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

Anil K. Rajvanshi

Majority of rural households in India use only kerosene for lighting. Most of the lamps are hurricane-type, which produce very poor light intensity 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 stoves. 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, affecting the quality of life of the rural poor. This paper 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 the rural poor.

IT is a matter of concern that even 55 years after independence, 63% of total rural households in India use only kerosene for lighting[1]. Most of the kerosene lamps are hurricane-type lamps with light intensity of only 60–70 lumens (lm)[2] (100 W bulb produces ~1300 lm; for reading ~100–200 lm/m^2 (lux) is sufficient). In some states like Bihar and Assam, about 90–95% rural households use only kerosene for lighting. Thus nearly 90–100 million rural households do not have electricity and with frequent blackouts even larger number probably use kerosene for lighting. Similarly, rural areas in India use about 180 million tons of biomass fuel for cooking though it is very inefficient and smoky[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. Our mass media rarely highlight this plight of the 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[4], and with ever-increasing petroleum imports, it is safe to say that the rural poor will remain in a primitive state for a long time to come. A country, which has 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.

Anil K. Rajvanshi is in the Nimbkar Agricultural Research Institute, Phaltan 415 523, India
e-mail: nariphaltan@sancharnet.in

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. Yellow 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). It is based upon incomplete combustion principle. Hence the yellow flame produces soot, CO and CO_2. In the confined space of rural households, use of such lanterns can be injurious to health. However, 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, small gas cylinders are not readily available in rural areas.

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 (efficiency of light production is called efficacy) of these mantles is ~2–3 lm/W (ref. 2), whereas the efficacy of light bulbs is ~10–15 lm/W and that of compact fluorescent lamps (CFL) is 50–70 lm/W (ref. 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%, Transmission and Distribution losses of 20% and fluorescent lamp efficacy of 60 lm/W. For small distributed electricity system the efficacy can 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 thoria mixture and also increase the efficacy. Some efforts have been directed towards using alternate materials like ytterbia for coating T/L mantles[6]. Similarly other rare earth oxides have shown promising light emission characteristics which can be used for T/L mantles[7]. 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 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 and carbon–carbon composites[8]. 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 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[9]. 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[9]. 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 3 to 5 months (as compared to 12 to 18 months for sugarcane). Besides, it is cheaper to grow than sugarcane and requires less water. Per unit of water it is probably the highest sugar-yielding crop. There is a need to develop mini distilleries of 5000 l/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 (ref. 10) 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 US and Europe where it is being used for power generation[11]. Being a medium CV fuel with about 25% moisture content, it can be used only in modified lanterns and cookstoves. R&D is there fore needed to produce 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 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[12]. 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 the 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 carried out in producing suitable stoves and lanterns to burn this oil. The economics of collection of seeds from existing trees and growing 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 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.

Distributed electricity-based lighting

A 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[13], gas powered 20–30 kW micro-turbine, etc.[14]. 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.

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.
Ethanol from:						
Sugarcane juice	3000–4000	25 (6% MC)	75,000–1,00,000	Y	No	29
Molasses	250 l/ton of molasses		–	Y	By product of sugar	29
Sweet sorghum	2400–3200		60,000–80,000	Y	Yes	9
Sugarbeet	4500–6000		1,12,500–1,50,000	R&D needed	No	29
Pyrolysis oil	3000–9000 (from 5–15 tons/ha agricultural residues)	17 (25% MC)	51,000–1,53,000	R&D needed	N/A	30
Bio-diesel from trees						
Karanja	600–2000		22,200–74,000	Y		31
Mahua	200–700	~ 37	7,400–26,000	Y	No	32
Sal	200–400		7,400–15,000	Y		
Neem	900–1200		33,000–45,000	Y		

MC, Moisture content.

Two electricity-producing technologies for lighting need to be mentioned 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 DC (PMDC) motors have made it possible to produce small amount of electric power via human power. This electricity together with rechargeable batteries can power a light emitting diodes (LED) system for lighting[15]. 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[16]. 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[17], and development of cheap LED units. A bicycle powered unit in which the members of a household can take turns to charge the battery and 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 except that 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 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[18]. 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[19]. Some of these thermoelectric elements have been able to break the ZT barrier of 1 and have reached a figure of 2.4 (ref. 20). 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[21]. 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% (ref. 22), 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. The Government of India initiated a National Program on Improved Chulha (NPIC) in 1985, through Ministry of Non-conventional Energy Sources (MNES). There are recent reports that after spending almost Rs 150 crores on it since its inception, MNES has shelved the program[23]. 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 shelving 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 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 stoves to run on 85% (v/v) ethanol[9]. The flame burns with bluish white colour 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[9]. Such low percentage ethanol solution can easily be distilled in any rural setting and is presently distilled as illicit liquor for drinking purposes.

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 medium pressures. R&D is being done world over in methane storage and recently experiments have been conducted in storing it at medium pressures (< 40 atmospheres) in hydrates[24], porous carbon[25] and porous organic structures[26]. 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[27]. 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.

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. The same is true for cooking and lighting technology for rural areas. Once the technology is available the cost reduction processes and creative financing mechanism for its availability to rural poor can be designed. Unfortunately until 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 happen if cooking is based on liquid and gaseous fuels using newer technologies outlined above. 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 that about 100–150 million households 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 l/year. With an average price of ethanol at Rs 18/l (ref. 28), 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 l/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/l) 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 a 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 (~ 100–200 lux) and user-friendly and clean cooking system 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.
3. 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 benefits.
4. A joint venture of NGOs and corporate sector should be encouraged and industrial production and sales techniques brought to bear on this program.
5. 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.

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.

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Electret sensors, filters and MEMS devices: New challenges in materials research

Malti Goel

Recent advances in electret technology offer promise to serve mankind through medical prosthesis and by performing other biological functions. Increasingly, we recognize the challenge it has thrown to materials science research. How electrets are being put to use in sensors, actuators, filters and what micro-electro-mechanical system devices are emerging on the scene, are described here. This article also presents some of the highlights of early researches conducted in the field of electrets and current trends.

THE term electret was conceived as a counterpart of magnet about one hundred years ago. A dielectric material, which has been electrized (polarized) is called an *electret*. Thermoelectret effect was discovered in 1925, when Eguchi solidified a mixture of carnuaba wax, resin and beeswax in the presence of a high DC electric field[1]. The energy absorbed during the charging process resulted in space-charge polarization by trapping of positive and negative charges at the interstitial sites. Nadzakov[2] observed the photoelectret effect in 1937, by exposing a photoconducting dielectric to light radiation and electric field simultaneously.

Both thermoelectrets and photoelectrets are proving extremely important in modern sensing as well as optoelectronic devices. Their utility arises from the fact that they exhibit persistent polarization and a surface charge, which remain stable for a long time. A major breakthrough in electret applications occurred in 1966, when Sessler at Bell Laboratories introduced an electret condenser microphone (ECM). At present, ECMs are commercially being produced in large quantities[3] for use in tape recorders, stereos, telephones, cordless and cellular phones and hearing aids (Figure 1). The author[4] and her colleagues[5] also presented specific reviews on electrets in the early 1970s. In the recent years, excellent reviews and books on electret techniques and applications have been published[6–9]. This is an article on the importance and emerging potential applications of electrets and not an in-depth review.

In this article, starting from basic concepts of electret formation in dielectric materials and methods of study of polarization in them, applications in transducers and air filters as low energy-consuming, cost-effective pollution monitoring and control devices, having capability to filter toxic gases as well as suspended particles are discussed. With the advancement in materials research, miniature electret microphones integrated on silicon chips as micro-electro-mechanical systems (MEMS) have been produced. Products employing electrets have been put into practical use in almost all walks of life. Use of electrets has been suggested for biomedical applications such as replacement of heart valve, bone implants and artificial muscles in robotic paradigm. Such developments have thrown new challenges in materials science research.

The views expressed in this article are those of the author and not necessarily those of the organization.

The author is in the Department of Science and Technology, Technology Bhawan, New Delhi 110 016, India
e-mail: mlg@alpha.nic.in