Lessons from the Pura community biogas project

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Based on a description of almost a decade of experience of the community biogas plant project in Pura village (South India), an overview is presented of the lessons to be learned and the challenges for the replicability of such systems. An indication is also given of the long-term sustainability of such rural energy systems.

1. Background

The community biogas plant project in Pura village[1] (about 120 km from Bangalore in Tumkur district of Karnataka state, South India) has a long history. The in-depth study in 1977 of rural energy consumption patterns [ASTRA, 1982] identified cooking as the main energy end-use and fuelwood as the dominant energy source. Contrary to the then prevailing view that dependence on fuelwood for cooking was the main cause of deforestation, it was found that women and children, the main fuelwood gatherers, concentrated on fallen twigs and branches, rather than logs from felled trees. Nevertheless, fuelwood was associated with a number of problems – the labour and time spent by women and children gathering the fuelwood, the indoor air pollution caused by the smoke from the fuelwood stoves, etc. An alternative to fuelwood was desirable and, in this context, biogas by the anaerobic fermentation of cattle dung-was highlighted [Prasad et al., 1974]. This paper argued for community plants (as preferable to the prevailing approach of family-sized plants) because not all households (1) have cattle and (2) can afford their own plants. There were also the economies of scale (a community plant for 56 households was estimated to cost only about 6 times as much as a family-size plant). A detailed proposal for a community biogas project was formulated [Reddy et al., 1978] and accepted for funding by the Karnataka State Council for Science and Technology.

2. First phase of the project

During the first phase of this project, which started in 1978, the attempt was to provide all the households of the village with biogas for cooking. In addition to two community-scale biogas digesters (of 4.1 m diameter and 4.2 m depth) constructed with the "floating drum" design, a biogas distribution network was laid down to enable the piping of biogas to specially designed burners supplied to all the houses. The adequacy of the gas supply depended on the size of the families – the smaller families with less than 5 members (constituting the majority of the households) could finish their cooking. In contrast, a minority of households with large families (and large cattle-holdings) could not complete their cooking tasks even though they were the predominant dung suppliers. Averaging over the whole village, the total gas yield turned out to be sufficient only for cooking *one* meal. The inadequacy of gas was not because of poor collection of the available dung – in fact, plant operators would go to all the cattle-sheds in the houses with a wheelbarrow, weigh the dung and bring it for processing, leading to dung collection efficiency of over 90 %.

The shortfall of gas supply with respect to demand was because of two reasons. Firstly, there was an overestimation of cowdung resources – the house-to-house dung survey was carried out after the rains in November whereas the availability of cowdung from free-ranging cattle varies with the season (and grass cover). (Figure 1 shows the monthly variation in the dung collection while Figure 2 shows the monthly variation in the rainfall.) Secondly, there was an underestimation of biogas requirements because the estimation (starting from fuelwood consumption) is sensitive to the efficiencies of fuelwood and biogas stoves, which had not been accurately measured at that time. The cooking gas phase of the project lasted more than one year before coming to a standstill in 1984. It *inter alia* demonstrated the willingness of the cattle-owning families to share the dung-derived biogas with cattle-less poor families provided the nitrogen-rich sludge was returned in proportion to dung contribution.

In retrospect, it appears that the low cattle-human ratio was the main barrier to meeting all the cooking energy needs of the village. It is conceivable, however, that villages with large cattle-to-human ratios (or with moderate ratios and stall-feeding arrangements) would be able to develop successful biogas-based cooking energy schemes more easily. Fortunately, after a few months, the villagers petitioned to restart the project with an emphasis on generating electricity from the biogas to pump drinking water and light homes. Though these end-uses together require only a fraction of the energy required for cooking, they correspond to a dramatic improvement in the quality of life.

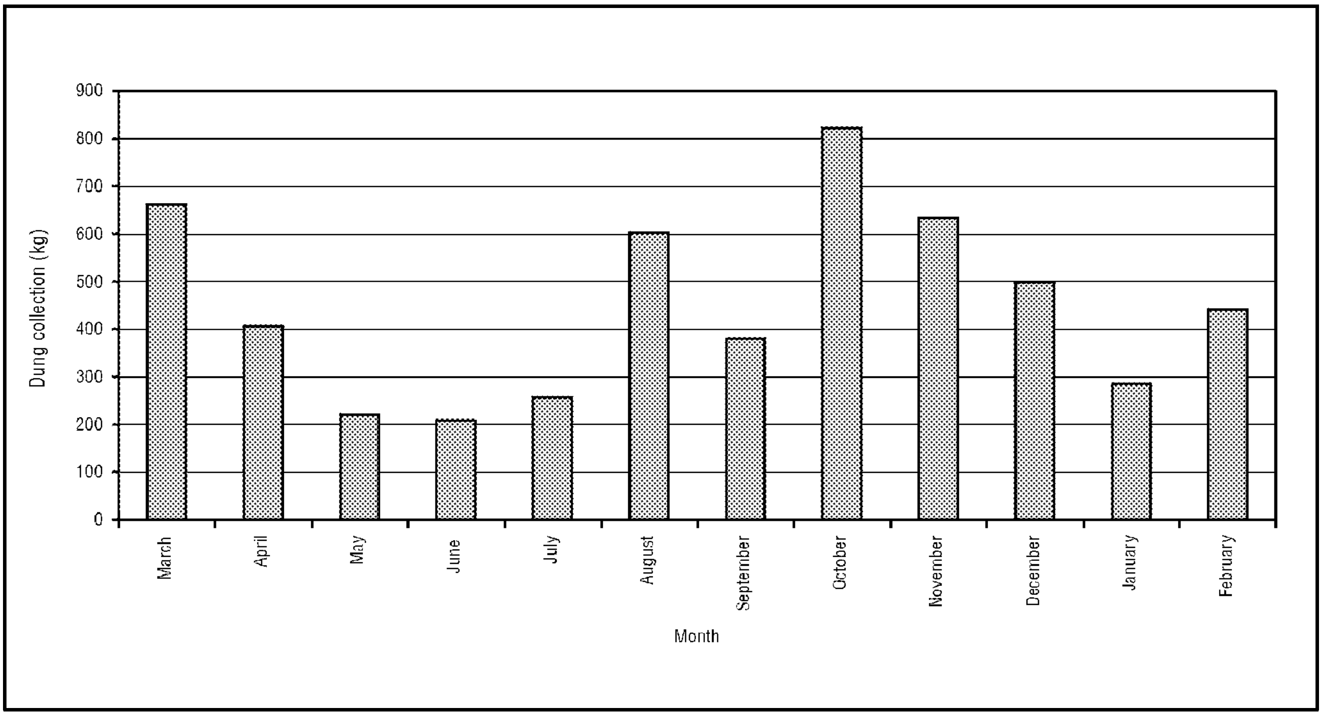

Figure 1. Dung collection in kg, monthwise from March 1982 to February 1983

Quite apart from the particular experience in Pura village, in general, the cattle-human ratios in that part of India do not correspond to sufficient biogas to meet the cooking needs of all the households in a village[2]. Thus, *biogas from free-ranging traditional cattle cannot meet all the cooking energy requirements of villages unless there is a substantial increase in the cattle-human ratio and/or there is a shift to stall-fed larger/hybrid cattle.*

3. Second phase of the project

In the second phase of the project, the scheme consisted of the villagers supplying cowdung to the biogas plant where it would be anaerobically fermented to yield biogas that would fuel a modified diesel engine that in turn would run an electrical generator. The electricity thus produced would run an electrical submersible pump in a tubewell and lift drinking water for the village, and in addition be supplied to the households to provide electrical illumination (Figure 3).

The same two community-scale biogas digesters used in the first cooking phase of the project were also utilised for the second phase. The maximum design input to the plants is 1.25 tonnes (t) of cattle-dung mixed with 1.25 m^3 water per day. The plants can produce, at an average ambient temperature of 25-26ºC, a maximum of 42.5 m^3 biogas per day (approximately 60 % CH_4 and 40 % CO_2). In addition to the gas, the charging of the dung plus water slurry would displace about 2.45 m^3 per day of digested slurry, which yields after removal of the water by filtration about 1.2 t/day of sludge. This slurry which contains 3.6 kg (2.2 %) of nitrogen – the same amount of nitrogen as in the input – was returned to the villagers in proportion to the dung that was supplied.

A 7-horsepower (7-hp, 5.2-kW) water-cooled biogas-diesel (dual-fuel) engine was installed in an engine room (5.05 m × 3.5 m) located at the edge of the village next to the fields. The biogas from the biogas plant passes through a condensation trap and then enters the engine where it is supplemented with diesel to run the engine. The engine is coupled to a 5-kVA 440-V three-phase generator to enable the operation of a three-phase submersible pump.

The *water supply* system (which started operation in September 1987) consists of a three-phase, 3-hp (2.24 kW) 6.75 m^3/hr submersible pump fitted into a tubewell. This pump lifts water from a 50-m depth to an overhead tank. The water is then distributed by gravity through nine street taps in the village. One of the taps is for livestock and one tap is in the biogas plant compound. In addition, there are 29 private taps inside the households.

The *lighting system* (energised in October 1988) consists of 103 20-W fluorescent tube-lights – 97 in homes, two at a public temple, and four in the biogas plant complex. 47 houses elected to have one tube-light and 25 have two. The life of the tube-lights was found to be between 1580 and 1957 hours on the basis of the empirical experience of replacing 58 tube-lights from August to December 1990.

In a sample period from September 1987 to April 1991 (44 months), the biogas-driven engine ran for 4,521 hr – 2,211 hr for supplying water and 2,310 hr for providing electrical lighting. The average daily operation time has been 4 hr 9 min – 1 hr 40 min for water and 2 hr 29 min for lighting.

This modified scheme was successfully operated by the villagers for almost a decade. The innovative institutional and management systems leading to a new "The blessing of the commons" paradigm [Reddy, 1995] made the project one of the few successful community biogas plant projects in the world at that time. The project became

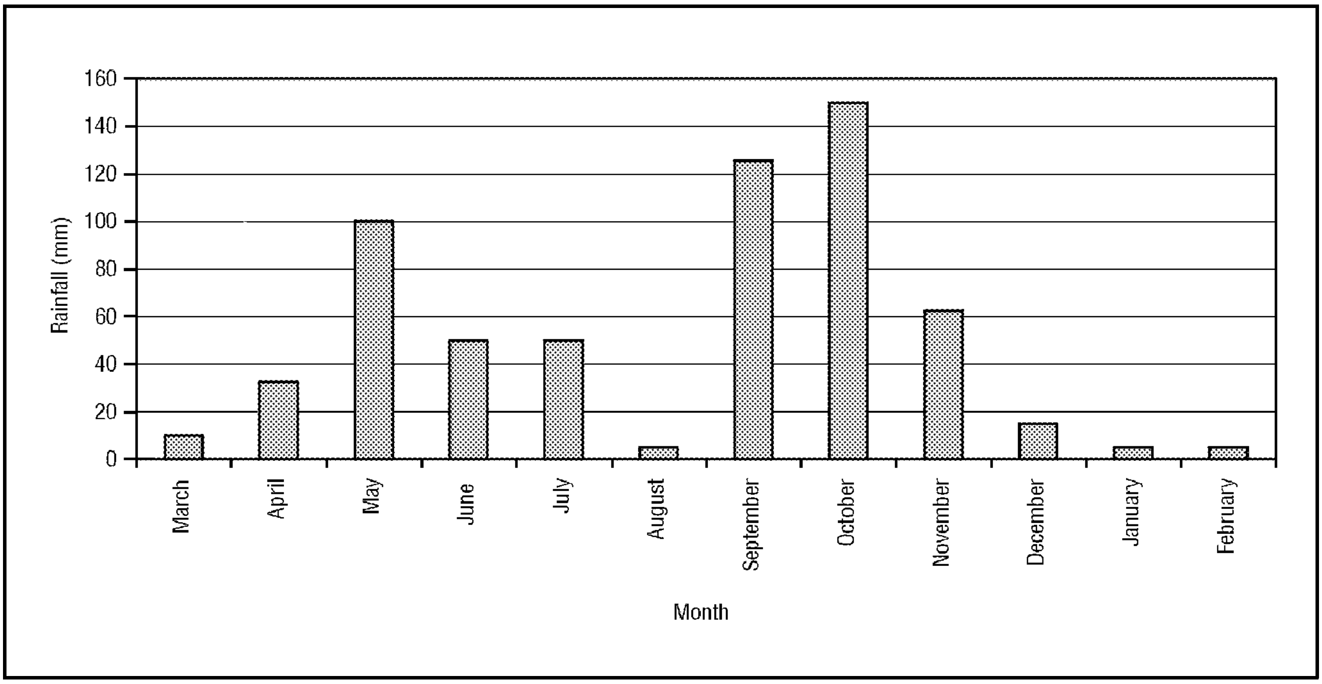

Figure 2. Rainfall in mm, monthwise from March 1982 to February 1983

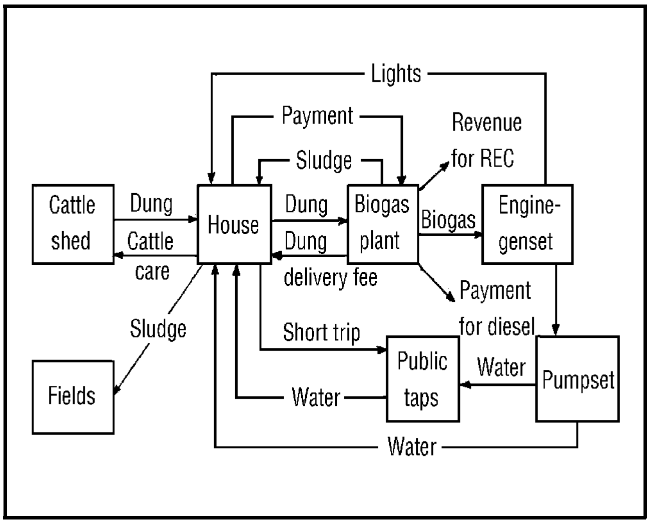

Figure 3. The community biogas plant system at Pura

Source: Reddy, 1995

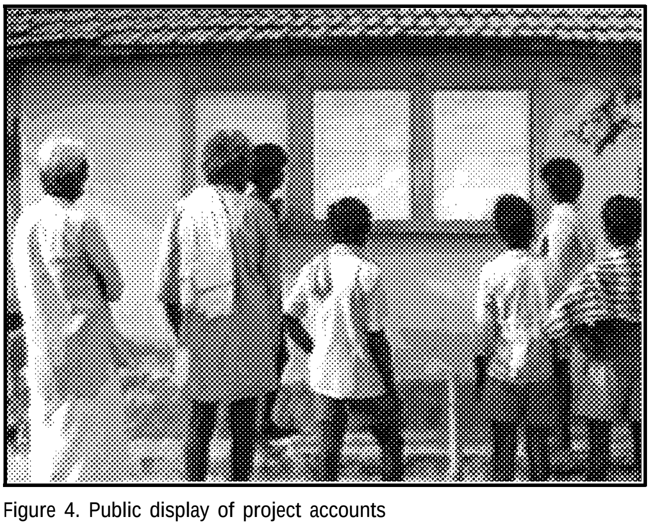

Figure 4. Public display of project accounts

well known for the following reasons. The Pura experiment was widely cited and described at the international level[3]. Pura has been visited by the head of UNDP, World Bank teams, several Chief Secretaries of the Government of Karnataka and about a hundred scientists who attended the international BioResources '94 conference in Bangalore (in 1994). The technical and economic performance from 1987 up to 1996 has been documented in great detail [Rajabapaiah et al., 1994; Reddy et al., 1994]. The rigorous financial and economic (social cost-benefit) analysis has been peer-reviewed by economists in India and abroad.

For almost a decade, the villagers sustained the operating and maintenance expenses of the plants with over 90 % of the households making payments for lighting and water. The tariff levels were set by a process of open meetings with the villagers (involving a one-to-one interaction between scientists and village communities with both sides having questions and answers). These meetings were based on a public display (Figure 4) of the household-wise number of fluorescent tube-lights and drinking water taps and payments to the project as well as daily dung contributions.

Noteworthy, for policy purposes, is the fact that all the households showed a sustained willingness to pay[4]. In the case of lighting, the tariff was actually less than the household expenditure on kerosene lamps, even though far more per kWh than urban electricity tariffs. In the case of drinking water, villagers tended to prefer priced safe (tubewell) water to free unsafe water from an open pond.

Despite the above success, the Pura community biogas plant system was terminated[5] between November 1997 and March 1998, for non-technical reasons beyond the purpose of this note. The Project Assistants working on the system were transferred out and the operations of the plants were closed down. The plants with all their assets were handed over to a new body whose approach differed from the Pura approach of waste utilisation, participatory management, building of local institutions and strengthening of self-reliance.

Attention will now be focused on the factors underlying the decline of the project, as well as some major problems associated with the replicability of the model on a wide scale. It is intended that the lessons learned are generalizable to other contexts.

4. Immediate reasons for the decline

1. Even during its heyday, the surplus of revenue over operating expenditures was only sufficient to allow for *minor* (routine) repairs and maintenance. With the 3.6 times escalation of diesel price (from Rs. 4.25 per litre, l, in January 1989 to Rs.15.20/l in September 1996) and 2.6 times increase in wages (from Rs. 11.00/day in September 1987 to Rs.28.55/day in August 1993), the system required external financial inputs to withstand *major* repairs such as engine overhauling or the lifting of the submersible pump that falls into the tubewell. Thus, when these inputs for major repairs were not forthcoming in November 1997, the system ground to a halt.
2. There was also a radical change in the decision-making process from community-based participation at the village level to top-down management by project administrators located over 100 km away in the metropolis of Bangalore. The villagers reacted to this abandonment of participatory management by withdrawing their co-operation.
3. An example of the rise of top-down decision-making was the imposition of tariff increases without community participation and approval. In the case of urban electricity or water, the consumers cannot do without the services (and therefore the elasticity of demand is largely inelastic with price); so, they protest/revolt by agitation to resist tariff increases. In contrast, the villagers of Pura always had the option of withholding the crucial input of dung without which feedstock the system cannot run. Even the termination of the services of electric lights and drinking water only meant that the villagers (unfortunately, the greastest impact is on women) had to revert to the pre-project situation of kerosene lamps and unsafe water from the open pond.
4. Finally, a change of feedstock from a biogas source for the dual-fuel diesel engine-cum-generator to vegetable oil from *Pongamia pinnata* seeds was imposed on the village. This drastic change was implemented without adequate reliability studies of the long-term performance of these engines with the new feedstock and without assured supplies of the feedstock at stable prices. One problem with bioresources is that their competing uses act as a pressure on prices, which can therefore escalate and undermine the economics of the bioresource-based energy system[6]. Furthermore, the technology change was implemented without creating widespread awareness among the villagers and securing their endorsement and approval. Thus, the project took the retrograde step of replacing a proven and accepted technology with an unproven and imposed technology[7].

It is clear that the difficulties described above are very significant, but none were irremediable. For example, the escalation of costs could easily have been explained to the villagers through the established practice of publicly displaying charts of expenditures and presentations at open village meetings. The project could also have countered the increased costs (of diesel, labour, etc.) by securing approval for increased tariffs. Major one-time repairs could have been handled with special financial inputs[8]. The high levels of participation and involvement of the villagers in techno-economic issues could have been continued to raise the performance of the system and overcome the difficulties. Whereas new locally available feedstocks are an attractive alternative to the diesel "imported" into the village for dual-fuel operation, the logical first step would have been to run laboratory trials of biogas-vegetable oil mixtures for the engines before replacing the biogas entirely.

5. Replicability of the Pura model

But even the above solutions to the immediate problems do not address three major obstacles to the widespread replicability of Pura-type biogas-based rural energy systems.

5.1. Relationship with government

In order to distinguish itself from the conventional government-run approach to rural projects, the technical team from the Indian Institute of Science, Bangalore, responsible for the Pura project functioned in a distinctly different manner. From the beginning they worked like scientists from an institution of education, science and technology who wanted to assist villagers to help themselves in a bootstrap operation to achieve self-reliance. Towards this end, they deliberately maintained a distance from the government and its departments. This approach was eminently successful in earning credibility and the respect of the villagers. However, the long-term success of this approach hinged on the government avoiding schemes that would interfere with and undermine the approach of the project.

The situation changed drastically when the government started implementing World-Bank-funded "free" water-supply schemes that undermine sustainably priced biogas-plant-system water supply. It is too much to expect that the long-term advantages of sustainability and self-reliance would overcome the immediate attractions of free supply of the same quality of water to villagers. From this point of view, *government-subsidised unsustainable projects with "free" services are inimical to the establishment and continuation of sustainable projects with fees for services.*

5.2. Distribution systems for water and electricity

The economics of the Pura energy system were such that the revenues were sufficient to pay for the *operating* costs of the system even at the 4 hr/day (16.66 %) of utilisation of the system. Greater utilisation of the system would also ensure the repayment of the principal and interest (at conventional rates) on the *capital* cost of the biogas digester and the engine-generator. But, the investment on the drinking water and electricity *distribution systems* requires either a grant or a "soft" loan (i.e., what is referred to in general as "concessional financing") with the justification that they are development-oriented infrastructural investments. Thus, *concessional financing for the investment on the water and electricity distribution systems is a necessary condition for the replicability of the Pura model. Such (perhaps government-assisted) financing can be justified on the grounds that sustainable clean-energy projects lead to public benefits otherwise forgone.*

5.3. Greater utilisation of the system required

The Pura project showed that greater utilisation of the system was essential to ensure the repayment of the principal and interest (at conventional rates) on the capital cost of the biogas digester and the engine-generator (that together account for roughly half the total capital cost of the system). It is important to note that the barrier to this greater utilisation was not an inadequacy in dung supply, i.e., there was no dung supply constraint – the operation of the Pura system for about 4.15 hr/day corresponds to a dung supply of 291 kg/day in comparison with the daily dung availability of about 1,250 kg/day (from a cattle population of 250 each yielding 5 kg of dung/day). Hence, only about 23 % of the dung resources were actually utilised. Interestingly, the villagers resisted greater supply perhaps because they could see that more dung supply to the plant would lead to unutilised gas that would be released into the atmosphere in the absence of greater demand. Thus, the low utilisation of the plant was because of a *(biogas) demand constraint* arising from a restriction of biogas utilisation to lighting and water for domestic purposes. From this point of view, attempts to increase dung supply (for instance, by linking the system to dairy schemes) are misdirected.

In retrospect, it is unfortunate that the Pura project did not incorporate a multipurpose platform of the type subsequently disseminated in Mali [UNDP, 2001]. There, an Indian diesel engine (of the same type used in the Pura community biogas plant project) is the basis of a platform that could power various types of equipment such as a cereal mill, husker, battery-charger, welder, and carpentry machine. *Such a proliferation of applications is necessary to increase the utilisation of the system and therefore improve its economics.*

6. Conclusions

The Pura experience shows that there are several conditions for such rural energy systems to be replicable and sustainable[9]. The issue is very important in view of the ongoing discussion about rural decentralised sources for village electrification, and many of the lessons are relevant for clean cooking projects.

- The establishment and continuation of sustainable projects with fees for services should not have to compete with government-subsidised *un*sustainable projects with "free" services.
- "Concessional financing" is required for the investment on the water and electricity distribution systems (about half the total capital cost in the Pura case). Though this point is specific to Pura, that concessional financing may be required (and can be justified on public benefits grounds!) is an important general one.
- There should be proliferation of applications (for example, through a multipurpose Mali-type platform) to increase the utilisation of the system beyond drinking water and home lighting, and therefore to improve its economics – the provision of biogas cooking fuel may be one of these extended applications.
- The project team has to be committed to decentralised energy systems based on utilisation of local resources.
- There must be strong technical back-up.
- Participatory management is essential.
- Local institutions must be built and self-reliance must be strengthened.
- The energy system must be outside the domain of intra-village factional conflicts[10].
- Whereas pilot/demonstration projects require the intimate involvement of a committed non-governmental organisation to seed early successes, it is conceivable that a combination of social momentum – nearby villages "learning" from others (see, for example, the experience of www.wotr.org) – will help reach the linear section of the S-curve relatively quickly. Large-scale replication, however, depends on entrepreneurs or an entrepreneurial agency. For example, a village committee could "lease" out building, operations and billing rights to energy services company (ESCO)-like enterprises with contractual obligations to serve. Women's microcredit or self-help groups could well have a major role to play in this challenge. ■

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Notes

1. When the project was designed, Pura village (latitude 12º49′00″, longitude 76º7′49″, height above sea level 670.6 m, average rainfall 50 cm/yr) had, in September 1977, 56 households, a human population of 357 and 189 head of cattle.
2. Pura's firewood consumption of 1.67 kg/person/day yields 2650 kJ/person/day for cooking at 15,900 kJ/kg firewood and 10 % efficiency of the traditional stove. To achieve the same heat output from a 60 % efficient biogas stove with a biogas calorific value of 22,320 kJ/m^3 produced in a biogas plant yielding 0.034 m^3/kg wet dung from cattle producing 5 kg wet dung/day, the cattle-human ratio must be at least 1.16. In fact, it is only 0.53 -- roughly half the required value.
3. Papers on the Pura project have appeared in books such as *Renewable Energy: Sources for Fuels and Electricity* [Rajabapaiah et al., 1993] and UNDP's *Energy as an Instrument for Socio-Economic Development* [Rajabapaiah et al., 1995]. Chapters/ sections/ boxes on Pura have appeared in the World Bank book on *Rural Energy and Development for Two Billion People* [World Bank, 1996] and the UNCHS book entitled *Application of Biomass-energy Technologies* [UNCHS, 1993]. The project has been highlighted in the Boston WGBH television series *Race to Save the Planet* and in IEI's video *Empowerment of Pura.* Papers on Pura have been the basis of workshops such as the November 28-29, 1994, Workshop on Biogas Technology for China in Beijing, China [Rajabapaiah et al., 1994; Reddy et al., 1994], and the workshop on February 24, 1995, in Bangalore to discuss the replication of Pura-type rural energy and water supply utilities (REWSUs) in Karnataka.
4. It is important, however, that villagers should not be forced to pay for unproven experiments; they can be asked to pay for what they receive after the successful conclusion of field experimentation.

5. The termination of the Pura project was also extended to the cluster of adjacent villages to which the community biogas system had been successfully disseminated to achieve cost-effective maintenance and monitoring compared to a single or dispersed bioenergy system.
6. Another example illustrating this problem is a biomass-based electric power project in North-east Brazil. In that project, expectations of biomass residues being available from a single supplier at reasonable cost were upset by a competing use (as pulpwood) that emerged for the residues. To avoid having to pay an unacceptably high cost for biomass, the project purchased land on which to plant fast-growing trees in order to ensure the biomass supply [Waldheim and Carpentieri, 2001]. Ultimately the project was cancelled in part as a result of the delays caused by the unforeseen difficulties with securing a sustainable supply of biomass fuel.
7. Not only in Pura but in the four adjacent villages of a cluster. Very soon, however, the *Pongamia pinnata* oil experiment was terminated. What is incomprehensible is why the *Pongamia* oil-based experiment could not have been tried in a new village, other than the community biogas plant villages such as Pura. Then, there could have been a competition in a level playing-field between the two feedstocks.
8. A committee appointed by the new management visited the Pura plant and gave a report that a trivial one-time requirement of about Rs. 100,000 would be enough to restart the plant again after extended disuse. The latter type of repair generally would not be relevant for projects that have not been shut down and then restarted.
9. For completeness, several other conditions are included even though they do not follow directly from the above description of the Pura project.
10. When I pointed out to a village meeting that the community biogas plant system would be undermined by intra-village factional conflicts, they replied that, just as they leave their (unclean) footwear outside their village temple when they enter it, they would set aside their factional conflicts to work together to utilise a common resource; this is how they managed other such resources such as their tanks (for harvested rainwater) and their village woodlots.

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Our next issue

The next issue of *Energy for Sustainable Development* (Vol. VIII No. 4, December 2004) is a special issue devoted to power sector reform and its impact on the poor. It comprises papers prepared for the Global Network on Sustainable Development GNESD), created in 2000 at the World Summit on Sustainable Development. The papers are based on a study for the GNESD's Energy Access Working Group, which has been been assessing the impact of reforms on the poor in developing countries and determining what approaches are more successful in safeguarding their access to energy.

The papers contained in the issue will include the following.

- Introduction (a global overview of the issue)
- Expanding access to electricity in Brazil
- Impact of power sector reform on the poor: a case study of South and South-East Asia
- Institutional reforms and electricity access: lessons from Bangladesh and Thailand
- Have power sector reforms increased access to electricity among the poor in East Africa?
- Electricity access to the poor: a study of South Africa and Zimbabwe
- Assessment of energy reform: case studies from Latin America