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A Micro Industry with Closed Energy and Water Cycles for Sustainable Rural Development

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Abstract

Sustainable development requires combining economic viability with energy and environment conservation and ensuring social benefits. It is conceptualized that for designing a micro industry for sustainable rural industrialization, all these aspects should be integrated right up front. The concept includes; (a) utilization of local produce for value addition in a cluster of villages and enhancing income of the target population; (b) use of renewable energy and total utilization of energy generated by co and trigeneration (combining electric power production with heat utilization for heating and cooling); (c) conservation of water and complete recycling of effluents; (d) total utilization of all wastes for achieving closure towards a zero waste system. *Enhanced economic viability and sustainability is achieved by integration of appropriate technologies into the industrial complex*.

To prove the concept, a model Micro Industrial Complex (MIC) has been set up in a semi arid desert region in Rajasthan, India at village Malunga in Jodhpur district. A biomass powered boiler and steam turbine system is used to generate 100-200 KVA of electric power and high energy steam for heating and cooling processes downstream. The unique feature of the equipment is a 100-150 kW back-pressure steam turbine, utilizing 3-4 tph (tonnes per hour) steam, developed by M/s IB Turbo. The biomass boiler raises steam at about 20 barg 3 tph, which is passed through a turbine to yield about 150 kW of electrical power. The steam let out at a back pressure of 1-3 barg has high exergy and this is passed on as thermal energy (about 2 MW), for use in various applications depending on the local produce and resources. The biomass fuel requirement for the boiler is 0.5-0.75 tph depending on its calorific value. In the current model, the electricity produced is used for running an oil expeller to extract castor oil and the

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castor cake is used as fuel in the boiler. The steam is used in a Multi Effect Distillation (MED) unit for drinking water production and in a Vapour Absorption Machine (VAM) for cooling, for banana ripening application. Additional steam is available for extraction of herbs such as mint and processing local vegetables.
In this paper, we discuss the financial and economic viability of the system and show how the energy, water and materials are completely recycled and how the benefits are directed to the weaker sections of the community.

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Keywords: Trigeneration; Micro-industry; Sustainable development

1. Introduction

It is now well recognized that economic growth alone does not lead to sustainable development. Besides techno-economic viability, we must simultaneously address energy, environment, water and social issues which are needed for sustainability. Conservation of human values and the ethical fabric of the society is an additional dimension. Industrialization must be planned within this framework assessing the technological system holistically.

Energy is a key input to mechanization. Ecofriendly and decentralized, renewable energy resources such as biomass and solar are most suitable for rural areas where there is good sunshine and conditions support agriculture. Generally, biomass is available and accessible in the form of residues from agriculture and various agro based industries besides dedicated energy plantations. Enterprises based on these resources may be developed at different scales from household to village clusters as shown in Figure 1.

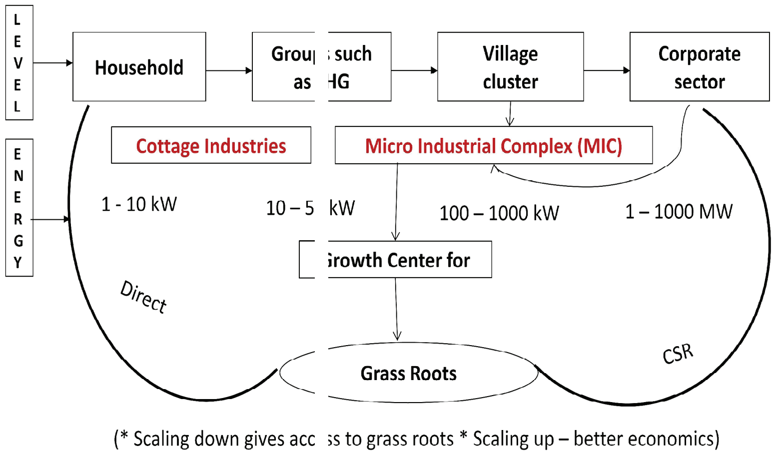

Fig. 1: Sustainable Enterprises at different scales

Both capital investment and energy requirements are scale specific. While, returns for investment would be higher at bigger scales of operation, at smaller scales there is a greater potential for local value addition and fostering employment and equity among the weaker sections. Hence, for achieving sustainability and spread effect, technologies and systems which are economically viable at small and intermediate scales have to be designed, developed and implemented at selected sites. Such scales are also suitable for designing closed energy, water and material cycles for environmental conservation.
Cogeneration and trigeneration help in the operation of closed-energy cycles. In the co and trigeneration mode, primary energy in the fuel is converted into electricity and thermal energy. The latter is used for heating and cooling in trigeneration. Thus, a broad range of energy services are made available at site. The systems can be configured and implemented in many ways, depending on the energy source, product and process requirements and the scale of

operation. Some examples have been listed in an earlier publication by the authors [1, 2].
Given the water scarcity at global levels, conservation and efficient utilization of water resources are of universal importance. Water of different quality and quantity is needed for drinking, domestic consumption, agricultural, industrial and other applications. The global demand is increasing with population and quality of life. Irrigation accounts for major water consumption in an agricultural economy. On the other hand, any industrial enterprise will necessarily consume water. The effluents from the industry have to be suitably treated for use within the premises for e.g. cleaning and for irrigation of land nearby for biomass production.
In general, to minimize footprints on the environment all efforts must be made to conserve and recycle all materials and wastes, solid, liquid and gaseous. For example, organic waste can be treated by chemical or bio chemical pathways to generate bio fuels, bio fertilizers, bio pesticides etc. or dried and pelletized for use as fuels.

2. Designing a Sustainable System

Within the above broad framework the design of the industry has to be based on site specific factors. To begin with we list out all the raw materials, energy resources and technologies available for energy conversion and utilization, processing of materials and waste management at the scales of operation desired. The technologies appropriate to the site and scale are selected and integrated to satisfy the sustainability criteria *viz* techno economic viability, energy and environment conservation and total waste recycling.

2.1 Energy from Biomass

*Biomass availability as Energy Resource: B*iomass resources may be classified under the heads agro residues, agro industrial residues and dedicated energy plantations. The quality, quantity and sustainable availability have to be considered. These vary widely with the agro climatic conditions and agro industrial base in the area.
By way of illustration, availability of biomass from selected agricultural residues and energy crops may be considered [3, 4, 5]. Agricultural crops such as rice and wheat yield about 1-3 tons per hectare of hay. Additionally when dehusked, husk and bran are available as residues. In the case of oil crops such as castor and groundnut, the seed availability under rainfed condition is around 0.5–1.5 t/ha, and the yield may be twice as much under irrigated conditions. Mostly the oil content is in the range 30-50%. Hence, while extracting oil more than 50% of the seed yield is returned in the form of oil cake. For example, it is reported that for each ton of castor oil, 1.31 ton of husk and 1.13 ton of meal are produced [6]. Further, in oil crops cultivation, stalks and other residues are also available. It has been reported that castor stalk, a by-product of castor plant cultivated for its seeds, has an average yield of 10 dry t/h, which is higher than average yield of forest in temperate zone [7].
Among energy plantations, high biomass yields of a variety of grasses have been noted. For example, switch grass (*Panicum virgatum*) and miscanthus spp. are reported to yield 5-23 tons and 5-44 per hectare of biomass respectively in a year [5]. Dedicated energy plantations of trees like Salix and Eucalyptus yield approximately 10-20 tons of wood per hectare post maturity. The yield increases considerably on irrigation especially with domestic wastewater containing nutrients [8].

2.1.1 Harnessing energy from biomass: There are a number of technologies for harnessing the chemical energy stored in biomass into other forms of energy. The pathways for energy harnessing may be classified as thermo chemical and bio chemical routes. *These include direct combustion and utilizing the heat, bio oil generation, pyrolysis, gasification and biomethanation among others.* The choice depends on the type of application and the scale of operation. These have been discussed in detail in the context of trigeneration [1]. It may be noted that among these, direct combustion of biomass in boilers for steam generation is most useful in an industry where steam is needed for processing and power is generated by a steam turbine (cogeneration).

2.2. Effluent Water and Solid Waste Recycling

It is useful to design for closed water and solid material cycles to ensure conservation. Any waste generated in liquid and solid forms can be treated and utilized for biomass production which in turn can be put back as fuel. This leads to no or low carbon footprint. Phytoremediation of waste water by passing through plants roots has emerged as an ecofriendly alternative for effluent water treatment. If waste water is devoid of toxicants it can be directly used for irrigation (also known as fertigation when waste water has considerable nutrients). In case, certain contaminants

need to be removed from the waste water, it can be passed through terrestrial constructed wetlands and floating wetlands [9, 10, 11]. Also, in water management it is useful to integrate rainwater harvesting in most sites.
As for organic solid wastes, these can be used for generating compost and vermi-compost which can be used to fertilize plants. Where, wet waste biomass is available, biomethanation is an alternative to generate nutrient rich compost besides biomass.

3. Setting up of Micro Industrial Complex (MIC): The Trigeneration system

Biomass which is a renewable resource is traditionally used in villages essentially for heating and lighting. This resource has to be made useful for providing “higher forms” of energy which can support micro enterprises. This way benefits would reach directly to the small farmers because they will be involved in the production of biomass and utilize the same locally. A conceptual framework has been developed for generating “sustainable livelihoods” using locally accessible biomass such as agro-residues, weeds and biomass grown specifically in the form of energy plantation. The process of “trigeneration” is at the heart of this system. Within this broad framework for interventions, technologies are selected and integrated depending on local specific conditions. For proving the concept MIC is set up at the village Malunga in Jodhpur district, Rajasthan. The design and initial work done has been described in our earlier publication [2]. As a sequel to this, the actual establishment of the industry is presented in detail herein.
Malunga was selected for setting up the MIC as a challenging task. The village is 37 km northwest of Jodhpur city in the rural hinterland. It falls in a semi arid zone with a rainfall less than 300mm per annum. The soil is sandy loam and groundwater is saline in many areas. The temperature in summer is very high (42 – 47°C) and sun shine is available for about 300 days. In winter the temperature falls to 10°C. There is water scarcity for drinking and irrigation in most places. Crops tolerating salinity and drought conditions are suitable for cultivation. Oil seeds e.g. castor and vegetables and fruits like tomato, Ber (Zizyphus spp) and amla (*Phyllanthus emblica)* are grown. Also aromatic herbs and spice crops like mint and cumin are cultivated. Cotton and chilli are cash crops. Opportunities for employment in agriculture and other sectors are limited. Hence, new avenues have to be opened up for income generation.

Given the above local conditions the following technologies are suitable for development of the area, where possible using local produce (table 1).

Table 1: Technology Selection for Malunga

Local Need	Technology Interventions Needed
Rainwater Harvesting	Check Dams and Rainwater Recharge, Roof top harvesting
Crushing Castor Seeds for Oil	Setting up Oil Mill
Drinking Water Production	Multi Effect Distillation (MED), Reverse osmosis (RO)
Premises Cooling	VAM Cooling, Evaporative cooling
Irrigation Conservation	Drip & Clay Pot Irrigation
Electricity and other forms of energy	Boiler and Turbine combination for co/trigeneration
Processing agricultural produce	Drying, Cooling, extraction and various food processing technologies using steam
Solar Devices for utilizing solar energy	Solar Thermal Devices for Steam Generation, Solar photovoltaic for water pumping, lighting and cooking
Income generation and value addition	Setting up an Industry for employment generation and processing local produce

The MIC was carefully designed to integrate all the above activities with synergy to create a sustainable system. School of Desert Sciences (SDS), which took the responsibility of running the MIC also helped in the design and construction. All the technologies chosen are ecofriendly and the system was designed to benefit the community in short and long terms. The schematics of the trigeneration system and product mix are shown in Fig. 2.

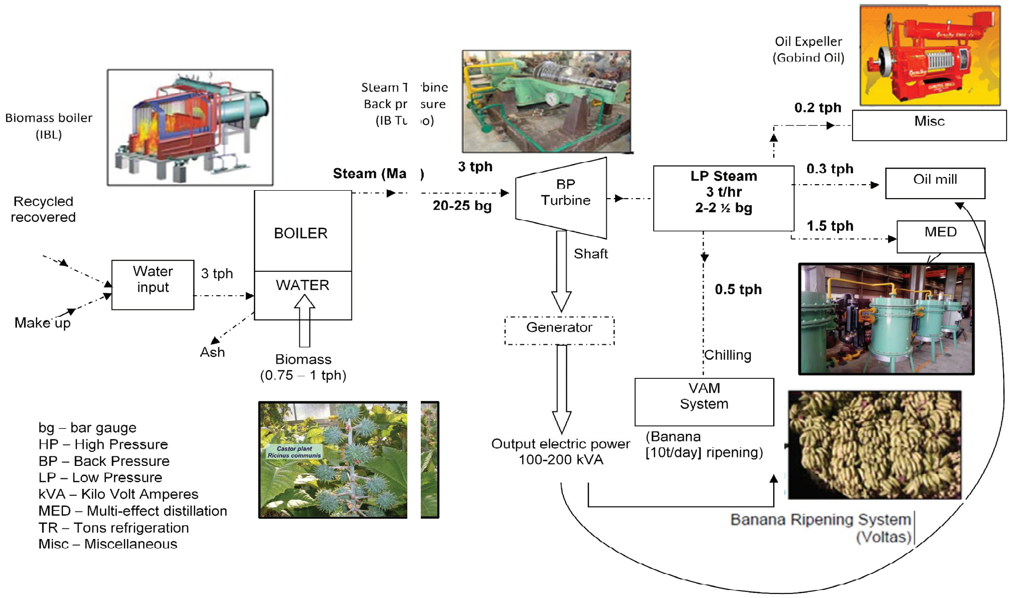

Fig. 2: MIC Model: Trigeneration System and Product mix

3.1. Site and equipment details:

The view of the site is shown in fig. 3. The workings of various individual components are discussed.

Fig. 3: MIC View

3.2. The Boiler and Turbine:

A biomass powered boiler and steam turbine system is the main component used to generate electric power and high energy steam for heating and cooling processes downstream. The unique feature of the equipment is the 100-150 kW back-pressure steam turbines developed by M/s IB Turbo (fig. 4&5). The biomass boiler raises steam at about 20 barge 3 tph, and this steam is passed through the turbine to yield about 150 kW of electrical power. The steam is let out at a back pressure of 1-3 barg.

Fig. 4: Biomass Boiler, Turbine and VAM Set Up

The steam, which still has high exergy, passes on the latent heat as thermal energy (about 2 MW), for use in various applications, namely VAM based chilling and preparation of drinking water using Multi Effect Distillation (MED). Various other applications may be added depending on local produce and resources. In the current scenario, castor cake and castor plant residues along with locally available wood are used as fuel for the boiler. Since oil cake has a high calorific value, only 0.5- 0.7 ton of fuel may be needed to generate 3 tph of 20-25 bar gauge steam.

3.3. Castor Oil Mill:

In the current system an oil mill with a capacity to crush 30 tons of castor oil seeds per day was set up (Fig.5). The oil mill requires significant amount of electric power (80-100 kWH) and some amount of steam (0.2-0.5 tph). These are drawn from the trigeneration system. Choosing castor for production of oil under MIC has multiple benefits. There are ready markets for castor oil. The oil is a chemical feedstock for a variety of products including lubricants and pharmaceuticals. The biomass residue (stalk and leaves) can also be used as fuel. Castor seed yields can be increased by using locally available wastewater for irrigation of this non-edible crop.

3.4. Banana Ripening Plant:

Under the MIC, the VAM (based on lithium bromide and water) system was selected for ripening bananas at 16°C in an ethylene based process (http://isopaninsulation.com). Each load of banana (10-16 tons per day) is ripened in a four days cycle. Banana is brought from the neighbouring states, is ripened at one load per day and is marketed locally with an added value as profit.

a b

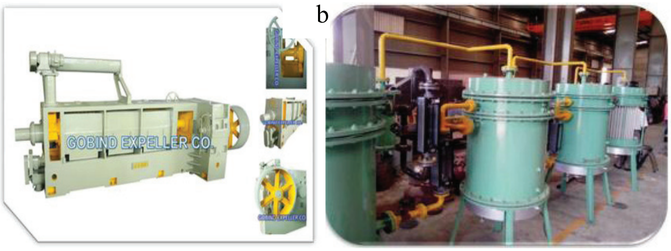

Fig. 5: (a) Oil Mill (b) MED Unit

3.5. Drinking water production by Multi Effect Distillation (MED): (Fig.5)

The other major product considered under the MIC is distilled water produced by using a small scale multi effect distillation technology [12, 13, 14 and 15]. The product water can be used for drinking water, battery water and other types of water as needed by the customer. Since ground water in the surrounding areas is saline (with TDS up to 2,000 ppm) there is a good demand for properly purified drinking water. A system for dosing, packaging and marketing drinking water has been set up.

3.6. Other activities:

Other uses of steam envisaged are for extraction of mint for essential oils and processing of vegetables such as carrots. VAM based cooling system can provide cooling for storage of most types of the vegetables in the area.

Management of wastes such as ash from the boiler, wastewater effluents, gaseous emissions and any solid organic wastes generated are given due consideration. Ash would be used for soil amendment or cement work. Wastewater will be recycled and rejects will be concentrated in solar evaporation ponds. Saline water can be used on the pads of green house for evaporative cooling [16]. Any organic waste, such as spoilt bananas, will be composted or dried and used in boiler.

4. Ensuring Sustainability:

4.1 Financial aspects: MIC as a business solution:

The MIC was designed to be a good business solution. Revenues will be earned from services rendered for banana ripening (10 to 16tons/day) and oil expelled from castor seeds (30 tons of seed/day). In addition, the plant will have capacity to produce 50,000 one-litre bottles of packaged drinking water per day. Costs will be incurred for the bottle components (pre-forms, caps, labels) and for the fuel, and returns will be from the sale of water.

The net revenue from MIC is estimated at 1lakh Rs/day, against a total capital investment at 600 lakh rupees. Details are available in our earlier paper [2].

4.2 Energy Related Issues:

On crushing (30t/d) of castor seeds about 12t/d of oil and 18/d of caster cake are obtained. In the main boiler which can generate 3-4 tph of steam, the biomass requirement is 0.75 to 1 tph. Since oil cake has higher calorific value, the requirement of cake may be less than 0.75 tph. There is an auxiliary boiler which can generate 1tph of steam, and can be used to run VAM when the main boiler is not in operation. The oil cake requirement for this boiler is 0.2 to 0.25 tph. It is estimated that about 10-12 t/d of oil cake may be used in the boilers and surplus castor cake will be available for sale. Also castor stalks from nearby fields will be available as fuel.

Water and steam are used to carry and deliver energy for different machinery. The efficiency of the boilers in converting water to steam is about 80%. As highlighted in Fig. 2 the steam is fully utilized in the trigeneration system.

Thus above 70-75 % energy in the biomass fuel is utilised for production. Heat losses essentially occur from the chimney and the boiler, depending on the moisture content of the fuel, and from pipe work and equipment. The electricity generated by trigeneration should be sufficient for running the MIC as shown in table 2. Grid power will be used at the time when the system is switched off. Also a 125 kVA (100 kW) diesel generator is provided as back up. Research is being undertaken to run this on Biodiesel.

Table 2: Electrical Load Balance (Demand): Peak Load Profile

Unit	Installed kW	Operating kW
Oil Expeller	96	77
Bottling Plant	50	40
VAM	25	20
Boiler	30	24
Total	201	161

It may be noted further that MED saves energy. Distillation requires high initial energy inputs. It takes about 1 kWh of energy to produce 1 Kg of steam or distilled water. Recycling the latent heat of vaporisation in multi effects gives several folds of distilled water per unit steam input.

4.3 Environmental aspects:

4.3.1 *Rainwater harvesting (RWH)*: This is adopted in the MIC to replenish ground water. Rainwater is harvested from an adjacent hillside, providing about 30 hectares collection area. About 90,000m^3 per year of water could go to the aquifer. The annual requirement of the bottling plant is 15,000m^3. Even with 20 per cent recharge efficiency, water taken from the tube well can get replenished by harvested rainwater (fig. 6).

Fig. 6: Rainwater Harvesting by SDS: Some Views of the site

4.3.2 Total water utilisation: Water is drawn by a tube well into MIC and used to raise steam in the boiler after suitable treatments. For this, water softening and RO units are integrated. Water cycle in the system is shown in Fig. 7. Water effluents are also treated and used for raising biomass.

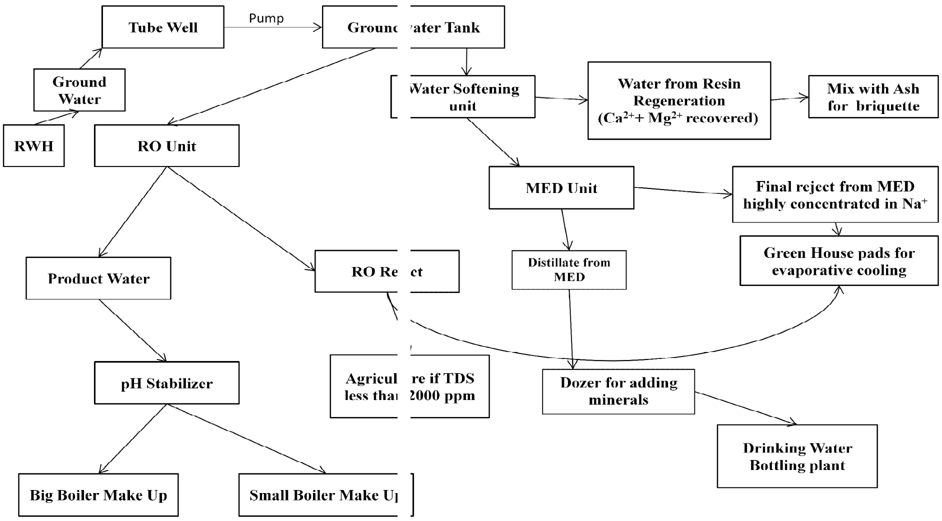

Fig. 7: The Water Cycle

Further to avoid air and land pollution, due consideration is given to chimney design for non-pollution by flue gasses and all solid and liquid wastes are recycled.

4.4 Social issues:

Use of local produce will lead to value addition and employment generation. Due to rainwater harvesting, water levels have gone up and the community is benefiting in agri- horticulture. Due to MIC set up, the village is getting better infrastructure like roads. The overall primary, secondary and tertiary impacts of MIC are shown in fig. 8.

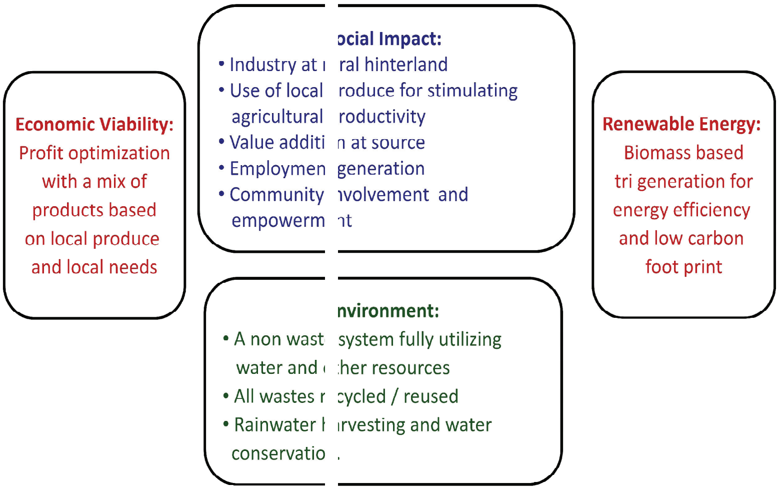

Fig. 8: Economic, Environment and Social Impacts

4.5 Future Scenario:

The unique feature of setting up of the MIC is that SDS which operates the system has pledged to deploy the profit for development of the rural areas. SDS will expand the factory production utilising steam in more activities like mint extraction and vegetable processing. Also solar energy devices will be introduced. The MIC in general can act as an anchor for development of the surrounding villages for awareness generation, training and technology transfer as shown in fig. 9.

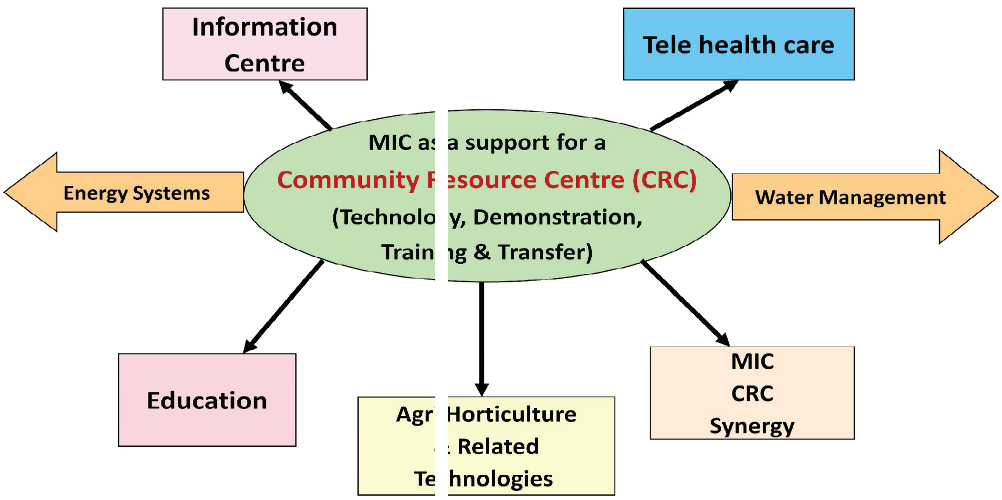

Fig. 9: Future Scenario: MIC as an anchor for Community Development

5. Conclusion

A MIC based on trigeneration has been designed and set-up in a rural hinterland. All the parameters which lead to sustainable development are incorporated in designing the system. It is envisaged that MIC can act as an anchor for development of the village cluster around it. The model could be replicated with appropriate technology mixes in other areas.

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