Energy R&D for Rural Development [1]

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Good afternoon Ladies and Gentlemen,

I am delighted and honored to be here to deliver the 6th Professor B. D. Tilak memorial and National Technology Day lecture. I must really thank Dr. Sivaram, the Director of NCL for inviting me for it.

Dr. B. D. Tilak was associated with our Institute as a member of our research advisory council from 1981 till the time he passed away. He was a remarkable person, a great chemist, good administrator and above all a very nice human being. In late 1981 I had just returned from US and had joined Nimbkar Agricultural Research Institute to work on rural energy problems. Dr. Tilak's desire and enthusiasm for the use of best tools of science and technology for solving rural problems matched mine and thus our meetings were very enjoyable.

The theme of my talk today is therefore the use of high technology for solving the energy problems of rural India and how NCL and NARI can work together in this area. As you know we have already been collaborating together for last many years and recently were jointly given the CSIR Rural Technology Award by the Prime Minister Dr. Manmohan Singh.

My talk is divided into 3 parts. Firstly I will talk about the problems of energy in rural India, followed by how sophisticated science and technology can be used in solving them. I will focus mostly on how energy from agriculture can create rural wealth and what needs to be done to solve the basic problems of cooking and lighting. In fact we in urban areas do not even think about these problems and yet 75% of total energy used in rural households is for cooking and lighting.

Last part of my talk will be focused on how NARI and NCL can work together in solving some of these problems.

Rural Energy Problems

Consider the following:

(1) 65% of India's population is rural-based. Out of this around 60% have nearly non-existent access to electricity. According to Government of India figures around 20,000 villages have never seen electricity which means almost 40-60 million people are still living in stone age. Even the other so-called electrified villages get only 3-4 hours of electricity every day which is as good as having no electricity. This is a sad state of affairs even 61 years after independence. In Maharashtra which was once an electricity-surplus state there is a peak power shortage of 6000 MW. Thus 12-16 hours blackouts are common in rural Maharashtra.

(2) Energy is the basis of life. Lack of it produces economic stagnation and social upheavals. Average per capita consumption in the country is 18 GJ/yr or 5% that used in U.S. (350 GJ/person per year). Per capita electricity consumption in rural India is just 60 kWh/yr and it is one of the

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[1] National Technology Day and Professor B.D. Tilak Memorial Lecture at National Chemical Laboratory (NCL), Pune May 22, 2009.

lowest in the world. Since Human Development Index (HDI) is directly linked to electricity consumption this results in the low quality of life in rural areas.

(3) Most of the villagers use kerosene for lighting through very inefficient hurricane lanterns and use about 180-200 million tons of biomass for cooking in ancient three-stone cook stoves. Biomass usage for cooking adds up to almost 6 GJ/yr per man, women and child and is almost 33% of total per capita energy consumption of an Indian citizen. Not only does it result in tremendous loss of useful energy, but this type of cooking is also injurious to their health. The cook stoves in rural Indian households produce tremendous indoor air pollution resulting in about 300,000 deaths/yr. It seems that the modern technology somehow has not touched their lives. Yet there is another India which is so developed that it is nearly ready to send the man to the moon! I feel that unless and until the rural population is brought into mainstream of development, India cannot aspire to be a great economic power.

(4) If adequate liquid or gaseous fuel which is environmentally friendly and locally produced is available in rural areas then the problem of cooking and lighting can be solved. India last year imported about Rs. 200,000 crores worth of petroleum products. 80% of India's total oil consumption is imported and with 8-9% growth rate per year will put a very heavy burden on the foreign exchange reserves. Besides this heavy dependence on imported oil also jeopardizes Indian security. It is estimated that in 15-20 years India and China might surpass the oil consumption of developed world. This may lead to strife and wars.

(5) Energy from agriculture can solve most of the problems outlined above and will be the main theme of my talk today. I will show that it can produce tremendous rural wealth and jobs.

I stand today in the auditorium of one of the prestigious national institutes and it is my desire and hope that you will become interested in attacking and solving the problems of rural India with the same sophisticated S&T tools that you use in solving the problems of industry, and of western countries. A national institute funded by the tax payers' money should be sensitive to the problems of rural India where majority of our population lives.

India is a young country with 54% of its population below the age of 25 years and most of them live in rural areas. Rural dwellers are not sub humans. They have the same aspirations as those who live in urban areas. With proliferation of mass media like direct to home (DTH) TV their expectation levels have increased and they yearn for better quality of life. It is in the interest of technologists, corporate world and government to help increase their quality of life so as to avoid social unrest.

Strategy for Rural R&D

The quality of life of rural people can be improved through the use of high technology which uses local resources. 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. All biological systems follow this strategy. 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. 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. Biomimicry is also very spiritual! It connects us to nature and requires very deep thought to understand it - the two fundamental tenets of Yoga.

Though every aspect of rural life can be touched and improved by sophisticated technology, I will restrict myself in this talk to two things. One is the production of energy from agriculture and the other is the basic area of cooking and lighting. These examples nevertheless can be extended to other areas of rural life like clean drinking water, sanitation, etc.

Production of Energy

About 600 million tonnes of agricultural residues are produced annually in India. Most of these residues are burnt in the fields as a solution to the waste-disposal problem. This not only wastes the precious biomass resource, but also produces tremendous air pollution.

Theoretically, these residues can produce about 80,000 MW of electric power year round through biomass-based power plants. This power is nearly 50% of the total installed capacity of India. Alternatively, they can produce 156 billion liters of ethanol (via lignocellulosic conversion), which can take care of 42% of India’s oil demand for the year 2012. Similarly, the residues can also produce about 400 billion kilograms of pyrolysis oil, which is equivalent to 80% of the total Indian oil demand for 2012. Thus the agricultural residues if properly utilized, can take care of a huge chunk of India’s energy needs.

Ethanol fuel is normally produced from agricultural crops like sweet sorghum, sugarbeet, sugarcane, corn, etc. However, to produce it in an affordable and environmentally sound manner will require tremendous inputs of biotechnology and good engineering. Thus research is being done in the US and all over the world in converting agricultural residues into ethanol via the enzymatic hydrolysis process.

Similarly, biodiesel can be produced from many oil-producing crops like jatropha, soybean, pongamia, castor, etc. Though the production of biodiesel is quite easy, there is a need to increase the yields of oil-bearing plants and to develop internal combustion engines which can run on a whole array of biodiesels. Presently the high-speed diesel engines require tailored biodiesel which can be done by suitable chemical additives.

Pyrolysis oil on the other hand, is produced by rapid combustion of biomass and then rapidly condensing the ensuing vapors or smoke to yield oil which is nearly equivalent to diesel. Pyrolysis oil still requires much more R&D in terms of producing it economically, improving its keeping quality and making it suitable for use in existing internal combustion engines. Nevertheless, experiments in Sweden on running a 5 MW diesel power plant on pyrolysis oil have been successful. Recently quite a few plants of producing pyrolysis oil have been set up in China, Europe and US.

In any agriculture only 25-40% of the produce is food. The rest 60-75% forms the agricultural residues. Any marginal farm can produce agricultural residues even if the main food crop fails. Our calculations show that on an average a farmer in India can get an extra income of Rs. 2000-4000/acre per year from the residues alone, if they are used for producing energy. This income can give him benefits, even in case of a distress sale of his crop. The farmer is a multipurpose industrialist producing a variety of outputs from the same piece of land. We do not know of any other industry which can exist or can survive after selling only 25-40% of its produce, with the rest being wasted. So why farming should be treated differently? Thus unless and until the farmer gets remuneration for his entire produce, farming will never become economically viable.

A part of these agricultural residues can also be used via the bio-digester route to produce fertilizer for the crops and methane gas to either run rural transport, irrigation pump sets or for cooking purposes. Another stream can be for producing fodder for animals. Thus the residues can produce fuel, fodder and fertilizer. Which stream of residue conversion technology is eventually followed will depend upon the existing market forces.

As the industrial demand for fuels and electricity increases, we might see large tracts of farmland coming under fuel crops and food production may suffer. People who have cars have money and when they give good money for the homegrown fuel, the farmers will put majority of their land under fuel crops. This is already happening in many countries around the world including India. Thus there is a need to seriously debate the food vs. fuel issues.

Consequently, R&D needs to be done on crops which produce both fuel and food from the same piece of land. Sweet sorghum is one such crop. Our institute, NARI has pioneered the development of this crop in India. We introduced it in the country in early 1970s. Sweet sorghum produces food (grain) from its ear head, fuel from its stem (the sweet juice can be fermented to produce ethanol) and bagasse and leaves make an excellent fodder for animals. Alternatively bagasse and leaves can also be used as fuel in power plants or as a fertilizer. Sweet sorghum is a thrifty crop and produces maximum sugar per unit of water of any crop known to man. Besides it is a 4 month crop so two crops per year can be grown on the same piece of land. Presently our hybrid MADHURA produces 2000-3000 l/ha of ethanol per year. It is presently planted in India and has been exported to a dozen countries in Asia, Africa, Europe and America.

Similarly, if the agricultural residues can be broken down by suitable enzymes to produce ethanol, then both food and fuel can be produced from all food crops. Extensive research in lignocellulosic ethanol conversion is being done by universities and industry the world over and this technology will be very useful for rural areas of the world.

Energy from agriculture could be an order of Rs. 250,000 crores/yr industry and can provide about 50 million jobs per year. To my mind this could be the biggest source of wealth creation in rural areas. No matter what is the state of the economy, people will always need food to eat. Hence an expansion of agriculture and consequently energy production from it will provide food, energy and economic security for India.

I strongly feel that when the farmers are neglected, the long-term sustainability of the country is threatened. When farms produce both food and fuel, then their utility becomes manifold. Now with the ethanol and biodiesel programs taking shape worldwide, I feel high-tech farming will be the center piece of economic activity of every major country. In India, 65% of its population depends upon farming for its livelihood and if energy from agriculture becomes a major focus then India has the potential of becoming a high-tech farming community and an economic power.

Lighting Energy Strategy

Due to unavailability of electric grid in rural areas and hence 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 which 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, solar cell efficiencies can go as high as 68%. Similarly solar antennas based on carbon nanotubes are being developed to produce electricity. Recently one such device has morphed into a nano-radio.

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 cycled millions of times. Also new materials are being developed which allow battery charging to be done very rapidly. This rapid charging also increases the efficiency of charging/discharging cycle. 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. There are also indications that sugar either in solid or in solution form can be directly used as a fuel in engines.

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 that of 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 is ~ 10 lm/W since 70% of energy is lost in power plant and another 20% during transmission and distribution. 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 can not only compete with, but even surpass in efficiency the electricity-based lighting. Our Institute NARI has pioneered a lantern running on 50-60% (w/w) ethanol/water mixture. This mixture which is safe and can be easily distilled in a backyard distillery can be an effective fuel for such high-efficiency lanterns. The lantern also doubles up as a cooking stove thereby increasing the efficiency of the device.

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 (LED) lanterns. The devices include thermionic and thermoelectric units (which directly convert heat into power), micro engines and small fuel cells. 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. Similarly, it is possible that mankind one day will develop a strategy where sunlight will photocatalyse two liquids, which when mixed together will produce brilliant light. Developing devices based on this mechanism could revolutionize decentralized lighting in rural areas.

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 50-60% (w/w) 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. Large-scale testing in the field has been positive and almost all the rural women who have tried it compare it favorably 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 program in India, despite being 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 compressed and cleaned biogas is being used in a substantial way to run automobiles and the public transport systems.

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. 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 nansocience 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.

Availability of devices for rural areas

I hope that what I have discussed till now has given you a flavor of what R&D can do for rural areas. However, no matter how good the research is unless its products are available to rural population it becomes only an academic exercise.

In the past also good amount of R&D in India 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 in India can afford to buy devices for household purposes. Their purchasing power can be further improved by creation of wealth from energy from agriculture.

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 these areas is made possible by micro-finance instruments from Grameen Bank. 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 which are 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 LPG gas stoves, 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 making them interested.

Another possible way to speed up the process is a partnership between institutes like NARI and NCL together with corporate bodies. NCL because of its premier status interacts with corporate world frequently and this can help all the three partners to forge a unique relationship. Also NARI is setting up a center of sustainable development at its campus in Phaltan which will primarily work on NGO/corporate partnership. This center can also help bring Institutes like NCL and corporate entities together for rural development.

Thirdly, 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 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. The rate of this change though is slow and the corporate world in India still works on the principle of rapid rate of return on its R&D investment which results in very few fundamental and long term projects financed by them. I feel Government of India agencies are more enlightened than corporate sector in this regards.

Finally I feel that all our endeavors are basically guided by the principle of happiness in whatever we do. Thus once our basic needs are satisfied, all of us long for some meaningful existence. This can happen by helping less fortunate people and by giving back something to the society. I believe that the whole purpose of our existence is to increase personal and societal infrastructure. Personal infrastructure includes our health, happiness and general well-being. By improving our personal 'infrastructure', we become better human beings and it helps in our emotional growth and evolution. By giving back to the society so that its 'infrastructure' increases we help in mankind's evolution. Both these activities when carried out simultaneously, can give us great joy and satisfaction. Our technological contributions towards raising the standard of living for rural poor should be based on this principle.

I will now end my talk by telling you an Indian story, a tale from our ancient scriptures, the Puranas. It is a typical Indian story of a sage and his disciples. The sage asks his disciples, "When does the night end?" And the disciples say, "at dawn, of course". The sage says, "I know that. But when does the night end and the dawn begin?" The first disciple, who is from the tropical south of India replies : "When the first glimmer of light across the sky reveals the fronds on the coconut trees swaying in the breeze, that is when the night ends and the dawn begins". The sage says "no", so the second disciple, who is from the cold north, ventures : "When the first streaks of sunshine make the snow gleam white on the mountaintops of the Himalayas, that is when the night ends and the dawn begins". The sage says, "no, my sons. When two travelers from opposite ends of our land meet and embrace each other as brothers, and when they realize they sleep under the same sky, see the same stars and dream the same dreams – that is when the night ends and the dawn begins". I feel when we technologists help light up the lives of rural poor through technology and resources then it will bring in the dawn of a new and prosperous India which will be fit to join the ranks of great nations.

Thank you.

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