R & D strategy for lighting and cooking energy for rural households

(Published in CURRENT SCIENCE August 25,2003)

Anil K. Rajvanshi

Nimbkar Agricultural Research Institute

P.O. Box 44, Phaltan-415523, Maharashtra

E-mail : nariphaltan@gmail.com

It is a matter of shame for all of us that even after 55 years of independence there are 63% of total rural households in India which use only kerosene for lighting. Majority of the kerosene lamps are hurricane type lamps, which produce very poor light of about 60-70 lumens. Similarly, rural areas in India use about 180 million tons of biomass fuel for cooking through very inefficient and smoky cookstoves. Cooking and lighting energy constitute 75% of total energy used in rural areas. Yet the quality of end product (heat and light) leaves much to be desired and the rural poor are still living in stone ages. A country which proudly claims to have made great strides in developing world class rocket technology and software can certainly create technologies to improve the quality of life for rural poor. This paper therefore presents some possible research and development strategies in lighting and cooking energy based upon the emerging technologies like nano and biotechnology. Various economic and policy issues are discussed which might make it possible to improve the lives of rural poor.

It is a matter of shame for all of us that even after 55 years of independence there are 63% of total rural households in India which use only kerosene for lighting [1]. Majority of the kerosene lamps are hurricane type lamps, which produce very poor light of about 60-70 lumens (lm) [2] (a 100 W bulb produces ~ 1300 lm and for reading about 500 lm/m^2 or lux is sufficient [4]). In some states like Bihar, Assam etc. there are about 90-95% rural households which use only kerosene for lighting. Thus there are estimates that 90-100 million rural households do not have electricity and with frequent blackouts and brownouts even larger number probably use kerosene for lighting. Similarly, rural areas in India use about 180 million tons of biomass fuel for cooking through very inefficient and smoky cookstoves [1]. Cooking and lighting energy constitute 75% of total energy used in rural areas. Yet the quality of end product (heat and light) leaves much to be desired and the rural poor are still living in stone ages. Our mass media rarely highlight this plight of rural poor who have the same aspirations as the rest of the country of getting clean fuel like liquid petroleum gas (LPG) for cooking and good high lumen light source. With electricity shortfall of about 15,000 MW/year in India; poor grid infrastructure in rural areas [3], and with ever increasing petroleum imports for the country it is safe to say that the lives of rural poor will remain in a primitive state for a long time to come. A country which proudly claims to have made great strides in developing world class rocket technology and software can certainly create technologies to improve the quality of life for rural poor. This paper therefore presents some possible research and development strategies in lighting and cooking energy.

Lighting Energy

It can safely be said that the history of present civilization is the history of lighting. Without the increase in waking hours for mankind all the major developments of this world might not have taken place. Adequate lighting during evening and night helped increase the productivity of people and enterprises. Adequate lighting should therefore be a part of minimum needs program of any government for its people.

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 so that yellow light results from the soot particles. This type of light is produced from open flame, candles and hurricane lanterns. Another example of thermal light is that produced by the use of thermoluminescent mantles made of rare earth oxides which are heated by high temperature flame. Most of the pressurized and non-pressurized mantle lanterns (generically called Petromax) fall in this category.

All the remaining lighting is effected by electricity. This includes incandescent bulbs, fluorescent tubes, high-pressure discharge lamps, etc. Since in rural areas of India the grid electricity will not be available for a long time to come, it is safe to assume that the lighting will remain dependent mostly on liquid fuels or at most on decentralized electricity sources. Therefore there is a need for R&D in these areas to make such devices affordable and efficient.

Liquid fuel based lighting

The quality of light obtained from flame type devices (hurricane lanterns, candles etc.) is very poor (< 100 lm). Besides it is based upon incomplete combustion principle. Hence the yellow flame produces soot, CO and CO_2. In a confined space of rural households the use of such lanterns can be injurious to health. However, the light from pressurized mantle lamps (Petromax type) is comparable to that from light bulbs or fluorescent lamps and hence these offer the best place for improvement. The good lanterns in this genre have efficient and complete combustion of fuel. Presently available "Petromax" lamps in India were developed in Europe in early 1920s and have been copied all over the world. In India they are available in hundreds of "avatars" with varying quality. Their manufacturing is in the unorganized sector and hence the quality of majority of them is quite poor. Recently there has been an upsurge of LPG-powered mantle lamps. However, the availability of small gas cylinders in rural areas is almost non-existent.

A major research program of mantle type lantern improvement was therefore initiated at the Nimbkar Agricultural Research Institute (NARI) in mid 1980s which resulted in the development of "Noorie" pressurized lantern [2]. It is lightweight (1.5 kg), easy to light and doubles up as a cooking device. It also has self-cleaning characteristics. The light output from Noorie is ~ 1300 lm and is equivalent to that from a 100 W electric light bulb. It is a multifuel lantern and can run on kerosene, diesel and ethanol (with slight modifications). Noorie lantern is very efficient and consumes 40% less kerosene than the "Petromax" for the same light output. However, development of Noorie lantern revealed that the bottleneck in light output is the low efficiency of rare earth oxide thermoluminescent (T/L) mantles. Presently the efficacy of these mantles is ~ 2-3 lm/W [2], whereas the efficacy of light bulbs is ~ 10-15 lm/W and that of compact fluorescent lamps (CFL) is 50-70 lm/W [4].

Thus R & D is required in developing better T/L mantles so that their efficacies can match those of the light bulb. With such efficacies, **liquid fuel lighting will be superior to electric lighting** in terms of overall power plant-to-light efficiency. Presently the overall power plant-to-light efficiency for fluorescent lamps is ~ 14 lm/W. This includes power plant efficiency of 30%, T&D losses of 20% and fluorescent lamp efficacy of 60 lm/W. For small distributed electricity system the efficacy can further reduce to 10-12 lm/W since the efficiency of electricity production from diesel or petrol in the 10-20 kW range is much lower than that of power plants.

The presently used T/L mantles in pressurized kerosene and gas lanterns have not changed since Aurbach developed them in Germany in late 1880's. They are basically a mixture of 99% Thorium Oxide and 1% Cerium Oxide (called Thoria mixture) [5]. However 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 radioactive Thoria mixture and also increase the efficacy. Research is also needed in developing better substrate for mantles. Presently the mantles are made of silk cloth and after firing them a very thin ash substrate remains which is very fragile. Consequently the mantles have to be replaced frequently which increases the running cost of such lanterns. There is thus a need to develop stronger and more durable materials such as those based on ceramics. With such mantles the liquid based lighting can become very rugged besides being efficient.

The total kerosene consumption in India for 2000/01 was around 11.5 million tons [1]. Out of this 60% was for rural areas which is mostly used for lighting and a small percentage (about 2-5%) is used for cooking. Anecdotal data suggests that recently a part of it is being diverted as an adulterant in the fuel of two wheelers in rural areas. Since India imports about 65-70% of its petroleum products there is a need to develop an alternative source of liquid fuels for lighting. One such alternative fuel is ethyl alcohol (ethanol). Studies at NARI have shown that it can easily be used for cooking and lighting in new stoves and lamps [6]. At the same time, it can be produced from locally available renewable sources like sugar crops. Traditionally, ethanol has been produced mainly from sugarcane and molasses. However, with the debate on food vs. fuel from the same piece of land going on, there is a need to use a multipurpose biomass source for ethanol production. One such source is sweet sorghum (*Sorghum bicolor* (L.) *Moench*). It provides grain from its earhead, sugar and hence ethanol from its stalk and the bagasse and leaves make an excellent fodder for animals. Thus it provides food, fuel and fodder. No other crop yields all these things together. Breeding work at NARI has resulted in sweet sorghum hybrids and varieties with 12-15% (w/w) total sugars in stems [6]. Besides being a multipurpose crop, sweet sorghum has a great tolerance to a wide range of climatic and soil conditions. It is a short duration crop, maturing in 100 to 140 days (as compared to 12 to 18 months for sugarcane). Besides, it is cheaper to grow than sugarcane and requires less water. There is a need to develop mini distilleries of 5000 liters/day so that ethanol production can become a rural based small scale industry. There is also a need to do R&D in identifying other ethanol producing crops like sugarbeet etc. The main thing to be looked at is that all the alternative crops should be multipurpose i.e. they should produce both food and fuel and should not take land away from food production.

Another technology for producing liquid fuels from biomass is pyrolysis oil. It is a medium calorific value (CV) fuel with CV of 17 MJ/kg [7] and can be produced from any biomass and agricultural residues via fast pyrolysis route (hence the name pyrolysis oil). Major work in this area is being done in U.S. and Europe where it is being used for power generation [8]. Being a medium CV fuel with about 25% moisture content, it can be used only in modified lanterns and cookstoves. R&D is therefore needed in producing it economically and efficiently in India and in developing suitable lanterns and cookstoves to run on it. It is equivalent to No. 6 oil and has good flowability, thereby making it quite an ideal fuel for cooking and lighting. Again a small unit producing 1000-5000 kg/day of pyrolysis oil will help the rural areas in generation of wealth. With 400 million tons/year of agricultural residue production in the country, which is mostly burnt in the fields, pyrolysis oil is an extremely attractive alternative to petroleum products for liquid lighting and power generation.

Recently there has been a thrust on bio-diesel in the country [9]. Basically this is produced from edible or non-edible oils after esterification. Non-edible oils derived from tree borne oilseeds have been used in India for centuries as lighting fuels in earthen lamps. Using edible oils for bio-diesel production is not feasible in India at least under present circumstances of edible oil shortage. Bio-diesel produced from non-edible oil, and which is similar to diesel oil, can also be used for cooking and lighting. However R&D will have to be done in producing suitable stoves and lanterns to burn this oil. The economics of collection of seed from existing trees and growing of non-edible oil seed producing trees on a large scale is still not very clear. R&D is required in breeding these trees so that their seed yield is increased and growing time could be reduced. Table 1 gives the characteristics of biomass derived liquid fuels and their suitability for cooking and lighting. From this table it is clear that ethanol from sweet sorghum (since it provides both food and fuel from the same piece of land) and pyrolysis oil from agricultural residues (since it produces the highest energy per unit area from residues) holds the maximum promise for providing fuel for cooking and lighting. Non-edible oil yields are low and it takes 5-10 years for the trees to start yielding seed for oil production.

With the above developments it is quite possible that liquid and gaseous fuel based lighting systems may provide a near term solution for distributed lighting in rural areas and may be far better than electricity based units. Distributed electricity sources will be more appropriate to be used mainly for communications like phones, internet etc. since there is no other alternative to them.

Table 1. Characteristics of renewable liquid fuels for cooking and lighting

Fuel	Production/yr. (kg/ha-yr.)	Calorific value (MJ/kg)	Energy production (MJ/ha-yr.)	Production Technology Available Yes (Y); No (N)	Multi-purpose crop	Ref
1. Ethanol from :						
a) Sugarcane juice	3000-4000		75,000-1,00,000	Y	No	10
b) Molasses	250 l/ton		-	Y	By product of sugar	
c) Sweet sorghum	2400-3200	25 (6% M.C.)	60,000-80,000	Y	Yes	10
d) Sugarbeet	4500-6000		112,500-150,000	R&D	No	6
						10
2. Pyrolysis oil	3000-9000 (from 5-15 tons/ha agricultural residues)	17 (25% M.C.)	51,000-1,53,000	R&D	N/A	11
3.Bio-diesel						
Karanja	600-2000		22,200-74,000	Y		
Mahua	200-700		7,400-26,000	Y	No	
Sal	200-400	~ 37	7,400-15,000	Y		12
Neem	900-1200		33,000-45,000	Y		13

M.C. = Moisture content

Distributed electricity based lighting

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 [3], gasifier based systems and very innovative technologies like space age steam engine [14], gas powered 20-30 kW microturbine etc. [15]. Distributed electricity sources can also help effectively in powering light sources for rural areas. However the subject is too vast to be covered in this paper. Nevertheless, it is sufficient to say that the liquid fuels developed from renewable sources outlined in Table 1 can also be used in existing small internal combustion engines to power distributed electricity systems. The cost of electricity will eventually determine which fuel will be used.

However, two electricity producing technologies for lighting need mentioning here for further R&D. One is the development of human muscle powered lighting system and the other is thermoelectric devices for light. Recent advances in lightweight and highly efficient permanent magnet D.C. (PMDC) motors have made it possible to produce small amount of electric power via human muscles. This electricity together with rechargeable batteries can power a light emitting diodes (LED) system for lighting [16]. Among all light producing devices, LEDs are one of the most efficient and long lasting. Freeplay in Europe and Light the World in Canada have pioneered this system [17]. 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 motor (40-50 W), development of efficient capacitors with suitable electronics as a substitute for batteries [18], and development of cheap LED units. A cycle powered unit in which the members of a household can take turns to charge the battery and which will give 3-4 hours of light will be a great boon for rural areas. This may be akin to Mahatma Gandhi's charkha except it will produce electricity instead of spinning cotton and in Gandhian analogy may help in sustainable development. Use of LEDs with efficient batteries will also be helpful in using photovoltaic (PV) units for lighting. Presently, because of poor efficiency of batteries and light sources, a relatively bigger area of PV panels is required. This increases the cost of the system since PV panels are the biggest component in the cost of these units.

Similarly majority of rural households use biomass cookstoves for cooking no matter what their economic strata are. The stoves are very inefficient and smoky with about 10-15% cooking efficiency. An extremely efficient thermoelectric device attached to the stove can produce 50-60 W of D.C. 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 [19]. A small fan may also be useful in creating gasification in the stove, which can further help the combustion process. Recent developments in nanotechnology and new materials have also shown that very efficient thermoelectric elements and thermionic devices can be developed [20]. Some of these thermoelectric elements have been able to break the ZT barrier of 1 and have reached a figure of 2.4 [21]. 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. Materials experts think this is only the beginning and predict that in 5-10 years these materials will form the basis of solid state refrigerators (via Peltier effect) and small scale power generators (via Seebeck effect). Similarly nanotechnology has been used in making an efficient thermionic device for power generation [22]. R&D is therefore necessary in developing these devices economically for cookstoves so that high temperature and soot loading can be tolerated by them.

Finally 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% [23], compared to that of a light bulb which is 7-10%. R&D should be done in trying to duplicate this mechanism. 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.

Cooking Energy

The major cooking energy source in rural areas is biomass. Around 180 million tons/year is used for cooking. It is used in extremely inefficient (10-15% efficiency) and smoky cookstoves or chulhas. Government of India initiated a National Program on Improved Chulha (NPIC) in 1985, through Ministry of Non-conventional Energy Sources (MNES). Last year after spending almost Rs. 150 crores on it since its inception, MNES disbanded the program [24]. Around 30 models of chulha were developed and distributed all over the country. However a recent evaluation by National Council of Applied Economic Research (NCAER) termed the program as a failure which led to its disbandment by MNES. One of the main reasons for NPIC failure was poor technology of chulhas and in quite a number of cases the so-called improved chulhas increased the smoke and amount of fuel used instead of reducing it. The rural poor have same aspirations as the rest of the country. Because of poverty they use the locally available biomass in whatever form they can get. However they would like to have a cookstove which produces blue flame, is easy to light and reduces their burden of collecting biomass fuel. No matter how improved the chulha is, it is still a chulha with its inherent problems. Anecdotal data suggests that as rural households increase their income they convert from biomass fuel to liquid fuel (kerosene) and finally to LPG for cooking energy. Thus the biggest challenge to R&D scientists is to provide a fuel and cooking stove technology, which gives complete combustion, based blue flame for cooking.

I feel the only way in which a clean, safe and convenient cooking system can be provided to rural areas, is by the use of liquid and gaseous fuels produced from locally available sources. Production of suitable liquid fuels has been described above. The cooking stoves to run on 85% (v/v) and higher ethanol concentrations are adequately developed. Both pressurized and non-pressurized ethanol stoves and their technology exist since they were used in Europe and the US in early and late 1920s. NARI has successfully modified existing kerosene pressurized stove to run on 85% (v/v) ethanol. [6]. The flame burns with bluish white color and the efficiency of stove is 40-50%. NARI's work has also shown that it is possible to run a stove with 45-50% (v/v) ethanol concentration. The stove is open combustion flame type [6]. Such low percentage ethanol solution can easily be distilled in any rural setting and is presently distilled as illicit liquor for drinking purposes. Use of this ethanol for cooking energy may also help rural women in two ways. Firstly, the illicit liquor distilled can be taken away from the men and then used in cookstoves. Secondly, women will not have to travel long distances and suffer hardships in collecting firewood.

R & D is also required in modifying the existing kerosene stoves to run on pyrolysis oil and bio-diesel. However, these modifications are not difficult and can be carried out quite easily.

The gaseous fuel can be produced either as biogas or producer gas from the existing biomass sources. Biogas has been used extensively in rural areas of India. However it is produced very inefficiently in fixed and floating dome systems and requires considerable amount of cowdung and other nitrogenous material. 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 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 in the development of extremely efficient biogas reactors so that the production/unit of biomass inputs could be maximized. The second area is to develop appropriate storage materials which could store biogas at low pressures. R&D is being done world over in methane storage and recently experiments have been conducted in storing it at low pressures (< 40 atmospheres) in hydrates [25], porous carbon [26] and porous organic structures [27]. There is thus a need to develop low cost storage materials so that biogas could be stored in them for usage in households. Thus a scenario can be thought of whereby a micro-utility company 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 India. Optimization of biogas production from a reactor requires sophisticated electronic based controls and bio-chemical engineering technology. A small utility can afford to do it whereas for a household it might be too costly. Tinkering around with existing biogas reactors will not solve the problem. A very sophisticated science and technology input has to be brought to bear on the problem for optimizing the biogas production in rural areas.

Producer gas produced from various types of biomass has been used for cooking and thermal applications [28]. However producer gas which is a mixture of carbon monoxide and hydrogen is poisonous and hence dangerous in confined spaces of a rural household. Thus its use as cooking fuel can only take place in very well ventilated households. Similarly considerable R&D has been done world over in using charcoal, derived from various types of biomass, in simple cookstoves. Charcoal burns very cleanly and can be a good fuel for rural households. Nevertheless making charcoal from biomass is wasteful energy-wise and about 30-40% of energy in biomass is lost in its production.

R&D is therefore necessary in developing an efficient biomass cookstove which produces a nonsmoky flame and runs on any form of biomass directly. A forced convection unit with a small fan, powered by electricity from thermoelectric element, may provide a solution.

Finally it should be pointed out that efficient and user friendly cooking and lighting systems together with fuel supply chain will free the rural households from the chores of collecting fuel and allow them better night light. This will help give them freedom to engage in gainful employment so that their income could be increased.

Economic Issues

Any technology becomes attractive if it becomes economically viable. R&D helps in increasing the efficiency of technology and hence improving its economics. Same thing will be true for cooking and lighting technology for rural areas. Unfortunately uptill now this whole sector is unorganized. The rural cooking technology is based on biomass cookstoves which are produced mostly by housewives themselves. Even the national program in India is focussed on a design similar to that used by housewives for centuries. I know of no other technology for household consumer in which the user is supposed to make it himself or herself. The only way in which cooking systems for rural areas can be modernized and improved is by doing R&D on it and bringing in the norms of industry as practiced in other consumer goods. That can easily happen if cooking is based on liquid and gaseous fuels using newer technologies outlined above. With such technologies the cooking and lighting industry can be a huge one. Simple economics calculations show that with a norm of two lanterns/household, there will be a need to provide about 200 million high lumen lanterns. With an average price of such lanterns at about Rs. 250-300/lantern, the lantern industry itself can be of the order of Rs. 5000-6000 crores. Similarly with a norm of one liquid fuel chulha for every household, the chulha manufacturing industry itself will be of the order of Rs. 2000-3000 crores. This assumes about 100-150 million households which use biomass cookstoves and each liquid fuel stove is expected to cost about Rs. 150-200.

Similarly, the liquid fuel supply chain can become a very major industry in rural areas. Besides helping the rural households, this industry will also bring large-scale employment and wealth in rural areas. To replace all the kerosene used in rural areas (6.9 million tons/year) by ethanol will require production of 14,700 million liters/year. With an average price of ethanol at Rs. 18/litre [29], the ethanol production industry will be of the order of Rs. 26,500 crores/year. Presently the Government of India is running a program of 5% ethanol blend with petrol. The total requirement of ethanol for this program will be about 300-400 million liters/year and will benefit a very small percentage of population who use petrol cars. Program for production of ethanol for cooking and lighting industry will be about 30-40 times bigger than automobile fuel-blend program and can affect the lives of about 500 million people in rural areas. Besides the implications for rural industry in terms of wealth and employment generation can be staggering. It will also help the country save foreign exchange that goes in importing kerosene. Similarly the pyrolysis oil and biogas production can also be a huge rural industry, bringing wealth to rural areas.

The cost of ethanol (Rs. 18/litre) is comparable to that of kerosene in open market and hence for lighting it will be accepted quite readily. For use as cooking fuel, innovative methods for providing finance to rural households to buy cookstove and fuel will have to be developed. The present financing norms for renewable energy technologies will have to be applied in this case since ethanol is a renewable fuel.

It should however be pointed out that in rural areas most of the biomass is available free of cost. Hence to make the rural population pay for cooking energy may be little difficult. Nevertheless the middle class and rich rural households may use cleaner and convenient fuels for cooking and this trend may ultimately be copied by rural poor.

Policy Issues

The lighting and cooking energy program can be a very major national effort touching every aspect of rural life. However the following policy issues need to be formulated for it to succeed :

1. A technology mission for cooking and lighting should be set up on the lines of existing technology missions for other areas. This technology mission's mandate should be to bring adequate light (~ 500 lux) and clean and user friendly cooking system, together with proper fuel supply chain, to every rural household by 2010.

2. All cooking and lighting energy programs which are scattered under different headings (like chulhas, biogas etc.) in different ministries should be brought together under one umbrella ministry. Since the long term future of this program will be renewable energy-based, the Ministry of Non-conventional Energy Sources will be a proper place to host this program. This ministry can also undertake to fund large R&D program in this area. Consequently, the necessary R&D budget provision should be made.

- Setting up of industries in rural areas to produce gaseous and liquid fuels from biomass should be encouraged in terms of availability of easy finance and tax breaks to them.
- A joint venture of NGOs and corporate sector should be encouraged and industrial production and sales techniques brought to bear on this program.
- Government of India should enact policies so that microutilities for producing power (~ 50 kW) proliferate in rural areas. The microutilities running on renewable energy fuels like ethanol, pyrolysis oil etc. will bring prosperity to rural areas. These utilities will provide power for lighting and other uses to rural households. They are small enough to be managed by entrepreneurs and should be encouraged by giving them soft loan from the banks.

Finally it should be pointed out that the whole issue of technology development for cooking and lighting for rural areas has been based upon tinkering with ancient and inefficient technology, whether for chulha, biogas, or liquid fuel-based lighting. The focus should shift now to putting in very intense and sophisticated R&D effort into these areas based on emerging technologies like nanotechnology, biotechnology etc. The evolution of modern household in developed countries bears a testimony to concentrated efforts by technologists and scientists in making user friendly cooking and lighting technologies, backed by efficient fuel delivery system. I hope this paper will create interest in the large S & T community of the country so that they can help in developing technologies for helping the lives of rural poor.

REFERENCES

Rural Energy - India country gateway; www.incg.org.in/countryGateway/RuralEnergy/ overview/RuralenergyinIndia.htm.

Rajvanshi, A. K. and Sudhir Kumar; "Development of Improved Lanterns for Rural Areas", Publication No. NARI-LAN-1 (1989); http://www.nariphaltan.org/lantern.htm 4 pg.

Rajvanshi, A. K., "Talukas can provide critical mass for India's sustainable development", CURRENT SCIENCE, Vol. 82, No. 6, 25 March 2002. Pp. 632-637.

IES Lighting Handbook, Published by Illuminating Engineering Society (1972 Edition).

Rajvanshi, A. K., "New Candoluminescent Materials for kerosene lanterns for rural areas", Final project report to DST, New Delhi (March 1998).

Rajvanshi, A. K., R. M. Jorapur and N. Nimbkar, "Ethanol from Sweet Sorghum", Publication No. NARI-ALC-1 (1989), 6 pgs.

A. V. Bridgwater, "Biomass Fast Pyrolysis and Application in Europe", Proceedings of 3rd Biomass Conference of the Americas (Ed. Overend and Chornet) Montreal, Canada, Vol. 2, pp. 797-809 (1997).

Y. Solantausta, et. al. "Use of pyrolysis oil in test diesel engine to study the feasibility of diesel power plant", Biomass & Bioenergy, Vol. 7, No. 1-6, 1994.

A. M. K. Patil, "Bio-diesel : Fuel for the next Generation", Ethanol, Vol. 6, Nov. 2002, Published by Winrock International India, New Delhi, pg. 2-3.

A. S. Chaudhari, "Ethanol production from Sugar Beet", Ethanol, Vol. 6, Nov. 2002. pg. 8-9.

Rajvanshi, A. K., "Potential of Briquettes from Farm Residues as Rural Energy Source", Changing Villages, Vol. 7, No. 3, May-June, 1985, 16 pgs.

Lakshmikanthan, V., "Tree Borne Oilseeds", Directorate of Non-Edible Oils and Soap Industry, KVIC, Bombay, 1978, pp. 59.

Wealth of India-Raw Materials 2000 (First Supplement Series), National Institute of Science, CSIR, New Delhi, Vol. 1, pp. 107-111.

"Zero Emission Micro Power Unit"; www.enginion.com, Aug. 2001.

Fairley, Peter, "Power to People", MIT Tech. Rev., 2001, 104.

Seth Coe, et. al. "Electroluminescence from single monolayers of nanocrystals in molecular organic devices", NATURE, Vol. 420, No. 6917, Dec. 2002, pg. 800-803.

www.lightuptheworld.org.

Andrew Burke, "Ultracapacitors : Why, How and Where is the Technology ?"; http://repositories.cdlib.org/itdavis/UCD-ITS-RSP-17, 2000.

Personal Communications, Tom Reed, U.S.A. November 2002.

C. B. Vining, "Semiconductors are Cool", NATURE, Vol. 413, 11 Oct. 2001. Pg. 577-578.

Rama Venkatasubramania, et. al., "Thin film thermoelectric devices with high room temperature figures of merit". NATURE, Vol. 413, 11 Oct. 2001, pg. 597-602.

Thermionic systems for power generation; www.powerchips.gi/technology/overview. shtml.

E. Wilson, "Light sticks", Chemical and Engineering News, Vol. 77, No. 3, January 18, 1999, p65

R. Mahapatra, "Up in Smoke", Down to Earth, Vol. 11, No. 17, January. 31, 2003. Pg. 25-28.

Low pressure storage of methane in hydrates; www. mines.edu/research/chs/Aftab.html

Porous carbon to store methane; www. acdlabs.com/webzine/24/24_2.html.

R. Dagani, "Crystal sponges", Materials chemistry, Vol. 80, No. 3, January. 21, 2002, pg. 8.

Gao XianSheng, "Biomass domestic cooking gasifier stove for use in rural areas of developing countries", Advances in Thermochemical Biomass Conversion (Ed. A. V. Bridgwater), Vol. 1, pg. 310-313, Blackie Academic & Professional, 1994.

N. P. Singh, "Ethanol as a bio-fuel option", Proceedings of Ethanol 2002, International Conference on Policy, Financing and Market Development Issues, Winrock International India, New Delhi, April 2002.