History of household energy R&D at NARI

(Chapter from book "Romance of Innovation")

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Almost one third of the renewable energy projects undertaken at NARI have focused on household energy. This is based on our belief that rural poor have the same aspirations as all of us and their quality of life can be improved by developing easy to use and environmentally friendly devices for cooking and lighting from locally available resources. This short history of R&D efforts at NARI in these areas is divided into two parts: production of renewable fuel for rural households; and development of devices for cooking, lighting, and production of clean water. All the projects undertaken at NARI are hardware oriented.

Ethanol from Sweet Sorghum

In late 1970s I taught for two and half years in Training in Alternative Energy Technologies (TAET) program at the University of Florida (UF). TAET was set up at UF by a huge grant from USAID to train scientists and energy planners from developing countries in the areas of renewable energy. One of the topics that constantly came up was the development of renewable fuel for cooking and lighting in rural areas. I therefore thought that ethanol would be an excellent renewable and non-polluting fuel for such purposes. The idea was to replace fossil fuels like kerosene and liquid petroleum gas (LPG) with renewable fuel, and ethanol seemed to fit the bill.

Studies on ethanol production had shown that the maximum energy is used in its distillation from the fermented mash; I thought it would be useful to use renewable solar energy to distill it.

When I came back to India and started working at NARI in 1981, the first project I did involved solar distillation of ethanol using a simple solar still. Since my Ph.D.

work in U.S. was on solar distillation of water, I thought of using a similar technology for ethanol distillation.

So I wrote a small proposal (Rs. 1.2 lakh for 2 years project) on solar distillation of ethanol to the Commission of Additional Sources of Energy (CASE) - a predecessor of Department of Non-Conventional Energy Sources (DNES), both Government of India (GOI) entities. CASE was run in those days by Maheshwar Dayal a dynamic engineer from Indian Atomic Energy establishment and who later on became the Secretary of DNES. I went to see him in Delhi, and he immediately sanctioned the project though fully knowing that I did not have a lab or the manpower. That was our first project. I have always remained grateful to him for reposing faith in me and our work.

Maheshwar Dayal laying the foundation stone of NARI lab. 1982

I think he was quite impressed by the fact that though I had worked in US under the solar pioneer Dr. Farber; I still decided to come back and work in rural India. Mahesh was a really helpful person – he also laid the foundation stone of our lab at NARI in 1982. His bright career was unfortunately cut short by his untimely and tragic death in early 1990s.

Phaltan in 1981 was really a very small town, almost like a big village with hardly any facilities. Our Institute was situated about 6-7 km from the town, and we had neither fabrication facilities nor staff! I designed the still and got it fabricated by a local welder. I had to sit with him on the bare ground in a dirty tin-shed workshop and get it fabricated as per my specifications, though the quality of work left much to be desired.

I had brought back a good amount of lab equipment from the U.S. including strip chart recorder, thermocouples, constant temperature baths, even silicone glue, and all these helped me to assemble and experiment on the simple solar still. The Indian participants in the TAET program at UF had told me what research equipment is available in India and so I thought in a remote rural area of Phaltan some basic equipment will be needed to immediately start work and this helped me to decide on what to buy.

After I came back, I realized that to get even simple things like thermocouples from Mumbai was quite a chore since it took almost a month or two to get them. In those days with lack of phone connection from Phaltan the only means of communication were letters by post and this delayed the purchase quite a lot. My equipment from US therefore helped us do our work for 4-5 years before we established good contacts with lab equipment vendors.

When I tested the still, I found that it only produced ethanol of 20-25% (v/v) concentration, which was not enough to be used as cooking fuel. The next step was to increase its concentration and that could be done by using a small vacuum. Since we did not have the facility to fabricate such a still, I designed it and a friend of mine, Mr. M. G. Pawar, got it fabricated at his workshop in Pune. The still (pictured) worked in batch mode with vacuum being pulled in the morning and ethanol collected in a condenser in the evening.

This single-effect simple vacuum solar distillation unit showed that one could produce a 40-60% (v/v) ethanol water mixture from fermented mash (7% (v/v) ethanol). In 1983-84, we developed a 1 kW (thermal) stove to utilize this mixture for cooking purposes. This stove (shown) worked on the principle of surface evaporation of ethanol from the mixture; once lit, the stove kept on burning till either the air supply was stopped (by covering the stove with a lid) or the ethanol evaporated out of the mixture. This, to our knowledge, was a unique stove running on low concentration, i.e., 40-60% (v/v) ethanol.

While we were working on the solar distillation unit, we also started a program on the use of sweet sorghum as an alternative crop for ethanol production. The main crop for ethanol production in India is sugarcane. It is an 18-month crop and consumes a huge amount of water. The idea was to use an alternative crop which would be short duration and uses less water. Sweet sorghum, which is a 4-month crop and consumes around 40% less water than sugarcane, is one such crop. It is a multipurpose crop, providing grain from its ear head, and sugary juice, which can be fermented to produce ethanol, from its stalks; the bagasse is excellent fodder for animals. Hence, sweet sorghum provides food, fuel, and feed from the same piece of land. Besides the output/input energy ratio for this crop was quite high making it very attractive to grow for fuel production.

Sweet sorghum was introduced in India by our Institute, NARI, in the early 1970s. Our program included breeding better varieties of sweet sorghum, improving fermentation efficiency of its juice, and finally solar distillation of ethanol. In the early 1980s we set in motion **the world's largest program on the use of sweet sorghum for ethanol production.** We were almost 30 years ahead of time because in late 2000 there was a great surge worldwide in programs to promote usage of sweet sorghum for ethanol production. We are proud to state that largely because of our efforts in the 1980s and '90s, the Government of India (GOI) launched a national program on sweet sorghum for ethanol production around 2005. Also our Madhura sweet sorghum variety has been tested and sown in more than 15 countries. We also use sweet sorghum for producing syrup which has medicinal properties and feel that syrup production from it is a better alternative than ethanol.

Our simple solar still gave us good publicity and was written up in local newspapers. One day a smartly dressed village woman showed up at our lab and told us that she wanted to buy this unit and would pay for it immediately in cash. I told her that this was just an experimental still and not for sale, but she insisted on buying it. When I enquired why she was in such a hurry, she replied that her business was distilling illicit ethanol using a wood-fired boiler and she and her gang were always getting caught by the police because they could detect the smoke coming out of the distillation unit! She thought our solar still, which worked silently and without smoke, could easily solve this problem!

Distilling and use of ethanol in India is controlled by stringent excise laws and one needs a special license. Getting an alcohol license is very difficult since there is a lot of corruption in the excise department. Consequently, illicit distilling activities thrive in the rural areas. There are rough estimates that illicit ethanol production industry is nearly 5 times bigger than the regular one.

Our work on this simple distillation unit also pointed to the fact that with better vacuum and a specially designed distillation column, solar energy could be used to distill high purity ethanol. I then wrote a proposal to Department of Non-conventional Energy Sources (DNES), GOI, for setting up probably the world's first pilot plant of solar-powered ethanol distillation. It was designed to distill 50 liters of 95% (v/v) ethanol per day.

In 1985 we started work on this plant and finished the testing and analysis by 1989. In 1985 I hired Rajeev Jorapur, an engineer who had just finished his B.Tech in Chemical Engineering from IIT Bombay and together with a four-member team of technicians we set up the plant. We hired a distillery consultant to design the distillation column. All his experience centered around designing 30,000 liters per day (lpd) plants running on steam, and he found it a challenge to design a low temperature (60-70°C) plant of 50 lpd.

Solar powered ethanol distillation plant (1988)

We went through a lot of trials and errors but were able to set up the plant in 9-10 months. Except for simple welding, drilling, and grinding machines we had no equipment for making flanges or for machining parts. Our resourceful technicians got them fabricated in Phaltan and we had the stainless-steel parts fabricated in Pune.

In those days Dr. A.P.B. Sinha, a deputy director of National Chemical Laboratory (NCL), Pune was a member of our advisory board. He used to come to Phaltan to advice us and review our work. Apparently, he told some of his colleagues that what he could not build in 10 years in NCL, Rajvanshi and his group has done in 10 months in rural setting!

This scorching pace was achieved by running the lab in an industrial mode. I would have weekly meetings with all my staff and very detailed timetable was made and followed through. Though we hardly had any facilities or equipment, the pace of work created a momentum, and we improvised as we went along. We would do the design and get it fabricated and then experimented on it. If the design did not work, then immediately we modified it. This has been the motto in our lab of constant discussion and improvisation, and we have used it in all our projects. I believe in a rural setup this is a good model to follow and feel that with high expectations from the staff positive and good results do take place.

We ran the plant continuously for about two years and found that for 70% of the year it could run on solar energy; for the remaining 30% (during the rainy season) it needed auxiliary heating from a wood-fired boiler.

In 1987 I presented the work on our solar distillation plant at the International Solar Energy Conference in Hamburg, Germany. The European scientists could not believe that a small NGO in rural India could set up such a pilot plant. I was interviewed on a German radio show, and the Chairman of European Economic Commission (EEC) on Bioenergy, Dr. David Hall, invited NARI to join the sweet sorghum mission of EEC. David visited NARI in 1994 and because of him *NARI became the first Indian organization in the early 1990s to become a member of EEC sweet sorghum consortium.*

We presented our work on sweet sorghum at an International Conference on Sweet Sorghum held in 1996 in Toulouse, France. This conference also gave us an opportunity to see the beautiful cities of Toulouse, Paris, Amsterdam, and Rotterdam. We rode the superfast TGV train from Paris to Amsterdam.

The pilot distillation plant gave us a lot of publicity, but an unintended outcome of the publicity was the visit of excise officials to my residence. One Sunday afternoon a jeep full of excise officials from Satara arrived at my residence and demanded to know who had given me permission to distill ethanol and threatened to put me in jail. They had read about our distillation plant in the newspapers. I informed them that this was an experimental pilot project funded by the Government of India, so we should be exempt from taking such permission; however, they insisted we had to get a state license to distill ethanol.

We asked them to give us an appropriate license, but they said that there was no provision to give a distillery license to such small experimental units, especially ones running on solar energy and using sweet sorghum fermented juice as raw material. Their rule books said that the plant should run on steam and should use only sugarcane molasses as a raw material. Such are our archaic laws which have not changed since they were formulated by the British in the early 1940s!

We approached Mr. Sharad Pawar who was the Chief Minister of Maharashtra at that time. He quickly understood the importance of using alternative crops for ethanol production and sanctioned a special license for our Institute. The license was issued in 1988 and we had to renew it every year. This proved to be quite a headache - three sets of applications with detailed attachments had to be provided every time. In 1998 the excise department took away the license, stating that since we were not running the plant, we did not need it! This was despite the fact that we were paying the license fees regularly. I guess they wanted money under the table, which we refused to give.

Because of the publicity given to this plant we had a continuous stream of visitors coming to see it from all over the country. However, when we tried to sell our technology to industries, we were not very successful; my guess is we were way ahead of time. In 1992 we almost set up India's first distillery running on sweet sorghum near Mysore. A detailed project, based on our technology, was developed by one party to distill 10,000 l/day ethanol from sweet sorghum. However the markets were not favorable and the GOI at that time did not have any policy regarding the use of ethanol for energy purposes. This was the disadvantage of being ahead of our time!

We stopped producing ethanol in our plant in the mid-1990s and dismantled it in 2000.

Now, almost 20-25 years later, there is a tremendous interest in India and worldwide in ***using sweet sorghum as an alternative crop for ethanol production*** and the use of renewable energy like solar energy for its distillation. We get a large number of inquiries about our solar plant and sweet sorghum seed. We have supplied large quantities of our 'Madhura' sweet sorghum seed in India and all over the world.

Energy security for India is a major cause of concern. We import 80% of our oil requirements and have become the 3rd largest oil importing country in the world after China and US. In the absence of local oil reserves there is a need to use suitable sugar crops and agricultural residues (India produces 600-800 million tons/year) and convert them into crude for producing chemicals and fuel. This is a challenge to all engineers and scientists.

Development of Lighting and Cooking Devices

Lanterns

In early 1980s Phaltan used to have tremendous shortage of electricity, and we often had to light hurricane lanterns at night. Coming from Lucknow and having been educated at IIT Kanpur and in the U.S., I rarely had the occasion to use hurricane lanterns. So when I used them, I discovered that their design had not changed since the early 1900s when they were introduced in India.

I started thinking of how to improve their lighting efficiency and did some preliminary experiments on the lantern. A small note on how to improve them was written and sent to Mr. K. C. Pant, Chairman of the Advisory Board on Energy (ABE), GOI. He had put me as an advisor on a couple of committees in ABE. He liked the note on lantern improvement very much since we were probably the first to suggest the use of tools of modern science and technology to improve a humble lantern.

In those days Mr. Jairam Ramesh (who later became GOI Minister for Rural Development) used to be an officer on Special Duty (OSD) in the ABE. Mr. Pant entrusted him with the task of taking forward my ideas on the improvement of lanterns. Jairam moved really fast and got me a project on improvement of lanterns for rural areas, and in 1984 we received a substantial grant for the same.

Noorie lanterns. 1988

I hired Sudhir Kumar, a fresh Ph.D. in Chemistry from IIT Bombay, to work on the project. He was a quick study and though a chemistry person, learnt the basics of engineering and fabrication and did good work. Our first task was to measure the lighting and fuel efficiency of all the existing lanterns used in rural huts. This measurement and comparison data in 1984 was probably the first such data reported anywhere and became a benchmark study on kerosene lighting, which was used and quoted by the World Bank and other agencies.

We developed quite a number of designs for improved lanterns and ultimately produced a pressurized mantle lantern called 'Noorie' (pictured above) which to my knowledge was the first real improvement in kerosene lanterns since Petromax lanterns were developed and introduced in the U.S. and Europe in 1920s.

These pressurized mantle lamps work on the principle of evaporating kerosene fuel to vapor; this kerogas is combusted to light a silk cloth mantle coated with a Thorium/Cerium (Thoria) mixture. The improvement in the Noorie lantern included ease of lighting by using kerosene as lighting fuel instead of ethanol as used in Petromax lamps; better combustion of the air-fuel mixture by designing an efficient venturi, which also resulted in lowering the pressure of the kerosene container;

improving lighting efficiency by designing a better fuel combustor; and using the heat of flue gases to cook small amounts of food.

The most important improvement was to increase the combustion efficiency of Noorie lamp and one of the ways to do so was to measure the signature of flue gases which would tell us whether the combustion was complete or not. For this we decided to purchase a Gas Chromatograph (GC).

In late 1980s, GC was a costly piece of equipment. With a grant from ABE we ordered one from Toshniwal Instruments (TI). In those days TI in Mumbai was the only Indian company manufacturing them. We asked for the quotation and then wrote to them to reduce the price by 30%! TI people were quite intrigued to get an order for GC from a small rural Institute and so a very senior manager came from Mumbai to Phaltan to discuss the purchase.

He asked me who is paying for the GC. When I told him it will come from the grant from ABE, he asked me why I was keen on reducing its price. I explained to him that if I reduce the price of GC, we can request ABE to allow us to use the saved funds under different heads of the project like fabricating more lanterns of different designs, etc.

He started laughing and told me that he sells GCs to major GOI research institutes and IITs and most of the time the concerned scientists instead of reducing the price ask him to mark it up by 20% or more! That is how the corruption took place in these labs.

I was shocked and pained to hear this and wondered what type of role model these teachers in IITs will provide and what examples they will set for the students! This was in late 1980s and I am told that such instances of corruption in these premier institutes and labs have increased manifold.

Besides the improvement in combustion and ease of use, one of the things we tried in 1986 was to improve the thermoluminescent mantle itself so as to make it strong and more efficient. I thought of using high temperature lightweight material for the mantles and new salts for thermoluminescence. We thought that the high temperature, lightweight tile materials used in the reentry space shuttle might be very useful for this purpose. I wrote to the Space Department in Bangalore, and they were thrilled that ablative material from reentry rockets would be used to improve the humble lantern. The Space Department went on to advertise the fact that space materials were being used for rural areas!

They sent us high temperature glass cloth and ceramic wool, which we tried as mantle materials. However they failed to glow when coated with thermoluminescent Thoria salts; since their thermal mass was high and hence could not attain the high temperatures necessary to produce light. We solved the problem of mantle stability by redesigning the lantern so that the impact on the fragile mantle could be minimized. This was achieved by improving the heat transfer characteristics of the fuel evaporating tube so that the extra loop of this tube, as in old Petromax lanterns, was not needed. This extra loop used to be the main culprit in mantle breakage. All these design features were incorporated in our 'Noorie' lantern.

We revisited the mantle development work in 1994 with the help of GOI Department of Science and Technology (DST) funding. The idea was to do a detailed theoretical study on how the present rare-earth coated thermoluminescent mantles produce bright light, and then to find new and better materials to replace them so as to improve their lighting efficiency. Since I did not have the requisite knowledge of solid-state physics needed for the study, we hired a senior and reputed scientist from Bhabha Atomic Research Center (BARC) as a Principal Investigator. He was a physicist and hence we thought he would be competent to help us out in this study. However he was not able to deliver the goods and we lost a tremendous opportunity to contribute to the improvement of mantles.

Besides the mantle work we also tried to reduce soot formation in kerosene. During one of my US trips I consulted my former colleague Dr. Dinesh Shah who was a professor in Chemical engineering department at University of Florida to provide suitable chemicals which could be added to kerosene so that soot formation could be reduced. The reduction in soot formation was needed so that nozzle choking in our Noorie lantern could be reduced. We tried few chemicals suggested by him, but the effort did not result in satisfactory performance. This is an area which still needs to be explored, especially for burning very cleanly kerosene or diesel in external combustion devices.

Since we were distilling ethanol at that time from our solar distillation plant, we thought of developing an ethanol version of the 'Noorie' lantern. The design of the kerosene 'Noorie' lantern was tweaked to consider the thermophysical properties of ethanol/water mixture and we were able to run the lantern on 85% (v/v) ethanol concentration. We finished the work on lanterns in 1989 and did not take up the work on lighting for households till 2004. This was because we got involved in developing a large scale sugarcane leaves gasification system, a system of detoxification of distillery waste, and electric cycle rickshaws among other projects.

Our lantern work gave us good publicity since it caught the imagination of people and the mass media by the fact that a simple lantern could be improved by the best tools of science and technology. We were therefore invited to give talks and show it at many seminars, workshops, etc.

In 1989 we were invited to show it at Teen Murti House in New Delhi in an exhibition to be inaugurated by Mr. Rajiv Gandhi, the then Prime Minister of India. I got a telegram from the concerned office just two days before the lantern was to be shown. I immediately replied with a telegram asking them to send me a helicopter! Obviously the babus in the office realized their mistake and sent me a telegraphic reply saying that I could come at my own leisure. I took the earliest available flight from Pune to Delhi, packing the lantern in a small box, which I carried as hand luggage.

In those days, Pune airport was just a tin shed and the Indian Airlines flight to Delhi was in the evening. As I was standing in line to get the boarding pass, the electricity at the airport failed. The whole airport became pitch dark, and the airport staff ran helter skelter to get candles since there was no electricity generator at the airport! I went to the Manager of Indian Airlines and told him that our 'Noorie' lantern could light up the whole airport provided we got kerosene! He obviously told me that it was not possible to do so.

Another time we were approached by the local shepherds to give them a lantern to keep the wolves away from the sheep at night. We provided them with a couple of lanterns, which seemed to serve their purpose. Our lantern was 15-20 years ahead of time and came much before the Solar LED lanterns which are in vogue today.

We also shipped quite a few of these lanterns to California in 2000 since some Americans were afraid that the Y2K problem would cause all the facilities to collapse, and they wanted to stock a reliable lighting device. Our 'Noorie' lantern seemed to have caught their imagination.

We tried hard to sell the technology of 'Noorie' to vendors and manufacturers in India. Most of them wanted to take a sample and see what they could do and were not interested in technology transfer. In the early 1990s Union Carbide (India) became interested in taking up our technology but I guess they got burdened by the problems of the Bhopal Gas Tragedy and so dropped the project.

Even today there is a tremendous shortage of electricity in rural areas and hence we feel that for quite a number of years from now on an efficient liquid fuel lantern can play an important role in providing adequate light to rural huts.

Cooking devices

Alcohol stove

In 1983 my good friend and fellow IITian Mr. Anil Agarwal, a well-known environmentalist who started the Delhi based NGO called Center for Science and Environment (CSE), invited me to Delhi for a conference/workshop on cooking energy needs. This workshop gave me good ideas on the needs and problems of rural cooking energy and on what could be done in this field.

After my return from the conference I thought that a modified Janata cooker would make a good rural cooking device. These slow steam cookers which were in vogue in north India in the 1950s and '60s used to run on charcoal. We experimented in our lab on these cookers (they worked on the heat pipe principle) in the early 1980s and tried to run them on wood and kerosene. One of these cookers (pictured),

manufactured in large numbers in the early 1950s in Delhi and sold all over the country, was used extensively by my mother in the 1960s.

In 1984 I got an old cooker from our Lucknow house and tested it to see its efficiency and how it worked. We developed complete performance parameters of these cookers running on kerosene and wood. This preliminary work on Janata cookers helped us to later develop them for the ethanol Lanstove™.

Our work on Janata cookers, published in NARI's first energy booklet in 1986, was the first attempt anywhere to characterize their performance. We feel that this work helped the development of Sarai and Bachat Cookers in the late 1990s.

In 1994 we hired a fresh Ph.D. in materials science from Uttarakhand for our mantle work. Anytime we hired scientists I used to ask them about the problems faced by rural folk in their area. He said that the biggest problem was distillation of illicit alcohol in the hilly regions of Uttarakhand. The men brewed it, drank it, and then beat up their wives. The women had to walk quite a distance in the hilly regions to collect wood for cooking. I thought if we could create a stove which would use this low concentration ethanol (almost like vodka!) for cooking then the men may not drink it and the women would not have to walk 5-10 km to collect wood. This might kill two birds with one stone!

Besides taking care of the drinking problem, another reason we worked on low concentration ethanol was its safety as household fuel. Pure ethanol is a very inflammable and extremely hazardous fuel. By diluting it to 60% ethanol/water mixture it becomes safe fuel for cooking and lighting.

Since we had already worked on a low concentration ethanol stove in the early 1980s, we revived that surface evaporation design, but found that even after complete burning of ethanol there was still 15-20% ethanol left in the mixture as it could not be evaporated. This was quite a waste of precious ethanol. We realized that somehow the whole mixture had to be evaporated and the ethanol combusted. For a couple of years we worked on the design of the system to evaporate the mixture and burn the ethanol. In 2003, after we were convinced of the efficacy of our design, we wrote a proposal to the Ministry of Non-conventional Energy Sources (MNES).

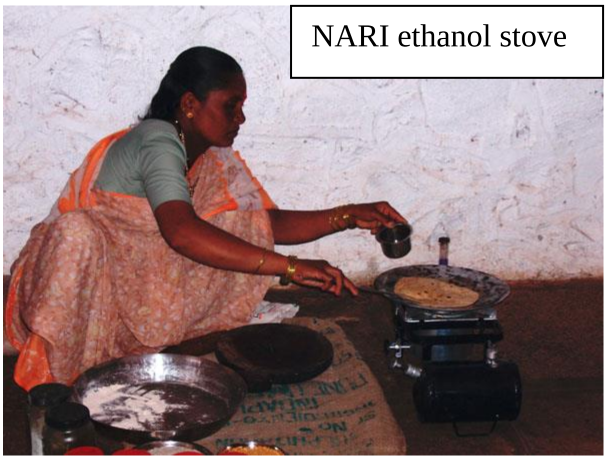
For most of our projects we have first done the preliminary work in our lab, and only after we believed that the design would work, did we write a proposal for funding agencies. This strategy has always borne fruit. The project money then allows us to tweak and optimize the design.

In 2004 we started work on developing a low-concentration ethanol stove for rural areas and finished it in 2006. To our knowledge this was the first serious effort anywhere in the world to develop a stove which could run on the illicit liquor (~60% ethanol/water mixture) that is produced in rural areas.

In 2003 I had published a paper on the strategy of cooking and lighting for rural areas. This paper, based on our work and experiences in cooking and lighting, elicited tremendous response worldwide and helped start international efforts on a fan powered woodstove (Philips and Oorja stoves) and the use of ethanol for cooking and lighting (in Africa and Latin America). One of the key recommendations in this paper was to set up a national mission in cooking and lighting.

Early in 2004 I went to New Delhi to meet Mr. K. C. Pant, who was at that time vice chairman of the Planning Commission, GOI, and apprised him of our work. He liked the idea of a cooking and lighting mission, and I was invited to address the rural energy group in the Planning Commission. The outcome of this meeting was a policy document to take this idea forward. Unfortunately by May 2004 the BJP Government fell and the new Planning Commission under the UPA had other ideas! The national mission on cooking and lighting is still in limbo; it needs to be revived so as to provide the basic necessities of life for 60% of our rural population.

In any case we developed our low-concentration ethanol stove in 2005. We tested it for a year by asking all the farm laborer women in our Institute to use it to cook. All the women used it by turn to cook a complete meal for a family of four or five. We collected the necessary data and discovered that almost all the women liked it. However, the use and storage of low concentration-ethanol required an excise license, and this proved to be a problem. In 2012 we sold the technology of this stove to a company in Indonesia, where the laws on use of ethanol in the household sector are much less stringent than in India.


NARI ethanol stove

This unique low-concentration ethanol stove helped spawn a number of international efforts in developing alcohol stoves for cooking. An alcohol stove program in Africa called GAIA, funded by the World Bank, probably came about as a result of our work.

As we were testing our alcohol stove, a couple of women suggested that this ethanol should also be used for lighting purposes. We had already done some preliminary work on an ethanol lantern running on 85% (v/v) ethanol-water concentration in 1989 and thought of extending that work to make a lantern run on 50-60% (v/v) concentration. We wrote a proposal for the Department of Science and Technology (DST), GOI in 2007 and developed the necessary lantern by 2009.

We tested this lantern in many huts without electricity near Phaltan and it was appreciated by the users. They suggested that instead of filling ethanol in a small tank and continuously pumping it, as was done in the existing Petromax lantern design, a better design would be one with fuel storage as in LPG cylinders, where with a flick of the valve the fuel (in this case low concentration-ethanol) would flow and could be ignited to light the lantern.

Lanstove™

During our kerosene and ethanol lantern work we had realized that the heat of flue gas could do a small amount of cooking like boiling eggs, making tea, etc. We thought of increasing the power of the lantern and using a modified Janata cooker to cook a complete meal for a family of four or five. This made the mantle lantern devices very efficient because heat, which was wasted before, was now used for cooking.

We used both the above suggestion and the idea and embarked on the design and development of an alcohol Lanstove™. This lanstove (lantern + stove) gave excellent light and cooked a complete meal for a family of five. For this invention we were given the prestigious Energy Globe Award in Stockholm in 2009.

Alcohol lanstove with modified Janata cooker

The Energy Globe Award gave us lots of publicity both in print and the mass media. A good outcome of this publicity was that the Secretary in the Ministry of New and Renewable Energy (MNRE) wrote to me asking how the GOI could help in this project! I went to New Delhi and told him that we would like to put this lanstove in about 50 huts. He immediately agreed to the suggestion and asked me to write a proposal.

From my previous experiences with the Excise Department regarding the distillation and use of ethanol for household purposes, I thought it would be better if we discussed this issue with them first before writing a proposal.

The Excise Commissioner told us that, according to the existing law, each hut where we would put our ethanol lanstove would have to have an alcohol license. Getting an alcohol license in India is a nightmare due to the large number of archaic rules, and it is probably easier to go to the moon!

He also added in a matter-of-fact way that if by chance any of the users drank this denatured alcohol and died, he would put us in jail for three months without any questions asked!

On the one hand we were trying to get these poor people a good lighting and cooking device and improve their quality of life, and on the other, the archaic government laws made it impossible for us to proceed. When we mentioned this to the MNRE, they said they were helpless in this matter since excise was a state subject!

Kerosene lanstove

We therefore decided to abandon our alcohol lanstove project and went back to the drawing board and designed it to run on kerosene instead. Almost everybody commented on why we were going backward from clean renewable fuel like ethanol to dirty fossil fuel like kerosene.

Kerosene lanstove

Most people do not realize that all fuels are dirty, and it is only the combustion process which makes the fuel clean or dirty. Our kerosene lanstove (pictured) produces only 4-5 ppm carbon monoxide (CO) levels in huts and burns with no smoke. Its particulate emission levels are equal to those from an LPG stove and hence it is as clean as an LPG cooking device. Besides Life Cycle Analysis (LCA) done on it showed that it was nearly five times more efficient than electric lighting and cooking!

In order to measure the particulate emissions from our lanstove we developed a very simple device to measure soot. The device works on the idea of collecting soot on a metal plate and then measuring the reflection of light from this plate using a smart phone. The reflected light is correlated with the amount of soot collected. We believe that this device is simple to use and very cost effective. Presently the soot determination methods use very costly particulate counters, are tedious, and use sophisticated labs to do it. We feel that our soot measurement device can also be used to evaluate soot production from biomass and other cook stoves used in rural huts. We have not patented it and have made it available free for anybody to use it.

Since our lanstove is a mantle type lighting device it produces good amount of heat via radiation. There is a great scientific and technological challenge to produce glass for these lanterns which can block all the heat. This will produce cool light and make the cooker even more efficient since all the heat wasted by radiation will go into flue gas for cooking.

One great advantage of ethanol is that it can be produced locally whereas kerosene has to be imported and is a product of fossil fuels. However, technological development worldwide is rapidly progressing and in the near future it may be possible to produce kerosene-like fuels from agricultural residues and other biomass. Kerosene will then become a renewable and clean fuel for rural households.

With the help of DST funding in 2011 we successfully put 25 kerosene-powered lanstoves in rural huts in four villages around Phaltan and tested them for one year.

One of the biggest challenges we faced in this project was the availability of kerosene. This was primarily because of two reasons: firstly, the GOI has limited the quota for poor people to just 5 liters of kerosene per family per month. This is a ridiculously low amount and cannot provide enough energy either for cooking or lighting in rural huts.

Secondly, most of the kerosene is siphoned off for adulteration of diesel because kerosene is much cheaper than diesel (it is highly subsidized by GOI). This results in the Public Distribution System (PDS) shops not giving it to the poor people since PDS shop-owners make more money by selling kerosene in black.

For our project we got special permission from the Collector of Satara to give an extra quota of kerosene to the beneficiaries but that dictat was continuously flouted by the lower staff and PDS shops on one pretext or another with the result that the poor hut dwellers never got the enhanced quota. This has limited the use of these devices in these unelectrified huts.

I wrote about this to the powers-that-be and also wrote an article on the whole issue of kerosene for rural poor. This article was picked up by the press and syndicated all over the world. I feel that it may have had some effect because now the Government of Maharashtra has opened up the kerosene sales at least on paper. Hopefully this will ease the availability of kerosene to poor people.

We believe that the present total kerosene consumption in India, if used through our lanstove, has the ability to provide a quantum jump in the quality of life of around

180 million people. Unfortunately GOI is phasing out kerosene completely and so we have modified our lanstove to work on diesel- which is available everywhere in the country. Diesel lanstove is even better than kerosene lanstove in terms of combustion and efficiency. We are now actively making efforts to sell this lanstove technology to interested entrepreneurs.

Clean Water Initiative and Rural Restaurants

When we started our work on testing ethanol lanstoves in rural huts we saw that one of the biggest causes of diarrhea and bad health of these hut dwellers was their use of dirty drinking water. We therefore embarked on a small program of developing simple and low-cost technology for sterilization of water using our lanstove.

By filtering the dirty water through four layers of cotton saris or eight layers of synthetic saris (the type normally worn by village women) and then heating the water to 60^{o}C for 10-15 minutes, we were able to completely deactivate all the coliforms from the water and make it fit to drink. The details are given in Chapter 5. An article on this was syndicated worldwide.

Thus our lanstove not only gives excellent light and cooks a complete meal for a family of five but also makes water fit for drinking. We feel that no single device presently available can do all these three things simultaneously.

We also found that most of the women who work as farm laborers come home very tired after working in the sun the whole day. They neither have the energy nor the mood to cook. Besides, they buy rations on a daily basis from the PDS shops, which often do not have adequate rations in stock. The amount and quality of food that these people are forced to eat leads to malnutrition and subsequently to poor health. We developed a concept of rural restaurants where it is proposed that the poor get subsidized meals and the GOI provides good financial incentives for running and starting them. A paper on it was syndicated and published all over the world and we feel may have inspired the concept of 'Amma kitchens' in the southern city of Chennai. Recently Government of Maharashtra has started Shiv Bhojan for poor people and we feel that it is even more close to our model.

Future Research Areas

While working with these poor hut dwellers we realized that most of them possess mobile phones and because of non-availability of electricity have to travel 10-15 km to the nearest town to charge them. For them, these phones are not only a means of communication but also entertainment. The hut dwellers listen to music on the radio and some enterprising ones also watch movies on the tiny screen. We felt that with a suitable low-cost thermoelectric device (TE) attached to the lanstove we should be able to charge these phones. This is a challenge which needs to be taken up.

Another challenge is to provide a low-cost refrigerator and a fan. Quite a number of hut dwellers do not have goats and hence they buy milk for tea. The leftover milk gets spoilt unless it is heated repeatedly. This is wastage of fuel. They also cook only once a day and need to store the leftover food. Thus a small low-cost refrigerator will go a long way in improving their quality of life.

Similarly, an efficient fan which moves maximum air with minimum power so as to maximize m^3/W would provide excellent comfort cooling in rural huts. Both the fan and the refrigerator can run on TE devices which convert heat directly into electricity. The challenge is to develop very efficient TE systems. Small refrigerators running on absorption principles which require heat to run them can also be developed.

Still another challenge is to produce biogas economically and very efficiently from agricultural residues and to store this gas just like LPG at moderate pressures in a suitably designed gas cylinder. Development of such a technology can revolutionize rural cooking and lighting.

Some futuristic ideas for household energy are:

1. Identification of a molecule which will dissociate into two with solar energy and when combined later on produce light.
2. Duplication of firefly principle of producing light. Thus chemical energy of molecules is directly converted into light.

3. Production of a material which will combine photovoltaic and Peltier effect to produce direct cooling and electricity by solar energy. It may be possible that energy from solar photons and heat from the room may combine to put the electrons in the device from valence band to conduction band producing both electricity and cooling.
4. Development of glass which reflects Infrared (IR) radiation so that only visible light is transmitted. This will produce cool light from lanstove. Recent researches have shown that it is possible to do so.
5. Development of chemicals to reduce soot formation in kerosene and diesel.

Finally, we should realize that the rural poor do not have a single neuron less than any of us; with their aspirations fuelled by the mass media they too want to improve their quality of life. This can be done by developing and providing suitable devices for the household. I feel the mantra of rural development should be **'Improve the quality of life one hut at a time'**. It is a great challenge to all engineers and technologists and if we can take this up then not only would we have helped create a great India but also helped 1/5th of mankind.

Team members

1. Solar distillation of ethanol: Anil K. Rajvanshi, Rajiv M. Jorapur
2. Noorie lantern: Anil K. Rajvanshi, Sudhir Kumar
3. Janata Cooker: Anil K. Rajvanshi, M. S. Joshi
4. Alcohol stove: Anil K. Rajvanshi, Yusuf Shaikh, S. M. Patil, and B. Mendonca
5. Alcohol lantern: Anil K. Rajvanshi, S. M. Patil
6. Kerosene lanstove: Anil K. Rajvanshi, S. M. Patil, K. S. Jagtap
7. Soot measurement device: Anil K Rajvanshi, Etienne Gayet (French intern), and K.S.Jagtap

These members were ably assisted by our technical staff of D. B. Jadhav (deceased), A. M. Pawar, D. B. Gadhave and R. S. Bale. Innumerable foreign interns have helped in lanstove projects since 2005.

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