Langmuir approach to rural development

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Historically, technology development for rural areas has followed tinkering approach or use of rudimentary technology. It is shown that very sophisticated science and technology is needed for producing devices for rural applications. This process can also result in fundamental research. Nevertheless, the availability of efficient devices for cooking, lighting and water purification on a large scale in rural areas is a bottleneck. Various strategies are outlined on how to overcome this barrier. A strong case is made for closer cooperation between the civil society and corporate world for rural development.

Keywords: Rural development, high technology, NGO/corporate partnership, renewable energy, potable water.

IRVING Langmuir, the US chemist who was the first industrial chemist to receive the Nobel Prize[1], showed that in the process of doing applied research one can be led to do fundamental research of the highest order. Thus in developing a better incandescent light bulb for General Electric (GE), Langmuir discovered atomic hydrogen and laid the foundation of surface science for which he received the Nobel Prize in Chemistry in 1932.

A similar thing could be possible in doing research for rural development. After all, in a developing country like India, a major portion of the state funding given to all universities, national laboratories and educational centres of higher learning should be utilized for the benefit of the economically weaker sections of the society. Yet our scientists and technologists working in premier scientific establishments much too often work in areas of interest only to the Western world, since they can publish in journals/magazines published from those countries. Thus the vital local problems are ignored for the esoteric ones. One of the major reasons given by these scientists for not working on rural problems is that the results cannot be published in international journals of repute[2].

I will try to show in this article how developing devices for rural applications can lead to fundamental research of highest order, and will also explore a possible strategy for their mass dissemination in rural areas. After all, the Langmuir approach succeeded in the US because his inventions were backed by the resources and management skills of GE, which made it possible for them to sell the products of his inventions on large scale.

About 60% of the rural population or almost 400 million people in India live under primitive conditions. This is a sad state of affairs even 60 years after independence[3]. They have no electricity and their lives are in darkness. They use inefficient kerosene lanterns for light and ancient biomass cook stoves for cooking. Modern technology somehow has not touched their lives. Besides, the poor quality of these devices creates tremendous household pollution. Thus there are estimates that around 300,000 deaths every year are attributable to inhaling smoke from these inefficient primitive stoves[4]. Unless and until these people are brought into the mainstream of development, India cannot aspire to be a great economic power.

The quality of life of these people can be improved through the use of high technology. Since the materials and energy resources available in rural areas are limited and often in ‘dilute forms’, the strategy of using high technology can allow maximum energy and materials to be extracted for useful end-products. This is the hallmark of evolution, where natural systems evolve into efficient materials and energy converters. In this process, size reduction and increased complexity of the system take place. Some of our designs and technologies are also following this route. For example, computer chips, cell phones, power plants, etc. have reduced in size, increased in complexity and become more efficient. Technology developers need to follow this strategy in developing rural technologies[3]. Besides, in most of the rural areas, efficient after-sales service is not available. Thus all the more reason to develop robust and foolproof technologies for these areas. Classical examples of such ‘technologies’ are all living systems. They are complex, robust, sophisticated and highly efficient. Thus biomimicry (learning from living systems) should be the mantra for research in rural technology.

Though every aspect of rural life can be touched and improved by sophisticated technology, I will restrict myself in this article to three basic areas of lighting, cooking and clean drinking water. These examples nevertheless can be extended to include other areas like agriculture, power generation, etc.

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Lighting energy strategy

Due to unavailability of electric grid and no alleviation of power shortage in sight at least in the near future, there is a need to develop decentralized lighting sources and devices. These devices should be based on locally available renewable fuels. Thus renewables like solar energy, ethanol or biodiesel can power decentralized lighting devices.

Solar photovoltaic (PV) systems are being promoted in a major way in the rural world as lighting sources. However, they are presently inefficient (<10% system efficiency) and suffer from problems of battery maintenance and have to be replaced every two years or even earlier. Recently, with a new class of materials being researched which can produce three electrons per photon[5], solar cell efficiencies can go as high as 68%. Similarly, there are exciting new researches being done in replacing lead acid batteries (which are the mainstay of energy storage systems in PV) with ultra capacitors, which unlike batteries can be recycled millions of times[6,7]. All these developments are multidisciplinary in nature and require fundamental discoveries in nanomaterials and understanding of photochemistry, quantum chemistry, theoretical physics, etc.

Another source of lighting is via liquid fuel. This can be done in two ways. First, through thermoluminescent mantle lighting and secondly, through the use of a prime mover running on renewable fuels, which produces electricity and hence light. However, in both these schemes the most important resource is affordable renewable liquid fuel. Fundamental researches are being done in biotechnology so as to increase the yields of fuel crops, to engineer organisms to increase the yield of ethanol from plant sugars and to do fundamental chemistry research in conversion of sugars into useful automotive fuels[8,9]. There are also indications that sugar either in solid or in solution form can be directly used as fuel in engines[10].

Thermoluminescent (T/L) mantles used in existing kerosene lanterns are made of silk cloth coated with rare oxides of thorium and cerium. Their efficacy is low (~1–2 lm/W) compared to the electric light bulb (~10 lm/W) and fluorescent lamps (~50–70 lm/W). However, the overall power plant-to-light efficiency of fluorescent lamps[11] is ~10 lm/W. With new materials developed through nanotechnology, it may be possible to increase the efficiency of T/L mantles to 10 lm/W. With this achievement the liquid fuel lighting based on renewable fuels like ethanol not only can compete with, but can even surpass in efficiency the electricity-based lighting. Nimbkar Agricultural Research Institute (NARI), Phaltan, has pioneered a lantern running on 50% (w/w) ethanol/water mixture (A. K. Rajvanshi, unpublished). This mixture which is safe and can be easily distilled in a backyard distillery, can be an effective fuel for such high-efficiency lanterns.

Similarly, there are other micro-technologies being developed to produce power in the range of 10–20 W, enough to power high-efficiency light emitting diode lanterns. The devices include thermionic and thermoelectric units (which directly convert heat into power), micro engines and small fuel cells[12,13]. All these devices are being developed to be powered by renewable fuels like ethanol, methanol, methane, hydrogen, etc. In developing these devices fundamental studies in nano-materials, MEMS, microelectronics and catalyst research are being used. Such small devices used for lighting will eliminate the heavy and environment-unfriendly batteries, since the storage of energy is in the fuel itself.

Finally, one of the most efficient natural lighting systems is bioluminescence of firefly and other living organisms, where the chemical energy is directly converted into light[14]. Developing devices based on this mechanism could revolutionize decentralized lighting in rural areas.

Box 1. High-efficiency solar cells

- Existing solar cells produce one electron–hole pair per photon. Classic photoelectric effect of Einstein.
- Process of impact ionization allows conversion of single high-energy photons to multiple electron–hole pairs.
- Nano-sized quantum dots of materials PbSc and PbS have demonstrated high efficiencies in multiple electron–hole pair generation[5].
- As many as three electron–hole pairs production is possible per photon in these materials, thereby creating 50% and above solar cell efficiencies.

Cooking energy strategy

Only liquid and gaseous fuels produced renewably can provide clean cooking energy. Three fuels fall under this category – liquid fuels like ethanol or biodiesel, and gaseous fuels like biogas.

Ethanol is an excellent fuel for cooking. NARI has developed a stove which runs on 50% ethanol–water mixture. The stove has a maximum thermal capacity of 2.5–3 kW and has a flame control for simmer and high settings, so that it works just like an LPG stove[15]. Large-scale testing in the field has been positive and almost all the rural women who have tried it compare it favourably with an LPG stove. However, in order that such low-grade ethanol can be used as a rural household fuel, the presently tough excise laws have to be modified.

A clean gaseous fuel that can be produced from the existing biomass sources is biogas. Biogas has been used extensively in the rural areas of India. However, it is produced inefficiently in fixed and floating dome systems and requires considerable amount of cowdung and other nitrogenous material. Hence it is not suitable for a household with less than 3–4 cattle. Besides, there are problems of gas production during winter and improper mixing of mixed inputs like biomass, night soil, cowdung, etc. The biogas programme in India, which has been heavily subsidized by different ministries for its large-scale availability in rural areas, has been a failure because of the technological shortcomings as outlined above. Also biogas, which is a mixture of methane and carbon dioxide, cannot be liquefied and requires high pressure of more than 100 atmospheres to compress it so that it can be used over extended periods.

These shortcomings can be removed by R&D in two areas. One is in the development of extremely efficient biogas reactors, so that the production per unit of biomass inputs could be maximized. The second is to develop appropriate storage materials which could store biogas at medium pressures.

Optimization of biogas production from a reactor requires sophisticated electronics-based controls and biochemical engineering technology. Hence research in rate process control and bioengineering of methane-producing organisms will greatly help in improving the efficiency of such reactors. Efficient and sophisticated biogas reactors are being developed and deployed in Europe and USA with an installed capacity of about 6000 MW. Also, in Sweden biogas is being used in a substantial way to run automobiles and the public transport system[16].

Research is also in progress in methane storage and recently, experiments have been conducted in storing it at medium pressures of less than 30 atmospheres in hydrates and porous carbon and organic structures[17]. Thus there is a need to develop low-cost storage materials so that biogas could be stored in them for use in households. New materials developed through nanoscience and nanotechnology can be used for this purpose. Thus a scenario can be thought of, where a micro-utility company in rural areas will buy locally available raw materials like cowdung, biomass, etc. and use them in a high-tech biogas reactor to generate biogas efficiently. This gas can be stored in small cylinders lined with gas-absorbent materials and transported to households, just like the present LPG cylinders. Such a strategy will revolutionize the cooking system in rural India and other parts of the world[3].

Water purification

Waterborne diseases are one of the greatest scourges in rural areas. According to WHO estimates, ~1.8 million people die every year worldwide because of unavailability of clean drinking water in these areas[18]. Often the focus of development agencies has been on providing simple water-cleaning technologies for individual rural households. These have included solar stills, hand-powered RO units, simple filters, etc. Most of the times these devices do not work, with the result that these households keep using contaminated water. I believe that the rural households should be supplied clean drinking water just like that in any urban household. Thus public/private water utilities should be set-up in rural areas to harvest rainwater in specially dug tanks, clean and purify the stored water, and supply it either through rural pipe networks or allow the inhabitants to take it in their own utensils, as they do presently from existing supply. Hence R&D and new policy framework are required for developing small water utilities in rural areas.

Two important issues in rural development are supply of clean water and electricity. NARI has developed a strategy, whereby it is shown that a microutility producing 500 kW power for rural areas can easily use the heat of the fuel gases of the engine to boil or distill water to make it potable. The 500 kW power plant is sufficient for a village of 2000–3000 people. The combined cycle of electricity and water production[19] will increase the efficiency of the power plant to almost 65–70% from the existing low of 35%. Nevertheless, R&D is needed in improving the distillation process and developing a compact water-treatment plant which can be attached to the engine/generator, so that potable water can be delivered at an affordable price.

Similarly, whole new areas of water purification research can be investigated by trying to duplicate the reverse osmosis process of mangrooves and other types of plants[20]. In rural areas where only chemically contaminated water (with arsenic or other contaminants) is available, distillation technologies are needed. These technologies being developed worldwide are driven by inputs from areas such as materials research, fundamental researches in heat and mass transfer, ocean chemistry and surface science. Besides, there is a need for waste-water treatment technologies which can recycle the water in rural areas. Small waste-water treatment utilities using the existing best practices may tremendously alleviate the rural water supply problem.

Availability of devices in rural areas

In the past good amount of R&D in India and in other developing countries has been done in developing efficient devices for rural areas. Somehow they have not become available at affordable price and on large scale. Part of the reason is the lack of purchasing power in the rural areas and partly because of shortcomings in technology. Recently, with the availability of microfinance and proliferation of rural self-help groups, a substantial section of the rural population worldwide can afford to buy devices for household purposes.

For example, the large-scale proliferation of cell phones in rural areas of India attests to the fact that the availability of a good technology at affordable price is the first step in overcoming financial hindrances. Similarly, in Bangladesh large-scale usage of cell phones in rural areas is made possible by micro-finance instruments from Grameen Bank[21]. The ‘industrial model’ of cell phones should be followed in producing devices for rural areas. The industrial model means large-scale production of goods and devices based on excellent technology, reasonably priced with excellent availability of after-sales service.

In order to extend the 'rural cell phone' model to cooking and lighting devices, it may be worthwhile to look at some relevant issues.

First is the issue of good and robust technology. Most of the rural devices have failed because of half-baked technologies, whether it is PV systems (lead acid battery failures), biogas systems (materials or gas delivery system failures) or improved chulhas (hardly reduced smoke). Contrast this with robust and good technology devices like electronic watches, cell phones, motorized two-wheelers, etc. which have shown excellent sales in rural India.

Second is the issue of corporate interest in developing and manufacturing these devices. Somehow the basic rural amenities are not in the vision field of the corporate world, since most of their efforts are in urban areas. For example, cell phones percolated from urban to rural areas, and so have other technologies. One of the reasons could be that the captains of the corporate world are not aware of the rural problems. Thus sensitizing them to the problems will go a long way in this regard. Secondly, in an Indian context, most of the leaders of the corporate world do not have too much faith in Indian R&D or, as a matter of fact, in R&D per se. There has been a long tradition among them of buying the technology from the West. Nevertheless, as the critical mass of Indian corporate CEOs who have been exposed to the Western technological development model is increasing, the mind-set is slowly changing to favour R&D.

A recent example of this is a tie-up between NARI (a rural S&T NGO) and Nagarjuna Fertilizer and Chemicals Ltd. (NFCL) – a corporate entity. NARI's technology of ethanol production from sweet sorghum and its use in specially designed lanterns and cooking stoves for rural areas has been taken up by NFCL. These types of examples will multiply in the coming times.

Another possible way to speed up the change in the mind-set regarding R&D for rural applications could be a change in curriculum of engineering colleges. Presently, most of the graduates of premier engineering colleges like IITs and NITs, after finishing their engineering degree opt for management programmes (MBA) or go into the IT sector since it gives them excellent salary packages. Thus the engineering education becomes a stepping stone for getting into these programmes with hardly any use of engineering knowledge in their job. This is a trend which unfortunately is found worldwide and may continue for quite a long time.

One change in the engineering curriculum of these premier institutes could be to sensitize the students and make them aware of what R&D is and how it can be done. Later on, when they become corporate managers after getting an MBA degree, they will have a healthy respect for R&D and may be able to initiate research programmes in their own companies.

To do this it may be worthwhile to have the students in the last year of the engineering programmes, carry out a project which is almost like a thesis, in which they not only make a working model but also do experimentation on it. Besides, the curriculum could be modified so that the students are also taught courses which lay emphasis on how the technological developments work in producing better devices or the history of modern technological developments. This will be more educational and enjoyable, rather than solving some archaic engineering problems which unfortunately has become the norm in most of the engineering courses. Naturally this will present a great challenge to the faculty to motivate the students to do research, since a substantial number of these members even in premier institutions are not known for their research capabilities.

At the same time as the mindset of the corporate world in India changes towards R&D, better pay packets will be offered to students who are good in technical areas. This may provide incentives for them to focus on research while they are studying. This trend can further be strengthened by having a strong academia–industry interaction. Thus emphasis should be laid in engineering institutions, on faculty spending time in industry. I feel a linkage between faculty promotion and time spent in industry should be encouraged. This trend was prevalent in European and American universities and needs to be emulated in India.

In case such a change can be effected, then besides becoming better managers in the modern technological world, these students might also be inspired to get into the technological field to either do their Master's or Ph D in engineering. This will help increase the number of technologists in India, which is presently in short supply.

Corporate social responsibility (CSR) is a buzzword which is now becoming fashionable in Western countries, especially after Bill Gates through his Gates Foundation pioneered rural health in developing countries. Hence more and more international corporations are financing activities the world over which will help the rural poor. In India, the multinational companies have taken the lead and it is a matter of time before the Indian companies will also get into the act. CSR allows for the first time a win-

Box 2. Nanostructures for methane storage[22]

- Presently CNG is stored at 207 bar in pressure vessels.
- Metal–organic frameworks (MOFs) have the capability of storing methane at around 35 bar.
- MOFs are light porous structures[17] with density of about 0.2 g/cc and surface area of 6000–8000 m^2/g.
- These structures can be tailor-made to store different gases like hydrogen, methane, etc.

Box 3. Biorefinery

- Long-term goal of producing all the demands of food, chemicals and fuel from biomass resources.
- Can be done by doubling the photosynthetic efficiency from 1 to 2%. Using engineered genes to improve plant enzymes that convert CO_2 to organic carbon is one pathway. Another strategy is to manipulate the genes involved in nitrogen metabolism[8].
- Genetically modified plants already help in overcoming biological and environmental stress, thereby improving productivity.
- Use of carbohydrates as chemical raw materials may help in the long run to produce most of the modern chemicals from biomass, thereby replacing petroleum products.
- Similarly, direct conversion via catalyst, of carbohydrates (fructose) into high energy density fuel for transportation is a step in the right direction for biorefinery strategy. This fuel (dimethylfuran) has 40% more energy density and higher boiling point than ethanol – the presently preferred automotive fuel[9].

dow of opportunities for the corporate world, to take part in rural development. Nevertheless, most of the corporate world is not involved in CSR as a charity. They see tremendous economic returns to their investments, both directly in selling devices and indirectly through the creation of goodwill. In India rural development by the corporate world can be a lucrative business. For example, there are estimates that cooking and lighting industry in rural India, based on liquid fuels like ethanol, could be of the order of Rs 30–40,000 crores per year[3].

Availability of venture capital funds for rural development work can also help start-ups in developing and promoting high technology systems for rural areas. Use of venture capital instruments for IT sector development worldwide is well known.

Thus at this juncture it might be fruitful for practitioners of rural development, both in civil society and in academics, to educate the corporate world and sensitize them regarding what is possible in technological development for rural areas. Science and technology-based NGOs can play an important role and should take a lead in working with corporations for producing specific technologies for these areas. Thus a partnership of NGOs, the corporate world and the rural population can help in creating an industrial model for rural areas.

The Government of India (GOI) can play an important facilitating role by providing tax benefits to the corporate world, so that they manufacture and sell devices which will provide environmentally clean cooking, lighting and water purification. Through these financial incentives the GOI can help, guide and herd the industries so that they exclusively provide services for rural areas.

Finally, it should be pointed out that most of the technological development for devices and products in the Western countries follows the Langmuir model. Thus basic research is either done in-house in the industry, or there is a strong industry–university partnership. Nevertheless, it is necessary that this model should be extended to rural areas of India and other developing countries. The problems of rural India are different from those in urban areas, and their solutions also have to be different. In trying to solve these problems both the industry and academia will benefit greatly in monetary and intellectual terms.

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