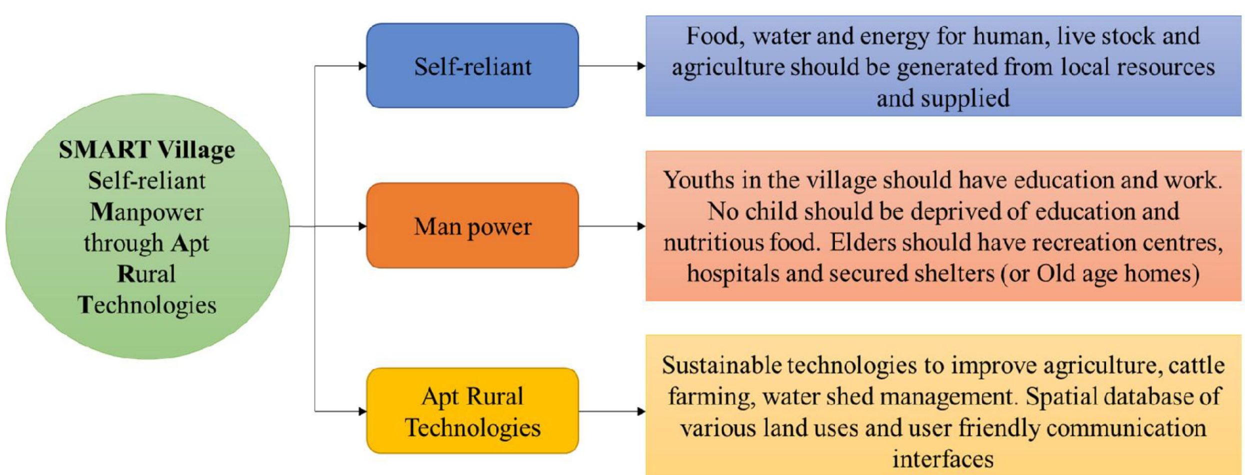
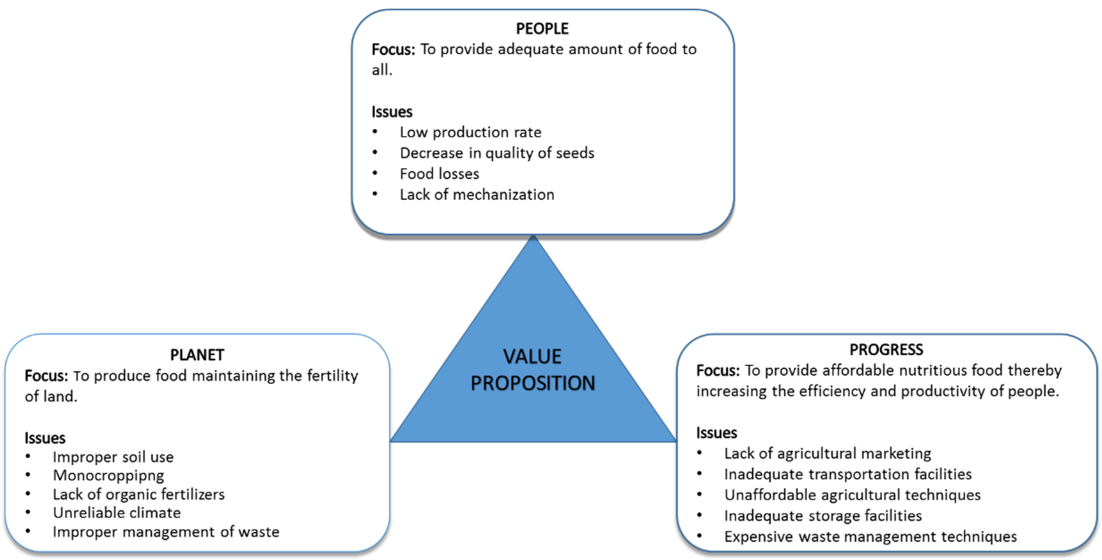


Figure 1: A Smart Village framework proposed by Ramachandra and co-authors [6]

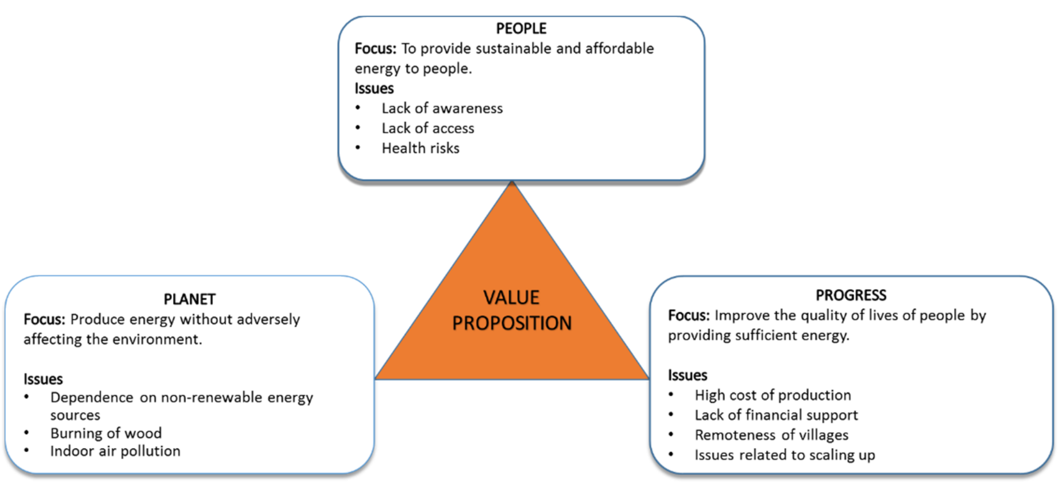
As food, energy and water are considered as central for sustainable development, by providing food security, reliable energy and clean water, the basic concept of smart village is achieved. Therefore, the focus in this essay is on highlighting the possibilities of improving the lives of people by addressing their food, energy and water needs and thereby attaining overall sustainable development. In order to attain sustainable development in off-grid villages, the issues associated with FEW nexus must be addressed with respect to social, economic and environmental aspects. Once the key issues are identified, the main focus is to propose a sustainable solution addressing the key issues and to provide people with opportunities for economic development, thereby providing them hope for a brighter future. Hence the fundamental question addressed is: "*How to provide safe water to people while addressing the issues of water scarcity, energy needs, waste disposal and land productivity in a sustainable, economic and environment-friendly manner and thereby improving the quality of lives of people?*"

Dilemma Triangle Approach to Formulate the Problem

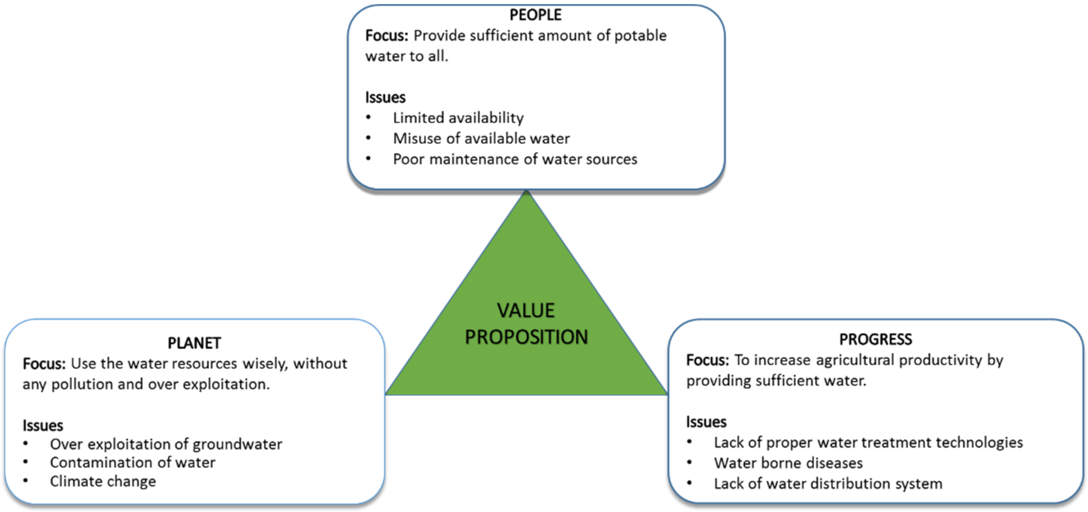
"Dilemma triangle approach" is used to identify the major focuses for sustainable development from the perspective of Food, Energy and Water and the issues associated with them [7]. The issues are identified with respect to three drivers of sustainable development – Social (People), Environmental (Planet) and Economical (Prosperity or Progress) aspects. The possible dilemma triangles for food, energy and water is shown in Figure 2. The issues which conflict in such a way that when we try to solve one issue, the other is impacted negatively, are identified as Tensions [7]. The different tensions within FEW nexus are prioritized giving importance to water and energy needs for food production. A set of possible solutions are identified and analyzed considering their advantages and disadvantages. The feasible solution that best satisfies the requirements and can be implemented in a particular off-grid village is selected.



(a) Dilemma triangle from the perspective of Food



(b) Dilemma triangle from the perspective of Energy



(c) Dilemma triangle from the perspective of Water

Figure 2: Dilemma triangles from the perspectives of Food (a), Energy (b) and Water (c)

Safe (clean and potable) water is one of the basic needs for life. Hence, the issues concerning the need for clean water is given more priority in this essay. Treatment of water is essential for making the available water safe for people. Recycling the used water, after proper treatment using appropriate technologies, can be considered as a feasible solution to address the issues of water scarcity. The need for sustainable energy is also as important as clean water. The dependence on non-renewable resources must be reduced and technologies supporting renewable energy sources must be promoted. For improving the health and hygiene of the people, proper waste management techniques must be introduced. This will prevent the unhygienic practices that cause pollution and outbreak of diseases. Giving importance to all the issues mentioned and prioritizing them, a comprehensive solution must be adopted and implemented in off-grid villages so that it can move further towards being a smart village. In Figure 3, the requirements identified for defining and formulating the problem are shown. The solution adopted must be sustainable, economic and environment friendly and should provide hope and happiness to the people living there.

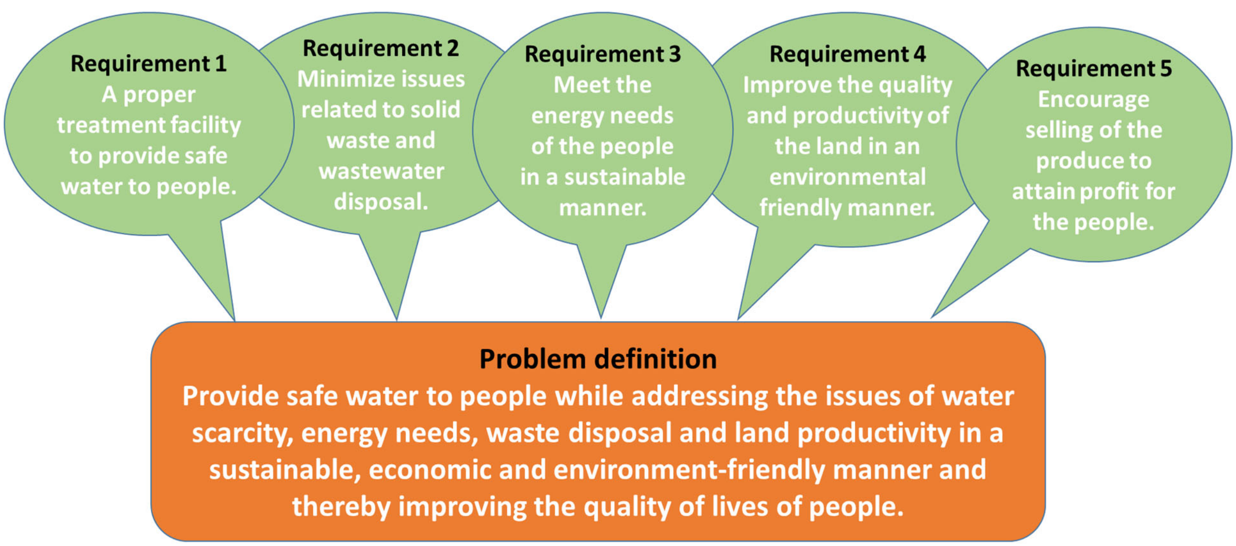


Figure 3: Requirements identified for problem definition

Research Gaps, Hypotheses and Questions

As discussed, for attaining self-sustainability in off-grid villages, the demand for clean water, sustainable energy and waste management must be satisfied in an economic and environment friendly manner. To address this need, several challenges and gaps are identified, see Figure 4. Out of the gaps in Figure 4, the ones highlighted in a yellow dotted box is addressed in this essay.

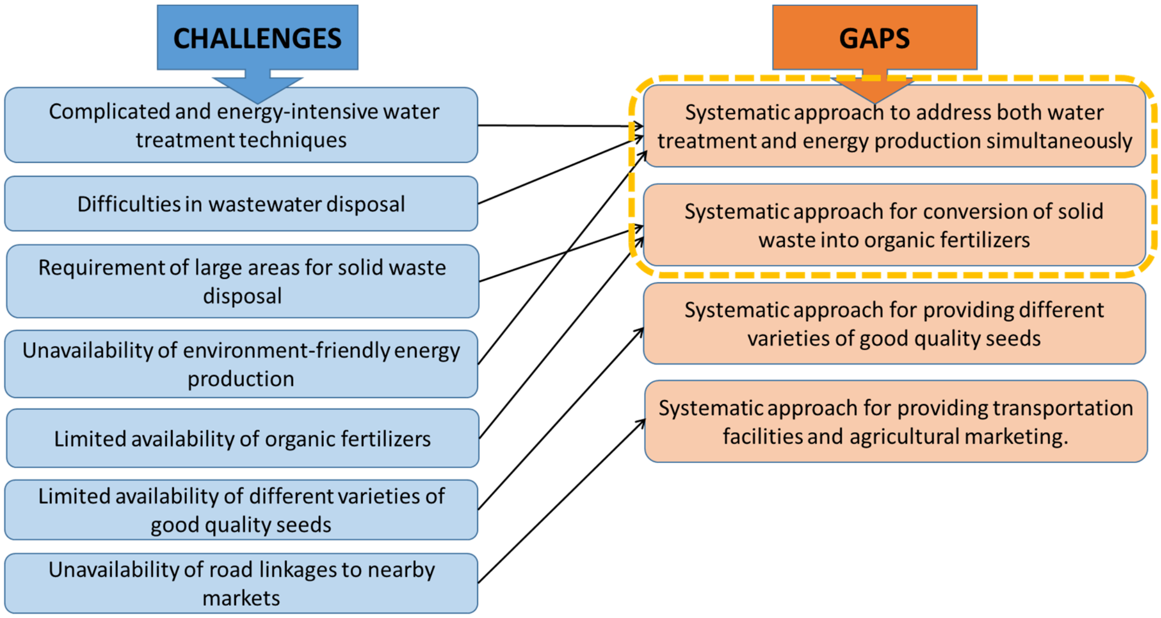


Figure 4: Challenges and gaps identified to address the problem

From the identified gaps, the following research gap is identified, and a hypothesis is proposed to address this gap.

Research Gap: *Self-sustaining system for simultaneous production of energy, treatment of water for village purposes, and, solid and liquid waste management supporting reuse.*

Hypothesis 1: By proposing an integrated system for water treatment, energy production and waste management simultaneously, in a sustainable, economic and environmentally friendly manner which involves the participation, collaboration and contribution of villagers, self-sustaining off-grid villages are possible.

The primary question for research is formulated from the hypothesis as,

Primary Research Question: *What are the working principles of an **integrated self-sustaining system** for water treatment, energy production and waste management meeting the needs of people in villages in a sustainable, economic and environmentally friendly manner?*

In the primary question, a comprehensive approach for satisfying the various needs of people in off-grid villages will be explored. This approach gives rise to the following secondary questions.

Secondary Question 1: What are the working principles of a systematic approach to carefully and scientifically identify and extract organic contents from solid waste that are generated from agricultural fields, households and other sources, facilitating solid waste management and reuse?

To address this question, research efforts are needed to develop a system which can effectively extract the organic contents from solid waste and convert into useful products, thereby providing opportunities for recycling and reusing waste materials.

Secondary Question 2: What are the principles of a systematic approach to effectively store, distribute and utilize the electricity generated from the system?

To address this question, research efforts are required for the systematic design and installation of equipment and technologies for effective storage, distribution and utilization of energy produced by the system.

Secondary Question 3: What are the principles of a systematic approach for treating water from integrated self-sustaining system, so that it can be further reused for household and drinking purposes?

To address this question, research efforts must be focused on designing and implementing appropriate technologies that are used for treating water and making it suitable for household and drinking purposes.

Proposed Solution: Technology, Integrated System and Approach

Constructed wetlands, bioenergy, solar photovoltaic cells, thermal hydrolysis and microbial fuel cells are some of the possible solutions that are identified. All these solutions have advantages and limitations in order to be implemented in an off-grid village, out of which Microbial Fuel Cell is considered as feasible.

Microbial Fuel Cell (MFC) is a device that converts chemical energy into electrical energy by the action of microorganisms [8]. Applications of MFCs include power generation, wastewater treatment, hydrogen production etc. MFC consists of an anode chamber containing anode and a cathode chamber containing cathode. These chambers are separated by a proton exchange membrane. Microorganisms at the anode oxidize the organic matter generating protons and electrons. Protons pass through the membrane to the cathode and the electrons pass through the anode to an external circuit to generate current. Protons and electrons reaching the cathode chamber reacts with oxygen to form pure water [9]. In Table 1, a literature search on microbial-fuel cell-based technologies and applications are presented.

Table 1: Microbial Fuel Cell-based Technologies – Literature Search

Topic	Reference	Application Details
A microbial fuel cell–membrane bioreactor integrated system for cost-effective wastewater treatment	Wang and co-authors [10]	• MFC–MBR integrated system for simultaneous wastewater treatment and energy recovery. • Low-cost materials were used for the reactor construction. • Influent flow rate was 2.33L/hr. • Average current of 1.9 ± 0.4 mA achieved over a period of 40 days. • Maximum power density of 6.0W/m^3.
Low-Cost, Single-Chambered Microbial Fuel Cells for Harvesting Energy and Cleansing Wastewater	Ashutosh Patra [11]	• MFCs were constructed from cheap alternatives to traditionally used, expensive Nafion® membranes. • A novel electrode-membrane-cathode assembly was shown to produce 4.33 times the amount of energy per dollar than the typical current laboratory MFC. • Current and potential of 0.78 mA and 0.59 V respectively were generated by a 9 cm^2 anode.
Pee power urinal – microbial fuel cell technology field trials in the context of sanitation	Ieropoulos and co-authors [12]	• Demonstrated the feasibility of modular MFCs for lighting. • A mixture of activated sewage sludge and fresh urine was used for treatment. • Total liquid capacity of the system was 25 litres. • Field trial consisted of 288 MFCs (8 modules with 36 MFCs in each) generating 75 mW (mean), 160 mW (max) with 400 mW when the lights were connected directly without supercapacitors.
Continuous electricity production from artificial wastewater using a mediator-less microbial fuel cell	Moon and co-authors [13]	• MFC was optimized in terms of MFC design factors and operational parameters for continuous electricity production using artificial wastewater. • Highest power density of 0.56 W/m2 was achieved with wastewater fed at the rate of 0.53 ml/min at 35oC.

The schematic representation of a conventional MFC is shown in Figure 5.

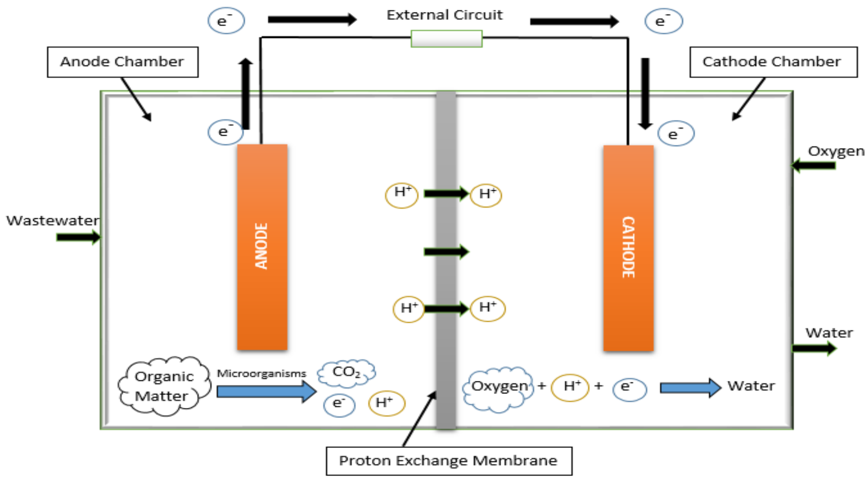


Figure 5: Schematic representation of a typical Microbial Fuel Cell

A mediator (chemicals like methylene blue, natural red, thionine, etc.) is used to transfer electrons from the bacteria in the cell to the anode [9]. Modifications can be done to the conventional MFCs to improve the performance and make the system economical and cost effective. Mediator-less MFC uses electrochemically active bacteria (*Shewanella putrefaciens*) to transfer electrons directly to the electrode so that use of hazardous chemicals in MFCs can be eliminated [14]. The power output generated from an individual MFC unit is insufficient for most practical applications, therefore to increase power, series configuration of individual MFC units needs to be implemented into a stack [15]. MFC stack designs can be adopted where a number of cells are connected in series and/or in parallel in order to achieve the desired voltage and current and, ultimately, power.

Microbial fuel cell can be adopted as a technique for simultaneous wastewater treatment and energy production. For achieving self-sustainability, an integrated system for water treatment, energy production and waste management meeting the needs of people in villages in a sustainable, economic and environmentally friendly manner is required. A possible approach involving microbial fuel cell that can be implemented in an off-grid village for addressing the issues of water treatment, energy needs, and waste disposal is schematically presented in Figure 6.

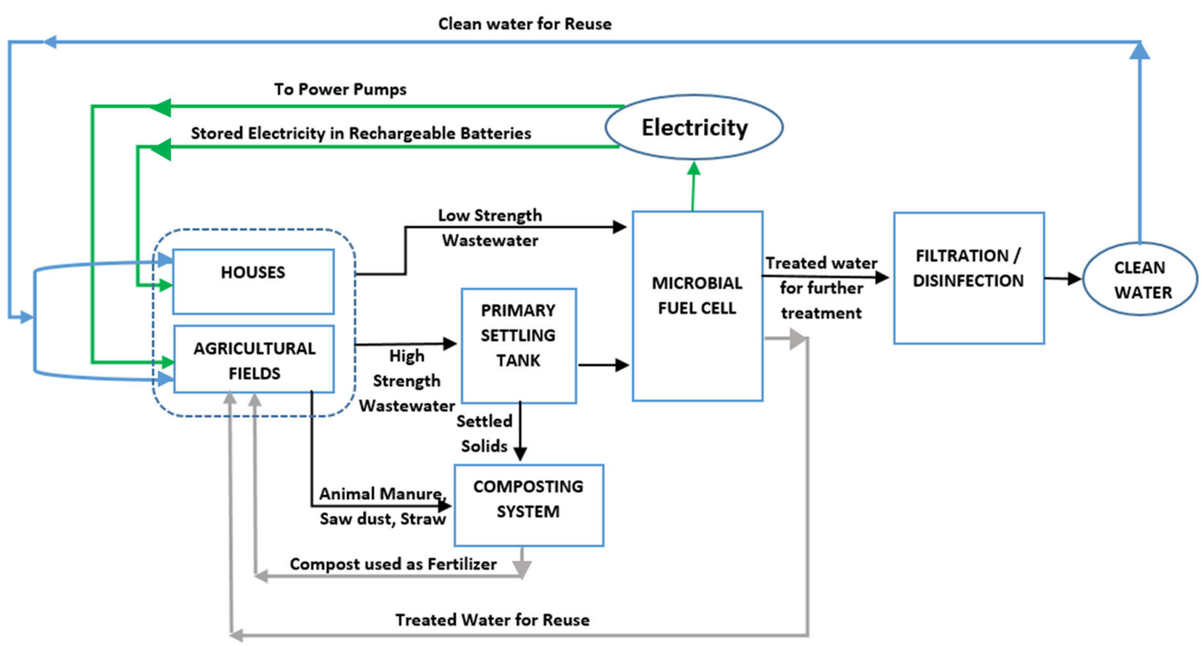


Figure 6: Proposed solution - An integrated system for water treatment, energy production and waste management, simultaneously

Low strength wastewater can be directly fed into the MFC system. A primary settling tank can be adopted for separating the solid content in high strength wastewater before feeding into MFC system. Wastewater reaching the MFC system is treated using microorganisms and electricity is generated. Electricity generated can be used to power pumps or stored in rechargeable batteries. Treated water from MFC can be reused for agricultural purposes or can be further treated using filtration or disinfection, if needed and used for household purposes. Settled solids from primary settling tank and agricultural wastes (animal waste, saw dust, straw, etc) decomposes in a composting system to form compost. Compost is rich in nutrients and can be used as an organic fertilizer for soil.

Way Forward using Internet of Things (IoT)

The expansion of e-tools in rural areas will enable villages to become more agile, make better use of their resources as well as improve their attractiveness and the quality of life of rural residents [16]. Once the off-grid villages are given access to electricity, the next step to become smart village is to have internet connections. Internet of Things (IoT) is the future of communication and technology. It is the extension of internet connectivity into physical devices and everyday objects [17]. With the help of IoT, smart villages can be set up by adopting sophisticated technologies for improving agriculture, health, environment, water treatment, waste management and safety [18].

Partnerships – Academic and Industrial

Sustainable rural development is not a simple technique that can be achieved by an organization alone. It requires multiple partnerships from different sectors of science and technology. The possible solution proposed in this paper involves technologies that require academic, industrial and economic support. The various techniques mentioned in the approach should be adaptable for an off-grid village. The characteristics and needs of each village will be different from the other. The primary step towards achieving sustainable rural development is to gather information about the actual issues and demands of the people in village under consideration. For this, social workers, non-governmental organizations (NGO) or volunteers from similar organizations have to meet the people in person and understand the socio-economic and environmental condition of the village.

The next step is to design the solution in such a way that it meets the needs of people in a sustainable, economic and environment friendly manner. Modifications for the proposed design must be done to make the solution adaptable for the village, which is possible only with the help of researchers and academic institutions. Collaborations from different industries and manufacturing enterprises are inevitable for producing and processing the required technology. Capital investment and financial backup is another inevitable factor required for making sustainable rural development possible.

Speculating the Future – Industry 4.0 and the Fourth Wave of Environmentalism

Industry 4.0 or fourth industrial revolution involves the present innovations like automation and data exchange in manufacturing technologies. The Fourth Wave of environmentalism is characterized by the use of technologies like Internet of Things for achieving sustainability and for conserving the environment [19]. By the year 2030, the trend in manufacturing enterprises will be exploring the combined possibilities of industry 4.0 and fourth wave of environmentalism. The technologies of industry 4.0 like artificial intelligence, machine learning etc., will be utilized for attaining sustainable development goals. Companies should consider both business and environmental goals simultaneously to stay ahead in the competition. The integration of intelligence in production machinery and across the supply and distribution chain has a large potential to reduce pollution, wastage, and emission - making contribution to sustainable industrialization through innovation [20]. The technologies and innovations driving sustainability in the world of 2035 is speculated in Figure 7. These include: data analytics and data-driven methods to capture information and knowledge; knowledge-based platforms for storage and reuse of knowledge; automation technologies that facilitate sustainable manufacturing and supply chains; cloud-based technologies that facilitate instant communication, sharing and collaboration; dematerialization to reduce the amount of resources for production, packaging, transportation along with reuse and recycling technologies; intelligent resources, sensors and smart products that support human decision making, machine learning and artificial intelligence to process information thereby supporting human decision making.

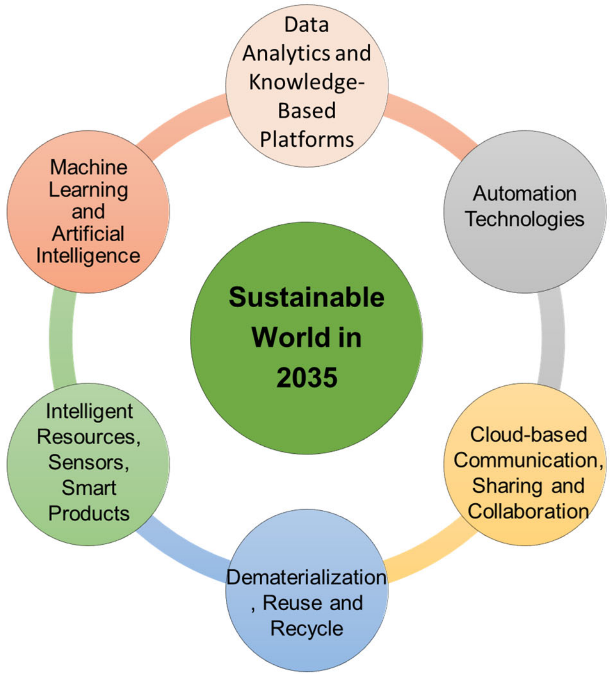


Figure 7: Speculating the technologies and innovations that drive sustainability in 2035

By leveraging these innovations and technologies, it is high time for business enterprises and leaders to raise the bar for sustainability to align business, social, economic and environmental goals. Industry 4.0 technologies like cloud-based design and manufacturing, see [21], and Fourth Wave innovations, see [22], can support these efforts by sharing valuable data, information, knowledge, and resources instantly. This paves way for open innovation and powerful collaboration between partners from industry, advocacy groups, and the communities thereby facilitating a cost-effective co-creation of value.

Closing Remarks

By the year 2030, sustainability will be the main focus in almost every sector worldwide. In such a competitive world, for a manufacturing company to persist, the business goals must be formulated with a mindset of attaining positive sustaining impacts on the society. To outstand the existing trend of development focusing mainly on urban areas, the company must shift its focus on designing and manufacturing technologies that support sustainable rural development. The possible solution proposed in this paper involves different technologies that can be addressed by a high-tech manufacturing enterprise for staying ahead in the competition. The challenges associated with achieving this goal can be overcome by the joint support and partnership with academic institutions, industries and other government and non-governmental organizations. Using Industry 4.0 technologies and the Fourth Wave of environmental innovation, businesses can scale the sustainable solutions making socio-economic and environmental partnerships more productive, measurable, open and collaborative.

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