Rocket Science for Rural Development

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Three billion people in the world earn $ 1-2/day. Majority of them live in rural areas with very primitive quality of life. For example in India, which boasts of a very active space and nuclear program, around 60% of rural population have no electricity, use 180 million tons of biomass/year for cooking via primitive wood stoves and have no clean drinking water [1]. Similar is the story in China, Brazil and other "advanced" developing countries.

Cooking and lighting-the two basic necessities constitute 75% of total energy consumed by rural population [1]. A user friendly and quality product to satisfy these needs from locally available resources like biomass can go a long way in improving the quality of life for nearly 3/5th of mankind. Recent evidence suggests that indoor air pollution from biomass cooking stoves results in nearly 1.6 million deaths worldwide every year [2]. Only provision of clean and modern cooking technology can avert this tragedy.

Rural population aspires to the same quality of life as their urban brethren and thus it is a great challenge for scientists and technologists to develop technologies to improve the quality of life of rural poor. I believe the emerging areas of bio and nanotechnology can provide very effective solutions in these areas.

Efficient Cooking Systems

Gaseous and liquid fuels from locally available biomass can provide safe and convenient energy. One such gaseous fuel is biogas. Biogas has been used extensively in rural areas and is produced very inefficiently in fixed and floating dome systems, requiring considerable amount of cowdung and other nitrogenous material. It is therefore not suitable for a household with less than 3-4 cattle. Besides there are problems of gas production during winter and improper mixing of inputs like biomass, night soil, cowdung, etc. Biogas which is a mixture of methane and carbon dioxide cannot be liquefied and requires very high pressure (> 100 atmospheres) to compress it so that it can be used over extended periods.

Thus R&D is necessary in two areas. One is the development of extremely efficient biogas reactors so that the production/unit of biomass inputs could be maximized. Genetically engineered microbes can substantially increase gas production efficiency. The second area is the development of appropriate storage materials, which could store biogas at medium pressures.

Recent experiments show that biogas can be stored at medium pressures (< 40 atmospheres) in hydrates, porous carbon and porous organic structures similar to those used in hydrogen storage [3]. Thus a scenario can be thought of whereby micro-utility companies can be set up in rural areas which will buy locally available raw materials like cowdung, biomass, etc. and will use them in a very high tech biogas reactor to efficiently generate biogas. This gas can then be stored in small cylinders lined with gas absorbent structures and can be transported to households like the present LPG cylinders. This will revolutionize the cooking system in rural areas. Optimization of biogas production from a reactor requires sophisticated electronics-based controls and bio-chemical engineering technology. A small utility can afford to do it whereas for a household it might be too costly [1].

Similarly liquid fuels like ethanol, biodiesel and pyrolysis oil from biomass can be used for cooking. Use of multipurpose crops like sweet sorghum which do not take away land from food production [4]; use of genetically engineered microbes for converting cellulosic material into sugars and high yielding hybrids of crops producing biodiesel can help in producing these fuels via small rural based utilities. Recently NARI has developed an efficient ethanol stove running on low concentrations of ethanol/water mixture [5].

There is however a need to develop stoves running on biodiesel and pyrolysis oil. Because of high viscosity and soot forming ability of these fuels, very sophisticated combustion science and technology is required for developing such stoves. Production of blue flame in such stoves will also help in developing combustors for liquid based lighting purposes.

Liquid Fuel based Lighting

It can safely be said that the history of present civilization is the history of lighting. Adequate lighting (50-100 lux) should therefore be a part of minimum needs program of any government for its people[1]. Presently mankind knows two methods to produce light. One is via thermal route where the fuel (like kerosene or oil) is used to produce an incandescent flame and the other is effected by electricity.

For rural lighting technology there is a need to again look closely at the liquid fuel lighting systems. One of the best system still in use is a pressurized mantle lamp where the combustion of kerogas lights up the rare earth oxide mantles. Recently NARI has developed an extremely efficient multifuel lantern called Noorie which runs on kerosene, diesel and with slight modification on ethanol [6] . This lantern produces light equivalent to that from a 100 W bulb and also doubles up as a cooking device.

The presently used thermoluminescent (T/L) mantles in these lanterns have not changed since Welsbach developed them in Germany in late 1880’s. They are basically a mixture of 99% thorium oxide and 1% cerium oxide (called thoria mixture) [7] and have very low light efficiency (called efficacy). Thus the efficacy of these mantles is ~ 2-3 lumens per watt (lm/W), whereas that of light bulbs is ~ 10-15 lm/W. The efficacy of compact fluorescent lamps (CFL) is however 50-70 lm/W [1].

With the present level of materials technology and use of nanotechnology, it should be possible to develop new materials for T/L mantles, which will use less of thoria mixture and also increase their efficacy. Some efforts have been directed towards using alternate materials like ytterbia for coating T/L mantles and have shown promising light emission characteristics [8]. Research is also needed in developing better substrates for mantles. Presently the mantles are made of silk cloth and after firing them, a very thin and fragile ash substrate remains. This breaks very often and consequently the mantles have to be replaced frequently which increases the running cost of such lanterns. Thus there is a need to develop stronger and more durable materials such as those based on ceramics and carbon-carbon composites. With such mantles the liquid-based lighting with improved lanterns like Noorie can become very rugged besides being efficient.

With suitable R&D it may be possible to develop mantles whose efficacies match those of light bulbs. This can make liquid fuel lighting superior to electric lighting in terms of overall power plant-to-light efficiency. Presently the effective overall power plant-to-light efficiency for fluorescent lamps is ~ 14 lm/W. This low number results because of losses in producing power from fossil fuels and transmitting it through utility lines. Thus with thermal power plant efficiency of 30%, transmission and distribution (T&D) losses of 20% and fluorescent lamp efficacy of 60 lm/W the final efficacy becomes low. Thus a liquid fuel lamp running on locally made fuels like ethanol, biodiesel or pyrolysis oil with efficient T/L mantles can be an excellent distributed light source for rural areas.

One of the most efficient lighting systems in the world is bioluminescence of firefly where chemical energy is converted directly into light. Estimates are that its lighting efficiency is around 85-90%, compared to that of a light bulb which is 7-10% [1]. R&D should be done in trying to duplicate this mechanism. The ultimate lighting system can be thought of as a solar powered unit producing luciferase enzyme and luciferin (the two chemicals used in bioluminescence of firefly) from a biomass resource and then using them at night to produce light. It is an utopian dream but will be the ultimate in a distributed light source.

With unavailability of grid electricity for majority of rural areas, large amount of R&D world over is also being conducted in developing distributed or decentralized sources of electricity. They range from 5-10 kW to 10 MW capacity. This includes taluka-based power plants [9], gasifier-based systems and very innovative technologies like space age steam engine, gas powered 20-30 kW microturbine, etc. Distributed electricity sources running on locally available biomass resources can also effectively provide light for rural areas. Nevertheless, R&D in three micro technologies for producing electricity need mention. One is the development of human muscle-powered lighting system; second is thermoelectric devices for light and third is nanoengines.

Micro technologies for Lighting

Recent advances in lightweight and highly efficient permanent magnet DC (PMDC) motors have made it possible to produce small amount of electricity via human power. This electricity together with rechargeable batteries can power a light emitting diodes (LED) system for lighting. Among all light-producing devices, LEDs are some of the most efficient and long lasting. Freeplay in Europe and Light the World in Canada have pioneered this system. Presently these systems are very expensive (US $50 for a handheld flashlight). Hence R&D is required in essentially three areas namely: development of very efficient and lightweight PMDC motors (40-50 W), development of efficient capacitors with suitable electronics as a substitute for batteries, and development of cheap LED units. A bicycle-powered unit in which the members of a household can take turns to charge the battery, which will give 3-4 h of light, will be a great boon for rural areas. This may be akin to Mahatma Gandhi’s charkha (spinning wheel) except that it will produce electricity instead of spinning cotton and in Gandhian analogy may help in sustainable development.

Similarly majority of rural households use primitive biomass cookstoves for cooking. The stoves are inefficient and smoky with about 10-15% cooking efficiency. An extremely efficient thermoelectric device attached to the stove can produce 50-60 W of DC power. This power can be stored in suitable high efficiency batteries for lighting. At the same time part of the power can also be used to run a small fan for the cookstoves. Recent biomass cookstove designs have shown that air draft powered by a 5 W fan can double the efficiencies of these stoves. This small fan can also in help improve the combustion process thereby reducing the particulate emissions from the stoves.

Recent developments in nanotechnology and new materials have also shown that very efficient thermoelectric elements and thermionic devices can be developed [10]. Some of these thermoelectric elements have been able to break the ZT barrier of 1 and have reached a figure of 2.4. ZT is a figure of merit which shows how good the device is in converting heat to electricity. The higher the ZT, the more efficient is the device. Similarly nanotechnology has been used in making an efficient thermionic device for power generation.

A penny size nanoengine running on biomass derived fuel like ethanol and capable of producing 10-15 W power can power LED lamps and can revolutionize the distributed rural lighting. These engines are being developed for defense purposes and as mobile phone power devices [11]. Such a compact system will bypass the bulky and costly battery technology since the liquid fuel itself will store the energy.

Any technology becomes attractive if it is economically viable. R&D helps in increasing the efficiency of a technology and hence improving its economics. The same is true for cooking and lighting technology for rural areas. Once the technology is available and the norms of industry as practised in manufacture of other consumer goods are brought to bear on it, the cost reduction processes and creative financing mechanisms for its availability to rural poor can be designed.

Preliminary economic analysis for rural India shows that the liquid and gaseous fuels based lighting and cooking technologies could be a $ 6 billion industry [1]. Similar numbers may exist for other developing countries. Use of these technologies can help increase the quality of life of rural population besides creating wealth in these areas in terms of fuel production and usage. This strategy can help bring three billion people into the mainstream of development and is the best way to create a just and sustainable world.

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