REPORT REPORT REPORT REPORT

A Biomass Option for Enhancing Energy Security

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Foreword

The National Institute of Advanced Studies has an energy studies programme whose objective is to look at the variety of different technology options that should be particularly relevant for India, where energy continues to be a serious problem. Part of this work is being carried out in collaboration with the Carnegie Mellon University.

The present report in this series looks at the potential of biomass as a source of energy. Technologies for biomass gasification have improved significantly over the last decade and now offer a serious option as a source of energy, particularly in a tropical country like India where sources of fossil fuel are either not plentiful or not sufficiently attractive economically; moreover from the energy security point of view biomass (with appropriate technologies and economic incentives) may be a very attractive proposition.

R Narasimha
Director, NIAS

Summary

This work is concerned with a strategy that simultaneously allows for complementing our centralized sources of energy in an economic way and, in the process, gaining global leadership in certain specific technologies. Explicitly stated, it envisages (a) an economic bioresidue-based power generation scheme in stand-alone as well as grid-interactive modes at power levels of 3 kWe to 3 MWe to augment the present centralized sources of electricity, (b) the possibility of bioresidue-based high grade clean heat for food-product and crop-drying applications, (c) providing a strong motivation for rural societies to preserve and even enhance biomass growth since such an act helps in bettering their quality of life through the availability of electricity under their own control, (d) the possibility of rural centres generating upgraded non-edible vegetable oils which can support both rural and urban transportation, and (e) pursuing strategies which provide far superior environmental-friendliness in terms of being near-CO_2 neutral and sulphur-free, objectives long sought in industrialised society, and very necessary now, thus

providing an opportunity for Indian technological effort to gain global leadership. This article describes the current status of the availability of bioresidues (both from agriculture and from plantations), methods to improve the available database, the techno-economic status of the biomass option, and different methods to advantageously deploy these resources for enhancing national energy security.

Introduction

India's power sector has a total installed capacity of approximately 89,000 MWe, over 70% of which is coal-based. The Government of India's Ninth Plan (1998/99-2003/04) envisages the need for an addition of some 57,000 MWe by 2003/04 to keep pace with demand. Coal is projected to continue to be the dominant fuel source for power generation in the country. While this target is unlikely to be met, it highlights the large requirement for new power generating capacity in the country.

Renewable energy for developed countries is considered as a strategy for the future. For oil-importing developing countries, particularly with widely distributed populations as in many South Asian countries including India, renewable energy from bioresidues could be the optimal solution. While fossil fuels are well-controlled by Government for their quality and availability, bioresidues are treated with scant respect. Powerful groups control them for value addition, e.g. tree stocks by the timber, paper and related industries; but the rest is taken free by anyone who wants it and can lay hands on it first. This has distorted public perception and the true value of bioresidues has rarely been taken advantage of. A case in point is rice husk, a residue from paddy cultivation and rice production. Rice is the staple food of most of South-East Asia. The way rice husk is used for fuel in small establishments like hotels only about 60% of the available energy is utilized. Rice husk is composed of 60% volatiles, 20% fixed carbon and 20% ash. Conversion of the char residue is slow and cannot take place in the stepped grate stoves usually used for burning rice husk. The residue, with 50% char and about 40% of the heat value still unutilized, is simply disposed of in an unhealthy manner. Further, efficiencies of cook-stoves using rice husk are documented to be about 30% at best (ref. 1), so that the net energy efficiency is about 18%. The residue which is about 40% of the original mass contains nearly 50% ash, with about 95% silica, which if extracted economically could convert the present environmentally unsound method of using rice husk to an economically and environmentally benign strategy. What is more, carbon can be specifically extracted with its own contribution to the economic value of the process. Thus nearly every bit of rice husk can be used for electrical energy or for generating carbon or silica. Even a fraction of the 24 million tonnes of rice husk being utilised in this way (see Table 1) would be of mind-boggling economic value.

Table 1: Estimates of Biomass Produced in India

Crop	Production (10^6 tonnes)	Type of residue	Ratio of product to residue	Quantity (106 tonnes/y)	Typical uses
Rice	80	Straw	1.5	120	Cattle feed in sourtern and eastern India and for roof thatching all over the country. Generally burnt in the fields in the North.
		Husk	0.3	24	Mainly as a fuel by small industries
Wheat	65	Straw	1.5	98	Mainly in cattle feed
Bajra	7	Stalks	2.0	14	Domestic fuel
Jowar	11	Stalks	2.0	22	Cattle feed, domestic fuel
Maize	10	Cobs	0.3	3	Cattle feed
		Stalks	1.5	15	Cattle feed and domestic feed
Millets (all varieties)	35	Straws	1.2	42	Partly as domestic fuel
Sugarcane	270	Bagasse	0.3	81	Mainly as a captive fuel by sugar plants, partly as raw material for paper making
		Tops	0.05	14	Cattle feed
		Trash	0.10	27	Mostly burnt in the fields
Coconut	14 x 10^9 nut	Shell	0.1 kg/nut	0.2	Partly as domestic fuel
		Fibre	0.2 kg/nut	3.4	Partly for making mattresses, carpet etc.
		Pith	0.2 kg/nut	2.3	-
Groundnut	8.8	Shells	0.3	2.6	Industrial fuel
		Haulms	2.0	17.6	Partly as a fuel in households
Cotton	2.5	Stalks	3.0	7.5	Partly as domestic fuel
		Gin waste	0.1	0.3	Fuel for brick making and in other small industries
Mustard & rapessed	6.4	Stalks	1.8	11.5	Partly as domestic fuel
		Shells			Domestic fuel
All other seeds	9.0	Straws	2.0	18	Domestic fuel
		Shells			Partly as cattle feed
Pulses	14	Straws	1.3	18.2	Partly as domestic fuel
Tobacco	0.56	Stalks	1.0	0.6	Partly as fuel for processing tobacco leaves
Jute	1.4	Stalks	2.0	2.8	Partly as domestic fuel
Mestas	0.2	Stalks	2.0	0.4	Partly as a domestic fuel
Total				545.4	

Similarly, coconut shell is used in several parts of South India to produce char for subsequent generation of activated charcoal by the age-old 'pit method' (ref. 2), which is crude, energy-wasting and unhealthy. It is possible to conceive of modern, environmentally benign methods of generating electricity and also producing charcoal. The magnitude of this can cover a substantial segment of the 0.2 million tonnes of coconut shell produced annually. Neither of these approaches has been examined so far. Thus a whole range of opportunities for economical power generation remains to be exploited.

Thus renewable energy based on bioresidues or biomass to be generated through plantations can be obtained from three sources as below:

1. Agro-residue utilization for value-added products and power generation.
2. Plantation residues for power generation.
3. Waste land utilization for growing oil-seed bearing trees and extracting oil and bioresidues for power generation.

Agro-residue Resource Estimates

The biomass availability potential for generation of power in India is substantial. Based on the amount of the final product of agriculture, namely grains or food-crops, and the ratio of waste-to-product, estimates of the amount of residues are obtained. These are illustrated in Table 1. This biomass is available in the form of straw, husk, stalks, bagasse, cane tops and trash, shells, fibre, pith, haulms, waste, etc. The ratios have mainly been taken from the report of the National Productivity Council entitled Survey of Biomass Availability in India, 1986 (these details can be found in the TERI Energy Data Directory Year Book, Ref. 3). The production values have been updated from various published data. Since the national grain output is known to reasonable accuracy, the errors involved in the estimate of the residues arise from the ratios. These could be uncertain to the extent of 10 to 15%. Thus the current estimates are expected to be no more inaccurate than this uncertainty. Since agro-wastes do not occupy a very high position on the energy ladder in terms of quality of fuels, strategies for their organized generation, preprocessing and commerce are virtually non-existent. The commerce that goes on now is on an as-is where-is basis born out of local necessity and lack of standardized forms of biofuels. This, in fact, makes it difficult to clearly assess the availability, current use and net material available, and, where used, to determine the end-use efficiency. One clear case where the bioresidue is totally wasted is with sugarcane trash, to the tune of at least 10 million tonnes of the total of 14 million tonnes available.

As can be seen noted from Table 1, about 23% of available bioresidue in the country is rice straw, 18% wheat straw, 16%

other straws, 15% bagasse, and 12% stalks of various plants; the remaining materials are distributed in smaller fractions between other residues. A typical distribution is shown in Table 1. An assessment of bioresidue which is likely to be available after use by the society as estimated from the present conditions is shown below. This estimate has been scaled from individual biomass assessment studies made in villages near Ungra by ASTRA and those initiated by MNES recently. A composite picture of the assessment studies carried out over 90 taluks in the country is still to be obtained. A brief review of the assessment studies is found in ref. 4. An estimate of the electricity that can be generated from the different wastes is presented in Table 2. The available residue amounts to an electricity generation capacity of 16000 to 18000 MWe at 6000 hours of utilization per year.

Table 2: Potential of Biomass for Power Generation

Source of biomass	Biomass generated (10^6T/Y)	Biomass utilised (10^6T/Y)	Biomass available (10^6T/Y)
Crop residues	414	280-300	114-134
Agro industrial residues (excluding bagasse)	50	50	-
Forest sources	35	-	35
Total (10^6T/Y)	499	280-350	149-169

The power generation capacity of the remaining bioresidue: 16,000 – 18,000 MW

Biomass Assessment Studies

It was indicated that the overall potential can meet the objectives of making an overall judgement. For these data to be useful, it is necessary that micro-studies be done to determine the actual mechanics of bioresidue generation and utilization in villages/taluks to help design bioresidue procurement plans for power generation plants. Towards this MNES launched biomass assessment studies all over the country at tehsil levels in the year 1995. As of today, 94 such assessment studies have been conducted in 2 phases in tehsils of 14 major biomass-producing states in the country. These include areas in Andhra Pradesh, Arunachal Pradesh, Assam, Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Punjab, Tamil Nadu, Uttar Pradesh, West Bengal, Kerala and Orissa. The studies were coordinated by the respective state nodal agencies for renewable energy development and conducted by select consultants/agencies.

These 94 studies have produced interesting results and the power potentials in these tehsils range from 1 MW to as high as 95 MW. The information generated from these studies is being compiled by the MNES into an on-line database, intended to be made available to investors/entrepreneurs, along with project notes/profiles for enabling them take a decision to go ahead with these projects.

MNES aims at covering assessment studies of 500 tehsils by the end of the Ninth Five-Year Plan period. The database being generated through this effort will be extremely useful for investors/entrepreneurs/financial institutions/related agencies for dissemination, focussing, R&D efforts and, finally, implementation of the projects.

Plantation residues

Agro-residues constitute an energy source which is generated at least once a year and, in some cases, with a the periodicity of three to six months. The other major energy route available is from plantation and forest residues. While it is true to say that it is not a publicly acceptable situation to design power packages based on solid woody bioresidues, since they are considered unsustainable, there are pockets like coffee and tea plantations, which are in the interior areas and are not well connected to highways where it is better to utilize these residues locally for heat and power generation. Considering the fact that the southern and north-eastern regions of our country abound in these plantations, substantial incursions are possible into bioresidue-based heat and power packages in these areas. The north-eastern region has also the benefit of the availability of natural gas in some pockets, and hence can be eliminated from consideration at present. The southern region, though having extensive tea and coffee plantations along the western hill slopes, does have serious problems with of the availability of fuel and therefore constitutes one region which must be considered for the applications of bioresidue-to-energy strategies. These packages can be based largely on briquetted agro-residues.

Waste Lands and Their Utilization for Growing Biomass Including Oil-bearing Trees

The other major problem of India, namely, the waste lands (or, what has been termed more appropriately, the wasted lands), can be tackled in a win-win manner. The essential idea is to convert these waste lands into marginally green lands and then to good lands capable of normal biomass yield. Estimates of the extent measure of waste lands in the country vary according to varies between different investigative agencies. Table 3 taken from the book of Ravindranath and Hall (1994) provides some information on this subject.

Estimates of the extent of waste lands vary from 66 to 130 million hectares. Biomass yield from marginal lands is about 5 dry tonnes per hectare per year. From well-maintained land with proper selection of species and application of nutrients and water, one can reach productivity levels of 15 to 20 dry tonnes per hectare per year in a five-year cycle. The potential of waste lands can be gauged by the fact that even at the low yield of 5 tonnes per hectare per year the productivity of, say, 100 million hectares of land works out to 500 million tonnes per year. For annual use of 5000 hours of power generation,

Table 3: Estimates of Degraded Land Availability in India (Mha)

SPWD (1984); degraded (waste) land, quoted in PC (1992)	Degraded forest	36
	Degraded non-forest	94
	Total degraded land	13 0
Chambers *et al.* (1989); land available for tree planting	Cultivated land	13
	Strips and boundaries	2
	Uncultivated degraded land	33
	Degraded forest land	36
	Land for tree planting	84
Kapoor (1992); land available for tree planting	Agricultural land	45
	Forest land	28
	Pasture land	7
	Fallow (long)	10
	Fallow (short)	15
	Urban land	1
	Total land for tree planting	10
Ministry of Agricultural Sciences (1992); land use statistics	Forest land with < 10% tree crown cover	6 11
	Grazing land (pasture land)	12
	Tree groves (degraded)	3
	Cultivable waste	15
	Old fallow	11
	Total	52
	Current fallow	14
	Total degraded land	66

SPWD (1984), **"Developing India's wasted land"**, Society for the Promotion of Wasteland Development, New Delhi.
Chambers R., Saxena N.C., Shaw T (1989), **"To the hands of the poor – Water and Trees"**, Oxford & IBM Publishing, New Delhi.
Kapoor R.P. (1992), "Investment in afforestation, on trends and prospects", In *The Price of Forests* (Ed. A. Agarwal), pp. 173.7, Centre for Science and Environment, New Delhi.
Ministry of Agricultural Sciences (1992), **"Land use statistics"**, GOI, New Delhi

the bioresidues from these amount to 60,000 MWe at a low conversion of 1.5 kg (dry biomass)/kWh. If the biomass productivity is increased by using known methods related to improvements in photosynthetic efficiency, the total power generation potential is a mind-boggling 100,000 MWe even without any other significant advance in new areas. It is entirely possible that in the new scenario when biomass growth rate is increased, newer uses of these for societal applications may arise and so alter the picture to some extent. But then, when things are in reasonably significant supply, the market forces of demand and supply will take over to reach a new equilibrium, which is much better than the current situation in terms of power availability.

A further point about waste-land utilization resides in the nature of the plantation to be grown. At typical biomass yields of 5 dry tonnes per hectare per year, the financial returns turn out to be about Rs. 6000 to 7000 per hectare (at Rs. 1200 to 1400 per dry tonne). *An alternate strategy is to grow oil-bearing plants or horticultural product-bearing trees so that bioresidue constitutes only the byproduct and the main product is oil-seeds or fruits.* Typical estimates indicate that biomass grown this way yields three products.: The first is Oil from oil-seeds to the extent of 0.5 to 4 tonnes per hectare per year. Oil yield being 10 to 50%, the amount of cake remaining is about 2 to 4 tonnes per hectare per year. This can be used in biogas plants to extract part of the hydrocarbons to generate biogas (50% methane and the rest carbon-dioxide). Subsequently, the residue is a partial replacement for high quality fertilizer. The residue being natural and organic in nature has much less negative effect on soil quality in the long-term sense. Even as of now the cake is being marketed for its fertilizer value. The yield of solid bioresidue, which is lignaceous, is about 2 to 4 dry tonnes per hectare per year. Thus this route allows land and water to be used with much higher larger efficiency, and is environmentally friendly. The estimated financial productivity of the land estimated from the products obtained would thus be about Rs. 18,000 to 25,000 per hectare per year. Thus one can extract from the land and water resources thrice the productivity as compared to traditional and classical approaches. The oil so obtained from these plantations is capable of being upgraded through trans-esterification to obtain fuels which can burn in diesel engines with an efficiency only 7 to 10% lower than high speed diesel. It is also possible to use these fuels directly in rural transport vehicles like tractors and in power generation equipment in dual-fuel mode with producer gas from solid bioresidues and oil from the seeds.

To bring home the importance of these concepts, it is useful to recognize that the current use of high speed diesel amounts to 40 million tonnes (1997-1998) nationally (see ref. 3, p. 67). The productivity of the waste lands of 66 x 10^6 ha waste lands if fully used is between 33 and 240 million tonnes. Thus all our oil demand can in fact be sustained from this source alone, even if the oils need further purification to match diesel fuels in terms of operational friendliness.

Thus utilisation of waste lands offers an important national alternative for generating useful biofuels to manage our societal needs.

Biomass Conversion Technologies via Gasification

Biomass gasification is basically conversion of solid biomass (i.e wood/wood waste, agricultural residues etc.) into a combustible gas mixture normally called Producer Gas or low BTU gas. The general composition of the producer gas is – CO: 20%, H_2: 15-18%, CO_2: 9-11%, CH_4: 1-2%, N_2: the remainder.

The process, developed earlier for woody biomass, was extended recently to include agro-residues by using briquetting technology to convert loose agro-and plantation residues to solid biomass of high density, and involves partial combustion of this biomass. Given that any biomass contains carbon, hydrogen and oxygen molecules, complete combustion would produce carbon dioxide and water vapour. Partial combustion produces carbon monoxide as well as hydrogen both of which are combustible gases. Solid biomass fuels, which are usually inconvenient and have low efficiencies of utilization, can thus be converted into a high quality gaseous fuel with its associated convenience.

While there are different types of gasifiers such as fixed bed downdraft, updraft and cross-draft gasifiers discussed in the literature (see for instance, ref. 5), the most extensive work done till date in India and elsewhere for small electricity generation via reciprocating engines, has been on the fixed bed downdraft gasifier. While research studies have been conducted on fluidised bed gasifiers, it has been concluded that these would not be suitable for producing the low tar gas required for reciprocating engines.

Bioresidue Gasifier IC Engine Systems

The biomass gasification activity in India is about 16-17 years old. It started around the same time at the Karnataka State Council of Science & Technology (KSCST), based at the Indian Institute of Science (IISc), and M/s Jyothi's (Baroda). The initial motivation was diesel replacement for agricultural pump sets (about 2.5 million in number at that time and about 6 million in 1998). At IISc, the challenge of building an efficient small gasifier, then considered very difficult if not impossible, was alluring and therefore taken up.

By 1986, successful open top downdraft reburn gasifiers with extraordinary test performances (85 to 90% diesel replacement even at 3.7 kWe) were built and demonstrated. M/s Ankur Technologies had just then started with a closed top design.

In the last ten years not only have a large number of systems been built by M/s Ankur Technologies, but several other manufacturers – AEW, Tanaku, and Cosmo Enterprises, Raipur have entered the field. Centres for scientific support were established at IISc, Bangalore, IIT/Bombay, IIT/New Delhi and Madurai Kamaraj University. Approximately Rs. 18 crores have been spent on these projects over the last 12 years. Of this about Rs. 4 crores was towards R&D. The rest was for demonstration purposes. Vigorous development and information exchange took place at national meetings organized under Ministry of Non-Conventional Energy Sources (MNES) patronage till 1993. There have been no major meetings thereafter.

It is important to discuss one aspect of small gasifiers which is relevant to the Indian context. Because there were large numbers of small power level pump sets, it was thought expedient to develop small gasifiers. However, this also became a tool for experimenting on small-scale designs, to enable better understanding of the processes involved, with minimal expenditure on research and development and then, of course, one scale-up to larger power level systems. The question of developing a good small gasifier has cropped up in the literature and at many discussion meetings. Solar Energy Research

Institute's (SERI, the present NREL) original document, which is the translation of the Swedish experience, states that building a lower power level system which runs reliably is more involved when compared to large power level systems because the volume to surface area is unfavorable for small systems and the heat loss issues cause difficulties in ensuring reliability. This statement is technically correct and has also been experienced by us in the early stages of the development of the gasifier.

Therefore it was assumed that if one could make a small gasifier that is efficient and emitting "minimum tar" as assessed by standard tests, then the concepts involved are worth preserving for larger gasifiers and the scalability of gasifiers based on these concepts becomes a strong point of these technologies. It is worth noting that in classical chemical engineering approaches, it is considered only appropriate to do model studies, build prototypes and examine issues of scaling, and this is exactly what is being followed systematically in the current approach through scientific and engineering studies on systems at increasing power levels.

The earlier international development in this area shows that only large lower level systems were addressed, due more to historical than scientific reasons. It is therefore meaningful to conclude that the development of small-scale gasifiers has given insights into what needs to be done at larger power levels, much in the same way as what happens in several other engineering fields.

During 1988 to 1992, MNES had a vigorous demonstration programme for gasifiers for water-pumping applications. About a thousand gasifiers were put up in three stages under this programme by at least three manufacturers, and the performance of the systems was monitored as follows. (a) Designers went round all by themselves to determine the usage pattern and problems if any in running the system. They also suggested changes needed to make the system more user friendly, (b) The state nodal agencies utilized a separate team of three technical personnel to monitor all the gasifiers in the field. (c) MNES utilized a separate national agency to monitor the performance and provide inputs to the Government on the design, operation, training and related aspects. The agency submitted its report directly to MNES. The duration of run on one of the designs is in Table 4, which includes the hours run on each system and the total run period, which indicates the experience accumulated. When all the gasifiers were deployed in the field, there were three levels of monitoring teams.

Table 4: Sample of IISc Gasification System Performance – Duration

Years	Capacity (kW)	Min-Max h/ System/Y	Number of Systems	Hours accumulated
1987 to 1990	3.7 kWe (pump)	100 to 500	120-450	40,000
1988 to 1995	3.7 kWe (Hosahalli)	1400	2	8,000
1995 +	20 kWe	2800	1	2800 (Hosahalli)
1990 to 1996	70 kWe (Port Blair)	1200	1	4000
1992 +	20 kWe	400	1	800 (Ungra)
1995 +	40 + 40 kWe	1800	1	1800 (Orchha)
1996 +	400 kWh	600	1	600 (Coonoor, tea drying)

Subsequent to the early efforts, 25 to 100 kVA systems were also permitted under the demonstration program. Further the technology developers gained confidence and started building larger gasifiers both for thermal and electrical applications. In 1994, because of an interesting development and connection with Swiss scientists through Dr. Hari Sharan of DASAG, Switzerland, the 75 kg/h (100 kVA) IISc system went through rigorous testing and evaluation in India and in Switzerland. In both places, tests were conducted with different bioresidues and loads for a total of 100 hours each. *This system is perhaps the only gasifier in the world which has undergone such rigorous testings.* The test results are presented in ref. 6, and have been presented at two major international meetings (refs. 7 and 8). Subsequent to these tests, Swiss scientists have used the system to check other subsidiary elements like the cooling and cleaning units rather extensively. It has also undergone a long-duration test of 150 hours continuously, as well as several intermittent ones after coupling the gasifier to a gas engine.

Subsequent developments at Bangalore involving other manufacturers in the country have resulted in gasifiers with capacities ranging from 100 kg/h to 500 kg/h, both for thermal applications and electricity generation. The quality of gas required for drying food products like tea posed difficulties which could be dealt with by cleaning the gas adequately. The class of engines used for power levels less than 100 kWe are mostly naturally aspirated and for those beyond 150 kWe are turbo-supercharged. The problems on gas cooling and cleaning for *larger sized engines* are more demanding *than for the lower power level systems.* These have been very inadequately explored in earlier work on gasifier applications for electricity generation.

The investment cost of the gasification technologies in comparison to coal-based power plants is as follows. For power generation systems of a couple of megawatts and above, the cost varies between Rs. 35 and 45 million per MWe (US $ 1000 per kWe). Bioresidue-based systems also have similar costing since all these power plants are generally based on combustion–steam power generation cycles.

The cost of small gasifier-based diesel engine generator systems at power levels of 100 to 500 kWe varies between Rs. 25 and 35 million per MWe (US $ 700 to 800 per kWe). In most of the applications, the cooling water clean-up and cooling for recycling applications is absent. When these are included, the unit cost is comparable to large power level system unit costs (US $ 1000 to 1200/kWe). The cost of electricity generated from small gasifiers is between Rs. 2.5 and 3.0 per kWh and in the case of large power level systems, it is between Rs. 2.2 and 2.5 per kWh. The simple pay-back period on investment in the gasifier for a retro-fit application works out to 15 to 24 months depending on the cost of bioresidue, which is taken as between Rs.1000 and 1500 Rs per tonne, and 24 to 30 months, if the electricity generation package consists of gasifier–gas engine-generator set, and 30 to 40 months if it is based on gasifier–diesel-generator (DG) set operating in dual-fuel mode with 75% diesel replacement. In all cases it is taken that the power package is used for 5000 hours per year.

A problem that is somewhat special to India in this scenario is that the market is almost entirely driven by diesel engines. Because stand-by power is an absolute necessity for industries, a large number of industries have DG sets. The total stand-by capacity all over the country is about 17000 MWe. This magnitude of power is used to the extent of about 500 hours over a year, essentially to take care of scheduled and unscheduled power cuts, due to a number of factors like grid stability, low quality of power (in terms of voltage and frequency), excessive peak demand, and non-availability of fuel at times. In some states and specific locations, the amount of electricity generated in-house in comparison to that from the grid is as high as 30%. Also the tariffs payable to the State (Rs. 3.50 to 4 per kWh) are higher than the cost of in-house generation of electricity (Rs. 2.75 to 3.15 per kWh).

These aspects have created the demand for cheaper processes of electricity generation in many instances and using the existing investment on diesel-generator sets more effectively. While most industrialists can easily appreciate the economics and the possible benefits, their problem is usually about examining a few working systems, for none of them wishes to risk being the first to venture into the field. The current MNES schemes do not have provision by which risk is initially taken by governmental agencies with subsequent transfer of financial liability to the industrialist. Laboratory testing and proving has been performed to a substantial extent in India through Swiss cooperation, up to a power level of 100 kWe. For power levels larger than this, industrial participation becomes essential. Industrial participation however can begin only when they can see a few successful systems in the field as already explained. Hence, it is extremely important to demonstrate a few systems under different conditions – largely industrial but also both in semi-rural and urban settings so that user misconceptions can be eliminated. Even under these unfavorable circumstances, some aggressive entrepreneurs have gone in for high power gasifiers. These are of course in the initial stages of demonstration and users still handle gasifiers with kid gloves. Also the developers are not in a position to provide guarantees which can be trusted at present. If no attempt is made to catalyse the process with financial, technical and monitoring inputs, the field will take a long time to grow. This is also because peer groups from overseas have largely been under the impression that the systems are not reliable, or are not economical, even if they are reliable. To erase wrong public impressions by documentation is even more difficult; however, this is taking place slowly by systematic dissemination by which technical questions are being responded to, joint testing conducted and third party verification of most of the task elements being done.

Gasifier-Based Power Generation Strategy

All these imply that utilizing the incentive driver in terms of lower cost of electricity generation for propagating the bioresidue-based renewable energy technology exists even today. However, it is necessary to overcome (through demonstration plants) the barriers created by (a) inadequate experience with large power level systems, certainly above 300 kVA, and (b) non- availability of gas engines to demonstrate the true potential of bioresidue-to-energy conversion.

It is therefore important to mould this programme so that a number of projects of reasonable power levels – 4 x 300 kVA, 2 x 600 kVA, and 1 x 1 MVA – evolve, being handled with proper cooperation between technology holder, client, monitoring scientific group and project initiator. Intermediate reviews and documentation, dissemination to peer groups through various means, such as referred journals and vetted reports (so that a common platform of understanding of all the issues involved develop), are also of paramount importance.

In these tasks it is important to generate appropriate fuel linkages. The issue is by no means small and is addressed in the next section.

Standard Gasifier Fuel (SGF)

One of the serious problems that besets gasifier users as well as technology suppliers who have to stand guarantee for performance is the nature of the fuel used in the gasifiers. The general quality of fuel to be used in solid bioresidue gasifier is as follows. Bioresidue chips of smaller than a certain size (typically 30 to 70 mm for power levels less than 500 kWe), with density greater than 200 kg/m^3 and moisture content less than 15%, are required; they should not contain inorganic material like sand, grit and mud. The major problem in the field is non-compliance with the requirement given in the manual. Sometimes users have used larger sized chips with resultant reduction in diesel replacement. The second non-compliance concerns moisture in the wood chips. Surprise checks also indicated the generation of tar. Investigation showed that the moisture content exceeded 30% and, in some cases, was around 50% (virtually green wood). Reprimanding the operating personnel resulted in improvement to the expected level. The third non-conformity discussed earlier, namely, the inclusion of inorganic matter in the form of sand and mud, these being picked up from the area where the biomass is harvested, results in the formation of a hard fused ash-like matter inside the reactor, and in some cases, on the ceramic reactor walls. What happens is that the ceramic wall of the container also reacts and fuses with the impurities and this results in the loss of the parent material as well. Resolution of these problems lies in generating standard gasifier fuel and supplying it through depots/banks.

We should recall that when fuels are to be used in reciprocating engines, the quality of the fossil fuel has to be controlled to a very good degree, and should be much superior to what is obtained from bioresidues. For the same reciprocating engine, if we have to supply gas of consistent quality, we should maintain minimum quality of the feed stock. In the current environment of bioresidue utilization, almost every household deploys it with poor end-use efficiency, with not much concern about the emissions which are a serious health hazard. This problem faced by solid fuels has remained unresolved because of inadequate attention paid to the science of their conversion process. Therefore, there is a strong case at the national level to upgrade the quality of bioresidue-based fuels which suffer from the common misconception (national or, perhaps, even universal) that they can be emission-friendly fuels. While there are technological interventions for better use of bioresidue fuels, even these can work more economically provided attention is paid to the preparation of these fuels at costs acceptable to the market. We should recognize that the density of fuels, their shapes and sizes and their moisture contents vary widely. The density of sundry fuels is 50-60 kg/m^3 for sugarcane trash, bagasse pith and coconut coir pith, about 100 kg/m^3 for rice husk and groundnut shell, about 175 to 200 kg/m^3 for cotton stock, *Ipomoea* (a weed) and coffee husk, about 500 to 600 kg/m^3 for causarina, eucalyptus and similar stocks, and about 1000 to 1200 kg/m^3 for padauk and briquetted fuels based on light agro-residues as mentioned above. Thus one can see that the density variation is a factor of 20. A typical truck with a storage space of 6 x 2 x 3 = $36m^3$ can at best carry 1.5 to 2 tonnes of the light agro-residues or the standard 10 tonnes of the higher density solid stock or briquetted fuels (in the latter the carrying capacity being decided by weight and not volume). Thus it is important to think of densifying the light agro-residues through briquetting at the location of the material or perhaps within a kilometer of its availability and then transporting it as needed. The cost of transportation works out to about Rs.10 to Rs.12 per kilometer for a full 10-tonne truck. This amounts to Rs. 300 even at distances of 25 km and, therefore, the incremental cost of transportation works out to Rs. 30 per tonne over 25 km. This is an economically meaningful incremental cost which the society should be able to sustain for the benefits that can accrue from bioresidues, electricity for various uses and, to a smaller extent, charred solid fuel for cooking. The strategy of local bioresidue collection is suggested because of the small land holdings that lead to distributed bioresidue availability and control. Thus it is important to develop bioresidue-based "Standard Gasifier Fuel" (SGF) banks. Such banks are expected to have tractor-trailer mounted equipment,· including chaff-cutter, waste heat drier-pulveriser and briquetting machine, all powered by an diesel-engine alternator system which can move from place to place and generate briquetted fuels. At the field site, the farmer who is involved in providing the fuel resource can be paid on the basis of the dry weight of the fuel he supplies. Typically this can be about Rs. at 300 to Rs. 400 per tonne of the raw bioresidue, so that the final cost of the processed bioresidue works out to about Rs. 1000 to 1200 per tonne.

It is necessary that the projects discussed earlier be coupled with the "Standard Gasifier Fuel" (SGF) strategy discussed above so that one has a complete package for power generation.

Oil Strategy

Oil and HSD consumption

The use of high speed diesel (HSD), which constitutes about 75% of the middle distillate output, and about 50% of the sum of the middle and light distillates and about 40% of all the refined petroleum products, is the backbone of the economy as reflected by the transportation of goods across the country. In the year 1995-1996 its consumption amounted to 33 million tonnes and its annual growth in its consumption is about 4 million tonnes. About 10% of the amount consumed is used by the rural sector for water pumping, transport-tractors etc. The diesel consumption in the agricultural sector is for six million, 5 hp pump sets which use one 1litre per hour of diesel for an average of 500 hours every year. In addition, there are about 2 million tractors which consume about 1 million tonnes of HSD. Thus, of the total HSD used per year which is 40 million tonnes (1997-1998), the amount used in the farm sector is 4 million tonnes.

One strategy to attempt to alleviate energy shortages is to allow the rural sector to generate oil for its own needs by various means as discussed earlier. It was brought that a better way of using waste lands is to grow oil-seed or horticulturally useful product-bearing trees so that bioresidues constitutes only the byproducts and the main produce is oil-seed or a fruits. Also it was brought out that oil yield from oil seeds is to the extent of 0.5 to 4 tonnes per hectare per year. In the total waste land area of at least 66 million hectares the oil that can be generated is 33 to 264 million tonnes per year. This range is obviously large, but unfortunately, inadequate data make closer estimates difficult. This is a mind-boggling figure, a fact not recognized by the planners as yet. At the least, a part of these lands must be used to meet the principal requirement of oil for water-pumping applications. This will need only 1 to 8 million hectares of waste land. This field is unfortunately only weakly appreciated and coordinated in the country today. As is further evident in the discussion presented in Annexure I, considerable potential exists for the development of theise areas.

The Overall Strategy

The overall plan is to set up a national level board/centre/ commission with the participation of membership coming from different ministries – MoEF, MNES, MoA, and Waste Land Board – with the idea of (a) encouraging the growing of trees bearing oil-seeds and streamlining related activities by providing various kinds of incentives; (b) promoting R&D to reduce the gestation period for the achievement of these objectives; (c) encouraging industries to adopt surrounding localities by planting such trees; (d) framing policy for investing in these oil cakes to meet the local energy demands; (e) orienting the whole programme so as to offer employment opportunities to the local labour force, incidentally discouraging needless migration to urban areas.

A number of bioresidue-based projects at the power level of 250 kVA, 600 kVA and 1200 kVA should be located near industries and chosen to meet the following criteria. (a) A sustainable supply of bioresidues for the foreseeable future – at least about 5 years (about twice the period for return on investment), (b) industrial operations that can permit generation of a minimum number of units of electricity, and (c) availability of different classes of bioresidues – solid stock, and standard gasifier fuels (SGF) along with the demonstration of the production of these fuels. Typical investments in the total package will be about Rs. 100 million including technical costs of monitoring and documentation.

Annexure I

(Constructed from the articles published in BUN – India newsletter, volume 2.3. The authors whose articles are used here are Dr. P Radhakrishna, MNES, Chennai, Drs. A Das and T B Reed of Colarado School of Mines, Colarado, USA, Sri. Vinayak Patil and Sri. Kanwarjit Singh, and Prof. U Shrinivasa and H S Mukunda, IISc, Bangalore)

(Summary drawn from articles published in BUN – India, v. 2.3, 1998 – ref. [10])

Vegetable oil as a source of energy has been known for a long time. Perhaps the presently administered affordable prices, international attention and convenience associated with petro-oils, have not promoted the required R&D for exploring the use of vegetable oils as future liquid fuels. Basically vegetable oils are either edible or non-edible and the plants bearing them are annual or perennial. Both these categories also have other applications in various other areas, apart from cooking, such as medicines, food preservatives, base for soaps, illuminants, lubricants, paints, drying agents, for curing of leather products and the like. Edible oils like coconut, sesame, castor, rape, mustard, safflower, niger, and linseed have the pride of place in Indian history, dating way back to the Rigvedic Age. Other edible oil-plants introduced later on include groundnut (introduced approximately in 1800 AD), soybean (1910), sunflower (1940) and oil palm (1966). Of all these oil-seeds, castor (introduced around 1000 BC) oil and cakes are not edible. In the category there are at least 150 species, mainly trees or shrubs, yielding oils that are not consumed directly by man or animal. The main uses of these oils in India are in soap-making and in ayurvedic medicines. Other activities associated with these oils are not documented to the satisfaction of researchers. In recent studies, some of the oils like *Mahua*, *Sal* and *Kokum* are introduced in proportional quantities in making *Vanaspathi* (hydrogenated fats) and chocolates respectively. In fact, many of these trees produce valuable chemical substances in s from their leaves, flowers, stems and roots portions, whose importance has been known from Yajurvedic times. Other economic activities associated with these oilseeds such as harvesting, collection, crushing, marketing etc. however are not well-organized like that of other edible oil products. The available potential is also not yet estimated since the collection of seeds is not a regular occupation. It is estimated that 76 lakh tonnes per year, and 2 lakh tonnes of seeds are collected from 7 other tree species in minor quantities.

Table A: Production of non-edible oil seeds and bio-residues in India

Species	Oil fraction (%)	Seed current estimates (10^6 tonnes/y)	Oil (tonnes/ha/y)
Castor	45–50	0.25	0.5–10
Jatropha	50–60	0.20	2.0–3.0
Mahua	35–40	0.20	1.0–4.0
Sal	10–12	0.20	1.0–2.0
Linseed	35–45	0.15	0.5–1.0
Neem	20–30	0.10	2.0–3.0
Pongamia	30–40	0.06	2.0–4.0
Others•	10–50	0.50	0.5–2.0

•*"Others" refers to seeds from a whole range of seed-kernels species: Jute plant, mango kernel, flame of the forest, Indian Coral, kokum butter tree, ink-nut, soap nut, milk weed, watermelon, yellow oleander, tamane oil-tree, crotan oil tree, palm, prickly poppy, wild walnut, almond, kamal, tung oil-tree tree, silk cotton, bullet wood tree, ironwood tree, bastard sandal, pilu, foon etc.Oil production depends on a number of agro-climatic factors and the choice of the species.*

Data on the availability and use of these oils for power generation are not as extensive as for fossil fuels. The limited information available in the literature is put together here. One of the biofuels considered by Das and Reed is hemp. Historically hemp (*Cannabis sativa L.*) has been a very high yielding plant (Haney 1975). Assuming that hemp produces up to 4 tonnes/acre of seed plus 10 tonnes/acre stalks, Table 1 shows how many gallons of liquid fuel import could be saved by each of the following proven conversion routes.

The hemp plant is a promising high yielding biomass fuel crop cultivator and both its production and utilization should be included in the DOE/TVA and regional biomass screening programmes. One hopes that DOE regional biomass programme contractors have no difficulty qualifying for the necessary permits. Most of the conversion technologies in Table 1 are well-known. Biodiesel from hemp is the newest conversion technology. Recently, at the Biomass Conference of the Americas (Biomass, 1993), nearly a dozen papers were presented on biodiesel fuel. It was recommended that farmers in Northwest America achieve self sufficiency to provide enough fuel for tractors, irrigation and combines in energy by planting oil-seed crops like sunflower or safflower on 10% percent of their acreage. Sunflower and safflower yield typically 60 gallons per acre of vegetable oil. Hemp-seed yields up to 300 gallons of oil per acre have been reported (Haney 1975), yet there was not one single mention of this promising fuel oil-seed crop anywhere in the Conference.

Table B: Conversion technologies for hemp stalks and hemp oil

Conversion technology	Conversion efficiency (%)	Gasoline equivalent (Gal/acre)
STALKS@10 tonnes as stalks/acre		
Ethanol from fermentation of hydrolyzed cellulose	20	200
Digestion of whole stalks to methane	50	500
Producer gas from thermal gasification of stalks	85	1000
Methanol from syngas from gasification of stalks	65	750
Wood oil from fast pyrolysis of stalks	60	700
Oilseeds@4 tonnes seed /acre		
Hemp seed oil from seeds, no conversion	100	300
Biodiesel-premium diesel fuel from hemp seed oil	90	270

The cost of oilseed fuels is linearly related to yield and farming cost. The cost of farming and pressing sunflower oil, yielding 116 gallons/acre, is $2/gallon (Peterson 1981). Assuming that hemp will cost the same as sunflower to grow, a hemp seed yield of 4 tonnes/acre (Haney 1975) can produce 300 gallons of hemp seed oil at a cost of $0.77/ /gallon. This may make domestic hemp seed oil economically viable today. [See also (Biomass, 1993)] *Biomass Conference of the Americas*, Burlington, Vermont; Haney 1975: "An ecological study of naturalized hemp (*Cannabis Sativa* L.) in East-Central Illinois"; Alan Haney and Benjamin B. Kutscheid: *The American Midland Naturalist* Vol 93, No 1, January 1975, 1-24; Peterson 1981: Vegetable oil as an agricultural fuel for the Pacific Northwest, C. L. Peterson, *et al*, Idaho Agricultural Experiment Station Bulletin No. 598, Moscow, ID 83843].

One area in which scientific work has led to clear conclusions of practical relevance is the use of bio-oils like rapeseed oil in some western countries and the possible use of non-edible oils in India. There has been a serious thrust on the production of pyrolitic oils from biomass in many countries such as Canada, Spain and Italy, to enable their use in reciprocating engines. Several studies have shown that pyrolitic oils have problems related to their acid content and water on ignition and performance in reciprocating engines. Gas turbine engines using this oils seem to have fewer problems of ignition and combustion, as these are continuous combustion devices.

One serious question to be debated is the relative importance given to the two routes –
(a) pyrolitic oils and their refinement, and
(b) non-edible oils and their refinement to enable use in reciprocating engines (the main focus of developing-country alternatives for small power generation will be reciprocating engines).

It appears that for India, the route involving the use of non-edible oils can be economically meaningful and can be used as the incentive a driver for restoring the environmental balance. Some experience has been obtained on the use of liquid fuels like *Pongamia pinnata* (Honge) oil as a substitute for diesel engine by Prof. U Shrinivasa under the project called SuTRA (Sustainable Transformation of Rural Areas) at the Indian Institute of Science, Bangalore. This has been done in seven villages located about 100 km from Bangalore for varying lengths of time, from 40 days to over 100 days. The number of hours of run accumulated over the period exceeds 4000. The following observations have been made based on this experience. (a) The oil as obtained from the expeller requires thorough cleaning, (b) the engine can be both started and run on Honge oil continuously whenever the engine itself is in good condition, (c) the engine exhaust appears clean during visual inspection, (d) engine fuel consumption increases by 10 percent by volume as compared to diesel. While more work needs to done in this area, it is obvious that this need not limit the expansion of the use of such oils for power generation.

Initial estimates and assessments suggest that at least in the semi-arid regions, enough Honge trees can be grown to enable most villages to operate local power stations using this oil, at the rate of about 0.5 kW per capita. This will allow villages to feed surplus power to the grid instead of being consumers of grid power as is the situation at present. It will also provide to the villages, electricity in sufficient quantities from one of the most inexpensive of the renewable energy options. The experience that has been gained in the country on growing oil-bearing trees and their utilization is significant with respect to a plant called *Jatropha curcas*, which is a wild dwarf bushy tree that is very hardy and grows in most climatic and soil condition. It is not browsed by animals, including sheep and goats. Its present use is in the soap industry and this interest is dwindling due to the availability of cheaper oils from overseas.

Some experience has been gained by Mr. Vinayak Patil and Kanwarjit Singh, through systematic studies in Maharashtra, on the subject of cultivation and marketing of *Jatropha curcas* through agro-forestry co-operatives. They have made a strong plea in this regard – "It is now increasingly being realised that co-operative agro-forestry can be used as an effective medium to fight the battle against environmental degradation. By motivating the farmers to adopt agro-forestry crops like *Jatropha curcas* as an alternative cropping pattern the energy and economic scenario in the rural areas can be drastically improved. Agro-forestry is the only effective means to enhance the area under actual tree cover for achieving the national goal of bringing 33% of the total land area under effective tree cover required for maintaining the environmental balance and for greening the country. Co-operative agro-forestry is a productive programme which holds immense potential to generate a sustainable source of self-employment, renewable source of energy and contribute to complete socio-economic and ecological development through the active participation of the people for their own welfare. The concept of co-operative agro-forestry was conceived in Maharastra State in 1993 with the formation of "Nashik District Eucalyptus Growers' Co-operative Society" at Nashik. Taking a cue and technical guidance from this pioneering co-operative agro-forestry venture initiated at Nashik more than twenty-five similar agro-forestry co-operatives have already been formed in Maharastra State and many more are in the process of formation. This process has finally culminated in the formation of the state level federation agro-forestry co-operatives in Maharastra State in November, 1990, which is the first state-level federation of its kind in India."

The chief aims and objectives of the agro-forestry federation are: to organize supply of the requisite propagation material, to guide the farmers regarding cultivation practices of agro-forestry crops; to help and guide the farmers in procurement of loans and to stand guarantee for repayment of loans; to organize harvesting and marketing of the agro-forestry produce and to organize setting up of suitable processing units based on agro-forestry produce.

Experience in agro-forestry in Maharastra shows that the willingness of the individual farmers to accept agro-forestry as an alternative cropping pattern is governed by the following factors, viz. availabiity and type of land, availability and quantity of water, distance of the farm from the residence of the landowner, exposure to cultivation practices of a particular crop, availability of trained labour and basic training instincts of the farmer. It has been observed that even if one of these factors is unfavourable, agro-forestry makes an ideal alternative.

The Eucalyptus Growers' Co-operative Society of Nashik has been campaigning for the cultivation *Jatropha curcas*, a dwarf bushy tree, which is very hardy and grows in most of monsoon and soil conditions and yet offers handsome returns to the grower. The soap manufacturing units in the country had been looking for an alternative to edible oil for the manufacture of soap for the past seven to eight years. Since some of these units showed interest in buying *Jatropha* seeds for extraction of oil, the agro-forestry co-operative at Nashik motivated 1450 farmers. In 1988-89, 3000 hectares, in 1990-91 another 3000 hectares and in 1991-92 4000 hectares of land have been covered under *Jatropha* plantation. Agro-forestry federation will organize marketing with buy-back guarantee for the seeds and provide technical guidance to the farmers regarding cultivation of *Jatropha curcas*.

The by-product from Jatropha seeds, in the form of oil-cake after extracting of oil, is an excellent organic manure, even superior to cow-manure. This pioneering effort of introduction of a systematic plantation programmme of *Jatropha curcas* in Maharastra State will prove to be a new trend setter which, hopefully, can lead to a revolutionary transformation of the gloomy economic and energy scenario into an era of economic boom and prosperity of all sections of the society including the rural poor. It will ensure optimal and harmonious utilization of our land, water, manpower and financial resources. The bio-crude oil of *Jatropha curcas* can save foreign exchange worth several thousand million dollars by the year 2000 AD and onwards. The water requirements are much less as compared to other agro-forestry crops. It comes to full fruition within 4 to 5 years and has a long productive period of around 50 years yielding handsome returns annually. These traits make it a low-cost model ideal for small farmers and a safe investment model both from the banker's and the farmer's point of view. Some basic research on cultivation has been carried out at Bharatiya Agro-Industrial Research Centre, Pune in Maharastra by Shri Ashok Raina. Research and development activity has also been undertaken by Godrej Soaps and Hindustran Lever who are major users of *Jatropha* oil in India. Preliminary experiments carried out by the authors at Nashik have successfully established that *Jatropha* oil could be used as an alternative to diesel as furnace fuel and also as an alternative to kerosene in specially designed stoves. Shri Kannighanti Chandrashekhar, an automobile engineer from Hyderabad has also conducted experiments on preparing 2T stroke oil from the *Jatropha* oil – a lubricating mixture used in mopeds, scooters and motor cycles. The future of *Jatropha* oil seems to be promising and the time is ripe for expanding the *Jatropha* oil base to enhance the availability of this useful oil as a raw material for industrial use and for generation of electric power in a decentralized manner.

The forest development corporations of Maharastra and Gujarat have also initiated introduction of *Jatropha curcas* in their afforestation programme for revegetation of denuded and degraded forest lands as a commercially important and hardy species for quick greening of public waste lands. Collection of *Jatropha* seed can provide a regular source of income to the local people and reduce pressure on forests. Tribal populations will also get an alternate source of livelihood and energy and the illicit cutting of forest trees and encroachments on forest lands will considerably relieved."

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