Making the Last Mile the First

Remote Rural Electrification Through Biomass Based Gasifiers

The LIBERA Project Experience

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Executive Summary

1. Introduction

The LIBERA (**L**ivelihoods **I**mprovements through **B**iomass **E**nergy in **R**ural **A**reas) project was a pioneering rural energy initiative conceived and implemented by consortium of partners between 2001 and 2005.

The goal of LIBERA was to bring about concrete and sustainable improvements in rural livelihoods –and the project sought to achieve this by:

- Providing energy services to improve the quality of life, including household and community lighting, and powered water supply
- By linking the supply of reliable and affordable energy to the development of productive activities aimed at improving food security and the generation of additional income.

The project targeted the remote tribal communities of rural Orissa.

LIBERA had a focus on collaboration and competence-pooling between organizations of complementary capacities. The core partner institutions include TERI (The Energy and Resources Institute) New Delhi; Gram Vikas (GV), a grassroots, community development organization in rural Orissa; SDC (the Swiss Agency for Development and Cooperation) and Sorane SA, a technical consulting firm based in Switzerland.

2. Charting Project Progress

The project was envisaged in two phases:

- Technology Development Phase*:* October 2002 to December 2003, which aimed at developing and testing a small gasifier based 100% producer gas engine power system, and
- Pilot Phase: January to December 2004, which envisaged Field-testing at Gram Vikas and technology transfer for promotion in rural areas of India.

Key elements of the technology development phase:

- A charcoal-based gasifier system, suitable for rural electrification was developed and tested at TERI's Gual Pahari campus. This was expected to provide inputs into the (future) development of a second generation, 100% wood-based gasifier, which once ready, would be disseminated in 5-10 remote villages in Orissa.
- The charcoal-based system was installed at village Kanheiput in Orissa in 2004 as a pilot project. This is owned and managed by trained operators from the community, with technical back up support from TERI and GV.

Major outcomes of the technology development phase:

- Technological innovations, including the replacement of the LPG generator with a pedal powered blower, which eliminated the use of external energy source for starting the system; and an electronic governing system and automatic grate shaker, that significantly improved system performance and manageability of the system.
- Intensive capacity building of GV staff and the gasifier operators, in TERI's Gual Pahari campus, and hands-on training on the Kanheiput gasifier.

- Lighting, fans, televisions and water lifting benefits for Kanheiput villagers. Other planned productive applications, such as a huller and a flour mill, however did not take place, because of a variety of constraints.

Before the project could be scaled up however, a number of pressures surfaced, which ultimately led to the closure of the project before all the planned outputs could be achieved.

- Biomass availability in Gram Vikas villages: The starting point for LIBERA was the understanding that many GV villages had established plantations, which could provide adequate biomass resource to support a biomass gasifier. In 2004 however, when the project was at the brink of scale up, it was realized that most of these plantations were either non-existent or not available; and the figures and estimates on which this assumption was based were no longer correct.
- Demands placed by other external factors, such as TERI being awarded funding for another gasifier project, which created pressure on TERI to have in place a working wood based within a limited time-frame.
- Gram Vikas was unable to secure the requisite certificates and authorizations it needed to proceed with other pilot projects in Orissa; thanks to the state bureaucracy. In particular it could not secure the necessary non-electrification certificates from the local electricity distribution company.

The LIBERA project came to a close in March 2005. The work done during the project did, however, lead directly to the subsequent development of a wood-based system by TERI and its installation in remote villages in other parts of the country. It also provided an impetus for further developing the energy programme of Gram Vikas.

3. Project Achievements

The LIBERA project was innovative in the way it was conceptualized; in the way biomass based energy service provision was visualized as something more than 'electricity supply'; and in the way it brought several key players together to collaborate and pay serious attention to biomass as a resource. Key achievements of the project are as follows:

a. A* prototype *model of rural energy service provision: The LIBERA project provided a model for energy service provision to remote rural areas, a model that brings biomass to center-stage as a fuel, that goes beyond electricity provision and addresses core issues of rural poverty by linking energy service provision with productive applications, and that is community-driven.

b.* Contribution *to national policy debate: The project contributed, to a large measure, to the national policy and programme development in the early 2000s, when the government was re-looking at the rural energy policy, which finally culminated in the launch of the Village Energy Security Programme (VESP). The lessons from LIBERA are particularly relevant in the VESP context, and the fact that there are more than 25,000 villages that require power supply of 5–25 kW daily, but are located in areas too remote for grid supply to be financially viable. Community managed, and decentralized biomass based gasifiers could be a viable option for these. It is somewhat difficult to cull out the direct impacts LIBERA had on government policy, however several of the policy developments that occurred were indeed in line with the goals of LIBERA and which LIBERA lobbied for included:

- The clear and specific inclusion of livelihoods development as a specific goal of energy provision (in both RVE and VESP)
- The development of integrated 'energy security' programmes that targeted energy service needs as opposed to focusing on the supply of a specific energy technology
- A rise in the level of subsidization proposed by the government
- The promotion of power plants sized to demand (In 2003, MNES began to promote smaller scale gasifier systems, more in line with the needs of smaller villages)

c.* Technology *development in biomass based power gasifiers: In technology development for biomass gasifier for power generation, the LIBERA project claims several achievements, some of which are:

- Development of a charcoal based power plant package of 10-15 kW capacity.
- Fine-tuning of the system to make it suitable for remote areas, by addressing issues of:
    - Inadequate preheating of air going into gasifier, resulting in higher tar content in raw gas
    - High maintenance requirement due to sticky tar deposit formed due to direct gas-water contact and condensation of tar
    - Wear and tear of engine piston rings-cylinder due to impurities in cleaned gas
- Introduction of a pedal operated starting system, negating the use of diesel
- Simple, easy to maintain alternate dry system configuration developed consisting of
    - In-built effective air pre-heater located inside gasifier shell
    - Dust settling chamber, gravel bed filter, cyclone for removing particulate in hot gas condition
    - Dry gas cooler (water film outside gas carrying duct and water is re-circulated and cooled using desert cooler concept) avoiding generation of tar laden wastewater and the associated disposal problem
    - Charcoal bed for tar adsorption
    - Simple foam filter to absorb mist as well as very fine dust and safety paper filter
- Development of standardized comprehensive tar dust content measurement protocol and apparatus
- Detailed tar and dust content measurement was carried out to systematically evolve final gas cleaning cooling configuration so as to reduce tar-dust content to minimal possible level with keeping system configuration low cost and simple.
- Standardization of engine parameters for 100% gas engine operation based on trial testing with existing 2-cylinder 100% gas engine
    - Procurement and modification of 3 cylinder gas engine of 15 kWe capacity
    - Development and trial testing of engine governor and speed control mechanism
    - Long duration testing of system with 2 and 3 cylinder gas engine with charcoal as fuel

d. A* Collaborative *model of rural energy service provision: SDC facilitated and brought together a complementary set of skills vested in a number of organizations, each an expert in its own field. The project forged new partnerships e.g. TERI–DTU-Sorane SA and strengthened the existing partnerships e.g. TERI-GV. The signing of a tripartite agreement between TERI, Sorane and DTU provided an opportunity for a systematic peer review of the technology by DTU.

***e.* Enhanced *visibility and recognition of TERI and GV* as organizations with competence in rural energy**

4. Lessons learnt

a. Complexity in livelihood improvement through energy services in rural areas: The goal of livelihood improvement and poverty reduction influences and is influenced by a range of parameters. Firstly, it must be recognized that energy by itself is capable of making only a beginning in the process of rural transformation and poverty reduction. Beyond that, as seen in village Kanheiput, other inputs are necessary to bring about more profound changes, especially the elimination of poverty. In particular, two kinds of inputs must be ensured, if energy services are to be optimally utilized for poverty reduction:

- Physical inputs, such as transport infrastructure, communication facilities and access to markets
- Inputs to develop human and institutional capacities of villagers (in areas of education, skills training, exposure, vision building and community organization)

Another important factor to be recognized, especially in the context of remote villages, is that *technology absorption* is a slow process. In newly electrified villages, it is unrealistic to expect villagers to become overnight, or even over a few years, highly effective entrepreneurs when they are in fact, first time users of modern energy services. Conservative goals such as increased cropping and value addition to agricultural and forest products through energy inputs into irrigation (as compared to large economic gains from new improved income generating activities) may be more realistic in the initial stages.

b. Investments required in facilitating demystification of technology: The LIBERA project highlighted the complexities involved in implementing biomass energy projects, including those related to handling the technology, management of biomass supply, and community issues at the field level. It takes a long period of sustained investment and handholding for a rural community to build their skills sufficiently to handle a power gasifier confidently. It also brought to the fore organizational issues related to competence pooling, handling inter-disciplinary teams, and the logistics of providing high quality service at remote locations.

5. Way forward

The LIBERA project provided an impetus to the ongoing work on rural energy, in a big way. Apart from contributing to the ongoing national debate on remote, rural electrification, both TERI and Gram Vikas used it as a basis for their further work in the area.

a. Generating a body of experience through implementation projects: Post LIBERA, TERI has undertaken a number of pilot projects for gasifier-based decentralized power generation for rural electrification in collaboration with other institutions. These include a pilot system of 10 kWe capacity, at village Deodhara in Komna Block, Nuapara district in Orissa; and one at village Jemara, Korba in Chhatisgarh, and another at village Bhaogarh, Anta district in Rajasthan, both implemented in collaboration with the NTPC (National Thermal Power Corporation).

b. Building Gram Vikas's rural energy portfolio: Since LIBERA, Gram Vikas has been actively implementing community-based energy programmes using bio-diesel, biogas, micro hydro, smokeless chulhas, and solar photovoltaic applications. As envisaged in LIBERA, Gram Vikas views energy as a service and a means to development, and promotes integrated solutions to address rural energy needs, where each project is directly linked to one or more of the core programmes. LIBERA was instrumental in building the technical capacities within Gram Vikas, which gave it the confidence to venture into new areas such as micro hydro.

c. A roadmap for gasifier technology development: The LIBERA project made many technological strides, including development of a charcoal based power plant package of 10-15 kW capacity and its field-testing in a rural location. This provided useful operating experience and data for assessing technical and economic viability of the system. Specifically, it led to initiation of R&D work on:

- Low tar two-stage wood power gasifier. The idea was introduced by the DTU team during the LIBERA project and TERI has further initiated work on the concept.
- The need for efficient charcoal making process was realized during the field demonstration at village Kanheiput. This has led to initiation of work on efficient charcoal making systems including turbo-stoves.

Section 1: The Context

In this Section…….

Chapter 1: Introduction

1.1 Background

In this chapter…….

Background….

Structure of the document….

The LIBERA project (**L**ivelihoods **I**mprovements through **B**iomass **E**nergy in **R**ural **A**reas) was a pioneering rural energy initiative conceived, developed and implemented by consortium of partners between 2001 and 2005. The goal of LIBERA was to bring about concrete and sustainable improvements in rural livelihoods –and the project sought to achieve this by:

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The project targeted the remote tribal communities of rural Orissa.

During its active life, LIBERA represented one of the country's more strategic rural energy initiatives. With its focus on collaboration and competence-pooling between organizations of complementary capacities, it represents a partnership model that is worthy of replication in the future. The core partner institutions include TERI (The Energy and Resources Institute) New Delhi; Gram Vikas (GV), a grassroots, community development organization in rural Orissa; SDC (the Swiss Agency for Development and Cooperation) and Sorane SA, a technical consulting firm based in Switzerland.

This documentation describes the activities pursued under the LIBERA project and attempts to analyze its successes, shortcomings and major lessons. As with all such work, the project did not take place in isolation and was affected by and also sought to influence the national policy environment. In addition to the project's material outputs and policy level impacts, the documentation attempts to cover the processes used to develop, implement and manage the project.

1.2 Structure of the Document

The document in structured in three sections:

Section 1 provides the context and background of the LIBERA project and is divided into two chapters. The current chapter serves as an introduction to the project, outlining the objectives of the documentation and the areas covered. Chapter 2 sets the backdrop and context of the project, in terms of the role of energy for the poor, the relevance of biomass based energy, and the policy context within which the LIBERA project operated.

Section 2 forms the core of this documentation and chronicles the project activities, as they took place. It starts with the genesis of the project presented in chapter 3, followed by a project sketch, including defining project objectives and the institutional setup, in chapter 4. Chapter 5 documents the pilot phase of the project, including the technology development process, and the field testing in Kanheiput village, in terms of the progress made, achievements and lessons learnt. Chapter 6 documents the challenges faced in further upscaling of the project.

The last section starts with chapter 7, which discusses the achievements made by the project, followed by chapter 8, which presents a synthesis of the experiences in terms of lessons learnt and way forward.

Chapter 2: Biomass Energy and the Rural Poor

2.1 The Broader Context: Energy Services and the Poor

In this chapter…….

The broader context….

The option of biomass energy….

Government focus on rural energy….

Positioning LIBERA in the national policy context….

Worldwide, more than two billion people are dependent on traditional biomass fuels for cooking and either lack completely or suffer from inadequate access to affordable modern energy sources such as electricity and gas. For most of these people, poverty and energy insecurity walk hand in hand. In the absence of modern energy infrastructure, local biomass is often the only fuel available for meeting their energy demands. The energy services available are limited to what can be delivered using the traditional fuel conversion technologies. Apart from being inefficient and 'dirty' (polluting the local environment and with detrimental health affects to the users), the traditional biomass technologies tend to be rather limited in the services they can deliver. As such, these communities suffer from a lack of access to a range of energy services necessary for productive activities and the reduction of labour intensive tasks such as water pumping.

Improving people's access to energy services can contribute to quality of life improvements on one hand, and economic and social development, on the other, by improving the range of choices available for livelihood strategies. The supply of improved energy services can

- Reduce daily drudgery, particularly for women, through labour saving devices such as water pumps and mills and increase the time available to engage in agriculture, food processing, cottage industries and education.

- Facilitate development of new livelihoods and improve the efficiency and productivity of traditional ones through the powering of small machines (such as leaf plate presses).

- Reliable, quality lighting makes villages safer and after-school education possible.

- Access to electricity, especially in remote locations, makes people feel *included* in mainstream society.

- Electricity can create additional monetary income through the powering of irrigation pumps, thereby allowing the production of more crops (grain, fruit, vegetables), thereby increasing the volume available for sale.

- Electrical lighting can extend the productive hours of a day, enabling processing activities and home based industries to operate after dark.

At the same time however, access to modern energy services alone cannot reduce poverty, nor does it automatically lead to sustainable improvements in quality of life for the poor. The supply of electric lights or mechanical power does not automatically mean that these will be productively utilized. Indeed, many past initiatives in rural energy focusing only on the *supply* of energy have floundered in their efforts to reduce poverty precisely because they have failed to link this supply to concurrent efforts to see that communities are supported to use this energy productively to improve their livelihoods. This link between energy and livelihoods may seem obvious; however, it has often been ignored.

The price people pay for energy poverty*

Energy poverty increases the actual cost people pay for the energy services they have and simultaneously inhibits their ability to increase their productivity. In the absence of 'grid' electricity, if people want light, they are forced to use torches, lanterns or candles. For cooking, women and children spend long hours every day collecting firewood.

…Light from a battery-powered torch costs ~30 times more than the equivalent light generated from 'grid' electricity, light from a kerosene lamp costs 70 times more and light from a candle around 150 times more (ESMAP 1999).

…The opportunity cost of the effort made in fuelwood collection goes far beyond hours of labour; it translates into hours away from other productive activities, in agriculture, in other livelihood activities like craft, in paid employment; hours away from school for girls who assist their mothers in fuelwood collection; curtailed rest hours for women; lost opportunities of self improvement and so on.

* Energy poverty can be defined as "the absence of sufficient choice in accessing adequate, affordable, reliable, high quality, safe and environmentally benign energy services to support economic and human development" (Reddy 2000).

2.2 The Option of Biomass Energy

There are a number of technological options available to meet the energy needs of remote, rural locations. Use of decentralized diesel generators is a widespread strategy; they are cheap to install and relatively easy to maintain; albeit not an environmentally friendly option. Another bottleneck is that the remoteness of these communities and limited transport infrastructure often makes diesel an expensive and difficult-to-access commodity. Renewable energy technologies (RETs) such as solar and micro-hydro can provide effective solutions. Both of these however come with their own inherent limitations: solar has excessive capital costs per unit of installed capacity, while hydro is limited by resource availability.

Decentralized, biomass-based energy systems such as power gasifiers on the other hand, offer a variety of benefits particularly suited to remote, rural communities. Firstly, biomass is by far the most abundant and widespread resource available in remote villages. In addition to forests, there are other biomass resources generally available in rural areas, including:

Procuring diesel in remote villages…….

The remote tribal communities of Orissa targeted by the LIBERA project represent some of the most remote communities in India. Often located high in the hills amongst jungles and rarely connected by roads, fuels such as diesel and petrol play little role in their lives. Even though kerosene is relatively more readily available through the public distribution scheme and used by many for lighting, it needs be collected from often distant godowns and hauled up the hills. Given such conditions, diesel dependent systems do not present an appropriate solution.

- oilseeds (for biofuels); either as crops (like *niger*), grown on field bunds (like *jatropha*), or collected from the surrounding forests from oil bearing species,

- fuelwood; either from established plantations or dedicated plantations-to-be, or through Joint Forest Management (JFM's) agreements granting villagers access to reserve forest areas for wood collection, and

- under-utilized agricultural residues like weeds and grasses, sometimes straw, and leaf-litter.

Where these are not already extant in the village environment, they can be easily produced and/or established using traditional skills and practices already present within these communities. To ensure that biomass supply systems remain sustainable, plantation development activities can be coupled to the establishment of the gasifier system and its management.

Biomass based gasifier systems offer combined benefits of renewability, decentralization and availability on demand without the need for separate storage of engine fuels. When appropriately designed and implemented, biomass based gasifier systems offer a number of advantages[1]:

- They can deliver clean and convenient, locally affordable and reliable energy to rural communities.

- By using biomass as a fuel, costs and difficulties associated with the purchasing of external fuels such as diesel can be avoided.

[1] The basic principle of gasification is explained in Annex 1.

- Systems can be readily scaled/configured to meet productive and domestic loads.
- Gasifiers enable the provision of a wide range of energy services: intermediate stage fuel produced by gasifiers (producer gas) can be used for both thermal applications and used in engines for motive power and electricity production.
- The resultant energy services can be made further cost effective by producing the wood in local forests and plantations and by integrating the harvesting of required biomass into traditional systems of collection.
- Power gasifiers can deliver improved energy services which actively encourage and strengthen the local systems of biomass based agrarian livelihoods and subsistence.

In addition to these benefits, biomass based power plants also prove to be the most economic of a range of RETs.

The one serious issue with using biomass for electricity generation is its sustainability. Even though biomass is renewable in the technical sense (can be re-grown), competing pressures on its use (for house construction, fodder, fencing material etc.) and its over-use can lead to severe biomass degradation. Where properly managed, biomass resources have the potential of sustainably meeting the energy needs of a community. Where demands cannot be managed however, biomass resources can be easily degraded and destroyed. It is therefore necessary to ensure that adequate plans are made to establish sustainable biomass supply systems that can be coupled to biomass energy systems where-ever they go in.

In summary, biomass can supply fuel for cooking and heating, for the production of combustible gases, and for the production of biofuels to supplement or entirely replace fossil fuels such as diesel. With efficient technologies, it can deliver modern energy services at a much lower capital cost than solar, is more accessible and affordable than diesel and is directly compatible with traditional cultural norms of energy provision. And because of its widespread availability, particularly in remote areas, biomass based energy technologies have a much greater geographic scope of applicability than wind- and hydro-power. Coupled to community empowerment and livelihoods initiatives then, biomass energy systems represent the most appropriate means of bringing improved energy services to a large number of India's remote rural villages.

2.3 Government Focus on Rural Energy

The lack of modern energy services has long been acknowledged by the government as a serious impediment to development and a major cause of poverty. Over the years, a number of programmes have been undertaken by the Government to improve energy services in rural areas. The specific focus and reach of these has varied: while some have been technology specific, others have adopted a more 'integrated' approach, addressing rural energy needs through a combination of technologies. In terms of coverage, grid extension for household electrification and energization of agricultural pump-sets are among the largest. Among renewable energy programmes, biogas plants and improved cook stoves for cooking, and small solar power units for lighting have been the major programmes. Other programmes include development of biomass gasifiers for thermal applications and water pumping; and development of micro-hydro for electricity and milling, particularly in the mountainous states.

These programmes have, unfortunately produced only sporadic success that has been far from uniform and often highly limited in scope. The reach of these programmes has neither been as extensive as hoped for, nor consistent in their impact between states.

After six decades of rural electrification programmes,

…India still has more than 96,000 villages that are un-electrified, and

….less than 45% of its 138 million households use electricity for lighting.

Electrification of remote, rural areas continues to be a daunting challenge. The economics of remote rural electrification based on grid extension are generally unfavorable, mainly due to high costs involved in grid extension, higher grid losses coupled with small loads and low tariffs. Out of the 96,000 or so un-electrified villages, the Government has identified 25,000 as remote, and difficult to access. For these un-electrifiable villages, decentralized power generation systems are desirable. Electricity needs of these villages are generally in the range of 5-25 kW depending upon the village size and population. It has been proposed that these villages should be electrified through renewable energy sources (e.g. biomass, small hydro, solar PV etc.).

Annex 2 summarizes the major rural energy initiatives undertaken by the Government which had an influence upon LIBERA's development and progress. In general, the older programmes tended to address the issue from a purely technological perspective, while the newer programmes are broader in their scope and recognize the role that energy can play in securing a quality of life and improving livelihoods. The two government initiatives that were launched during the life time of LIBERA, had considerable impact on the project and were influenced by it were the RVE (Remote Village Electrification) Progamme and the VESP (Village Energy Security Programme). The RVE, launched in 2003, aimed to deploy RETs such as solar photovoltaics, small hydro, biomass and hybrid power systems for the electrification of remote villages and hamlets which were unlikely to get covered through grid extension in the near future. The VESP was an improvement over the RVE concept as it goes beyond just electrification and seeks to address communities' total energy requirements for cooking, electricity, and motive power. This is to be achieved through primarily biomass based energy technologies and, where these were not feasible, other RETs. In a significant departure from past planning processes, the VESP outline plan was prepared by the Ministry in association with forestry officials from the Ministry of Environment & Forests and the states.

2.4 Positioning LIBERA in the National Policy Context

In 2003, when the LIBERA project was being oprationalized, there existed few successful models for the development of reliable and affordable energy supply systems in remote villages. To a great extent, this was due to a lack of mature technological options available at that time. Only solar power had reached any great level of commercialization, yet its cost on any scale larger than basic home lighting units made it prohibitive for village electrification. Other than solar - and aside from hydro and wind energy technologies with their limited applicability, there were hardly any viable alternatives.

Research work on use of biomass for decentralized electricity generation is being carried out since early 80s in India. Jyoti Solar Energy Research Institute, in Vadodara, Gujarat (presently SPRERI, or Sardar Patel Renewable Energy Research Institute) designed its first system to power a 5 hp irrigation pumping system. The first gasifiers developed in India were of small capacity, and for single use applications. It was only later that these and other similar gasifiers were further developed for multi-use applications, including for electricity supply.

There has been some experience with dual fuel engine gensets for producing electricity, which utilize producer gas (produced through gasification) for small-scale decentralized power generation. In a dual fuel system, diesel is required for pilot ignition, and up to 70% of the diesel required can be replaced with producer gas. TERI was one of the first institutions to do so successfully: it operated a small 7 kVA (kilovolt ampere) combined briquetting gasification system using biomass briquettes made of sawdust, coconut pith, mustard stalk, pearl millet stalk, and groundnut shell for more than five years in Dhanawas village in Haryana. The power produced was used in the local temple, for street-lighting and also to produce the briquettes it used as a fuel. This system was a dual-fuel system originally intended for operating an irrigation pump. In 1988, IISc (Indian institute of Science) Bangalore, installed a 5 hp dual-fuel system in Hosahalli, a non-electrified village in rural south India. The system was coupled to an alternator and provided electricity to households, pumped drinking water and ran a flour mill. It achieved more than 65% diesel replacement, with specific fuelwood consumption values of 1.5-2.0 kg/kWh and its performance was monitored for more than three years. Unfortunately, due to problems associated with high cost of diesel and ensuring continuous supply of diesel to remote villages, dual fuel systems have proved to be of limited use in remote rural electrification. Until recently, there were no widely proven systems that use 100% biomass.

Over the two decades prior to LIBERA, Gram Vikas, TERI and SDC had all been involved in one or more of the government initiatives in the rural energy sector. LIBERA, a collaborative project of GV, TERI and SDC, formally launched in October 2002, was greatly shaped by their experiences. In a sense, LIBERA was the culmination of the individual experiences and expertise of the three organizations in the field of biomass energy. Begun in 2002 and running until 2005, the project was notable for bringing together institutions of differing skills on a common platform for exploring the issues involved in remote village electrification. Over this period, the LIBERA concept was fully developed; a project dissemination plan created; and a pilot system developed and installed in a small tribal village in Southern Orissa. In addition to these material outputs, LIBERA offered its core project partners, Gram Vikas and TERI, an opportunity for reciprocal capacity building, which helped develop their individual capacities to effectively pursue rural energy work, both in partnership and alone. It also served as an effective tool by which Gram Vikas and TERI could promote key principles linking rural energy supply to socio-economic benefits. In the following chapters, we examine this experience in further detail.

Section 2. The LIBERA Project

In this Section…….

Chapter 3. The Genesis of LIBERA

3.1 Getting Started

In this Chapter…….

Getting started….

LIBERA concept….

LIBERA: a dynamic reference framework….

The LIBERA project was a response to the existing rural energy issues in early 2000s. In 2001, when the activities that led to the LIBERA project began, levels of access to energy services in rural Orissa (where the project was being planned) were abysmally poor, with more than 6000 villages un-electrified. Burdened with an inefficient and far-from-extensive grid; an uninterested, privatized electricity sector; and a passive state government, there was little hope amongst remote villages. For Gram Vikas, an NGO working with the tribal poor of Orissa, this was a reality to live with. Since early seventies, GV has been addressing rural poverty issues, working on diverse areas from health and housing to natural resource development, community mobilization and empowerment, rural energy, micro-credit and education. Among others, Gram Vikas implemented an extensive programme of establishing community-owned social forestry plantations, in over 200 villages, strengthening the local resource base of involved communities and providing fuel, fodder, timber and fruit for consumption and sale.

As part of the initial brainstorming and assessment, a series of joint field visits were undertaken by TERI, Sorane SA and GV. This included a pre-feasibility mission to assess the biomass availability, subsistence and livelihoods patterns amongst the target communities; followed by a field survey of selected villages in Orissa; culminating into the development of an action plan for the project. The information collected during these visits helped build a clearer picture of the conditions in the concerned villages: what the principal livelihoods and means of food production are, what energy services and technologies are available, and what is the level of physical and social infrastructure and natural resources.

Two significant conclusions, that had serious implications for the future of the project, were drawn: Firstly, it was concluded that there were sufficient biomass resources present in GV villages to support the operation of biomass gasifiers. Secondly, there seemed to be significant potential for utilizing energy services to enhance livelihoods within the targeted villages. The field visits also made it amply clear that the villages GV wanted to electrify were so remote and poor that the gasifier would need to be fully biomass based, with no reliance whatsoever on diesel or any other fuel. Finally, the technology would have to be simple enough for trained villagers to operate and maintain, with occasional external support.

The complexity of the situation also indicated that to successfully achieve these multiple objectives, the project needed to adopt a truly collaborative approach to all its work, skill-sharing and capacity building. This was in contrast to the past project-specific collaboration between TERI and Gram Vikas, in which each played its respective role much more strictly.

3.2 LIBERA Concept - The Joe-Pierre Diagram

In the months following this initial round of work, Joe Madiath, the Executive Director of Gram Vikas and Pierre Jaboyedoff of Sorane SA set about developing and defining the project concept around the core idea of achieving Livelihoods Improvements through Biomass Energy in Rural Areas. The two driving forces were:

- Development of village livelihoods as the ultimate goal of the project, as against just providing electricity; and
- The availability of the 200-odd community social forestry plantations established by Gram Vikas, as a resource on which to base the project.

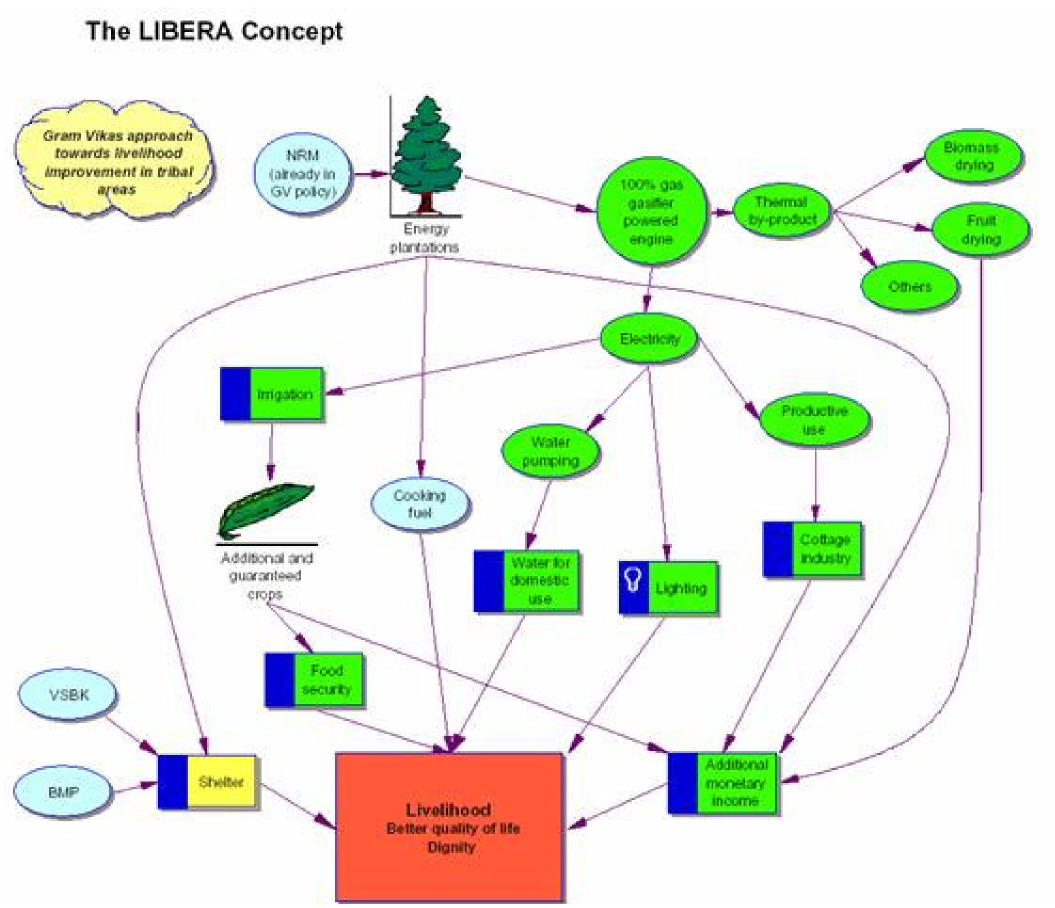

Figure 1. The LIBERA Concept Diagram

The result of this development process was the LIBERA concept diagram, or *Joe-Pierre diagram* as it was often called, which depicts the working vision of the LIBERA project. Rooted in an appreciation for energy sources to promote livelihood development in remote villages, the diagram draws critical links between energy supply and its application for improving agricultural production; powering cottage industries; providing lights for safety, education and domestic needs; and powering pumping for safe water supply to a remote, rural community.

The Joe-Pierre diagram makes a further distinction between the fuel, the energy it can produce and the service provided (figure 2).

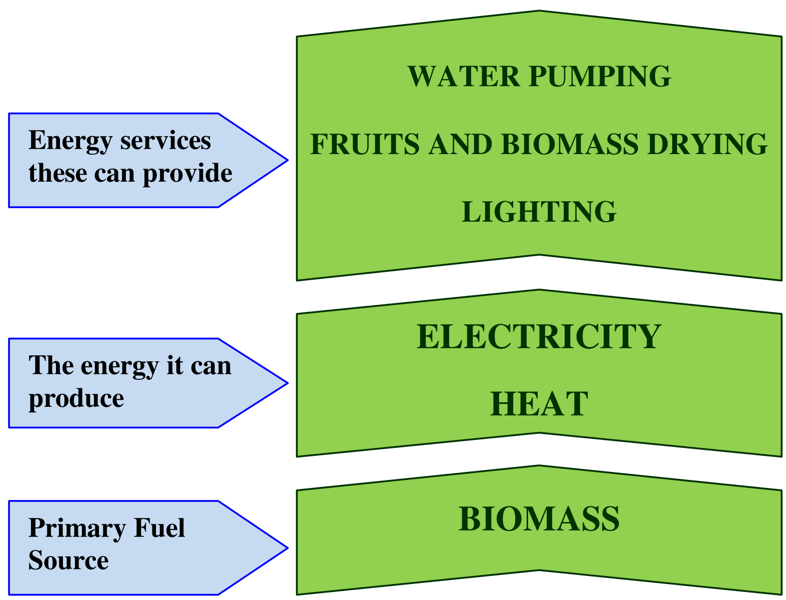

Figure 2: Fuel, Energy and Energy Services

By doing so, links could then be made between the various forms of energy supply available using biomass and the potential demands for the energy services these could provide. This meant the project was not bound to the delivery of one form of energy alone and ensured that the project remained focused on the end goal of improved livelihoods, which could be achieved through a variety of paths.

The LIBRA concept: what it means in a remote village …….

In remote villages, starting from the premises of absence of grid electricity and availability of biomass resources, activating the LIBERA concept would necessitate a number of simultaneous processes:

- For the plantations to sustainably produce woody biomass sufficient for running a power gasifier and meeting communities' other requirements, appropriate biomass management strategies needed to be established.
- The actual technology would need to be developed to use this biomass.
- Given the low levels of education and no prior exposure to technology, the design and operation of the gasifier needed to be simple and inexpensive to operate and maintain.
- The system needed to be of a scale and design suitable for powering a range of productive applications. The thermal by-product needed to be available for a variety of applications, depending on need; and the electricity produced of a quantum large enough to provide services such as pumping, milling and lighting.

Put together, these processes, technologies and initiatives would facilitate significant improvements in people's quality of life and dignity.

3.3 LIBERA: A Dynamic Reference Framework

The LIBERA concept diagram was not a plan; instead it served as a reference framework that helped guide the project. Neither was it static- as new ideas developed and lessons learnt, the diagram was subject to re-interpretation.

The one significant change that was made to the original concept diagram was the explicit inclusion of food security at the village level, which occurred during a project planning meeting in June 2003. Ensuring food security (the production of additional and guaranteed crops) was identified as being of equal, if not higher, importance than the augmenting the monetary incomes in the target villages. Prior to its inclusion, the means by which electricity supply affected *improved livelihoods* through i*rrigation* was indicated only by the production of *additional crops*. Without any further indication as to how these additional crops were to improve *livelihoods*, there was the risk that it would only be interpreted as crops for sale and not for consumption. The explicit inclusion of *food security* ensured that in villages where the most pressing need was for food, energy supply would be directed towards this and not towards increasing local income (possibly through production of more cash crops). In doing so, the project was better able to account for the stark reality of abject poverty and hunger in many of the target villages.

Later on, during another workshop in August 2003, the definitions for both livelihoods and food security were further clarified and broadened. It was agreed that *livelihoods*, could mean a whole range of economic and non-economic activities ranging from the processing of NTFP (Non Timber Forest Produce) to the creation of employment opportunities; while *food security* would be defined to include access to sufficient food, production of sufficient food as well as access to health-care. As such, the number and diversity of activities that could positively impact on village livelihoods and food security was far greater than originally planned for and the ability of the project to effect improvements in them needed to be re-assessed in light of this.

This LIBERA *concept development process* was an intellectually stimulating exercise for the team. By frequently challenging conventional wisdom and questioning the rationale for the activities being undertaken, it forced the project partners to constantly evaluate the direction being taken and the degree to which their actions remained in line with the concept. Also furthering this process was the interplay between the various skills, experiences, and experiential learning of the partners.

Chapter 4. Project Sketch

4.1 Project Objectives

In this Chapter…….

Project objectives….

The LIBERA partnership….

To achieve the goal of effecting concrete and sustainable improvements in village/ community livelihoods, the LIBERA project aimed to deliver biomass based micro-energy systems to those tribal villages in rural Orissa unconnected to the main electrical grid and expected to remain so for the foreseeable future. A number of objectives needed to be met, namely:

- The development of a small biomass based energy system capable of delivering reliable and affordable energy to remote rural communities of a capacity sufficient to meet their domestic and productive needs; that was operable by them (with training), and appropriate to local conditions;

- The development of an appropriate dissemination plan for the technology package.

In addition to the above, the project was seen to have other, equally important objectives, which were:

- Development of closer institutional ties between GV and TERI as a means of more effectively pursuing their shared vision of alleviating rural poverty through the supply of secure energy services.

- To use LIBERA as a means by which project partners could effectively lobby government for positive changes to state and national rural energy policies.

- Development of technical partnerships with individuals, R&D institutes and organizations whose skills and experiences would benefit not only the immediate project, but also stimulate longer term work of developing reliable biomass based power gasifier technologies for rural energy supply.

In line with these objectives, the project was visualized to have two major components:

October 2002 – December 2003

Phase 1: Develop and test small 100%gas based power gasifier system for its long duration performance and reliability

Work elements:

- Startup phase (October 2002 to February 2003): Long duration testing of existing concept prototype and getting insights for developing improved system configuration
- Development of field prototype (March to May 2003): Development and fabrication of new system configuration based on experience and insight gained during long duration testing
- Laboratory testing (June to December 2003): Systematic laboratory trial testing to evolve system configuration through performance monitoring, and long duration testing of prototype for gaining confidence with respect to reliability

January – December 2004

Phase 2: Field-testing at Gram Vikas and technology transfer for promotion in rural areas of India

Work elements:

- Continuation of long duration testing (January to February 2004): Gaining further confidence of final system configuration, training of GV field staff at Gual Pahari, design of field prototype for improvising design
- Fabrication-installation-commissioning of system at village Kanheiput (March to May 2004): The gasifier was fabricated at Mumbai and the engine modified at Delhi. Both systems were transported to field testing site at village Kanheiput in Ganjam district of Orissa and commissioned on 11th May 2004.
- Training of field operators (May 2004)
- Field performance monitoring (June to December 2004): Systematic field performance monitoring to test system reliability under field conditions, to assess its acceptability, and to understand the maintenance requirement

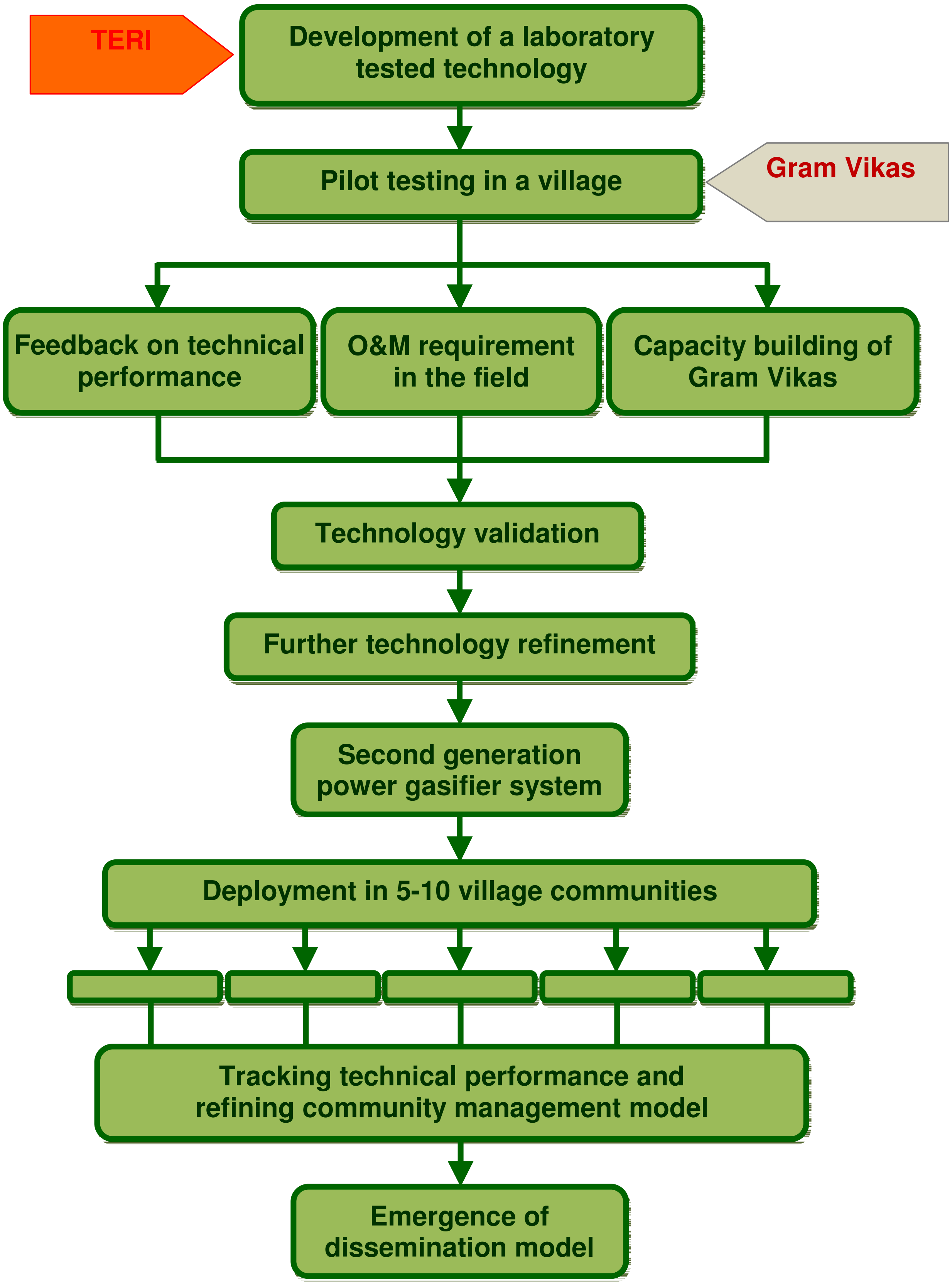

Figure 3. Implementation model of LIBERA

4.2 The LIBERA Partnership

Skills and enabling conditions required to operationalize LIBERA

- Technical skills for developing an appropriate technology package
- Real but supportive environments to pilot and test the technology
- Field staff experienced in working with tribal communities in Orissa
- Skills in assessment of rural livelihoods and food security
- Skills in developing and implementing livelihoods programmes in remote tribal communities
- Coordination, facilitation and networking skills to bring about effective competence pooling between various partners
- Organizational support and resource allocation for both hardware and software (human and institutional development)
- Capacities and means for influencing policy with the local and national government

At the outset of the project, it was recognized that the development of a gasifier appropriate to LIBERA's needs would require a pooling of skills of all project partners, and, where necessary, inputs from a range of external supporting actors. It was understood that this would not be an overnight affair and would require a multi-stage process of laboratory and field trialing, review, redesign and re-trialing. The process would need to be accompanied with concrete mechanisms for delivering feedback on performance and other design parameters on a regular basis.

Brain storming on technology development

It was against this backdrop that the operational make-up of the LIBERA project emerged and a core partnership between Gram Vikas; TERI (the Biomass Energy Technology Applications - BETA group); SDC and Sorane SA was forged. At various stages, other individuals and institutions, such as experts on forestry and biomass assessment, rural energy, livelihoods and food security, gasification and gas engine technology, were called upon, incorporating new thinking on emerging issues.

	Role in LIBERA	Expertise
TERI	To provide technical assistance to Gram Vikas in providing technical solution/option: • Oversee and support the manufacture of the pilot biomass gasifier systems and their transport to the field • Install and commission the project field pilot systems (1st and 2nd generation) • Ensure adequate transfer of operation and maintenance skills to GV staff • Ensure adequate ongoing technical support for problem troubleshooting, performance monitoring or alterations to the system	A premier research institute in energy and sustainable development: • Development and design of biomass based thermal gasifiers for use by the rural cardamon, areca nut, and silk-reeling industries • Development of dual-fuel power gasifier systems for village electrification and irrigation pumping
Gram Vikas	To take the lead in field testing of the gasifier, including: • Select a suitable site • Prepare the community • Build capacity of staff and local operators • Ensure regular data-logging and providing feedback on further technical improvements • Primary responsibility for the dissemination phase	Established in Orissa in 1979, Gram Vikas works with over 400 habitations or more than 20,000 households in the fields of water supply and sanitation, health, education, watershed and land development, disaster mitigation, access to land and services and rural energy supply
SDC	Overall steering role for the LIBERA programme: • Programme development • Facilitating linkages with the government • Organize technical backstopping services • Ensure funding in line with approved budgets and an action plan in conformity with major decisions taken • Financial monitoring and controlling.	Promoting constructive partnerships for sustainable cooperation. • Values and invests in relationships between its partners, thereby optimizing interactions; • Endeavors to identify changes in the context of the partnership so as to effectively address them • Ensure openness and transparency in communications and interactions
Sorane SA	Provision of high-end technical expertise aimed at enhancing and fast-tracking the development of the gasifier technology at TERI. Pierre also played a major role in coordination and network development for the project. Being a joint-author of the LIBERA concept diagram, he was instrumental in the collaborative concept level management of the project	• Sorane SA is an engineering consulting company based in Switzerland specializing in energy efficient design. Helps and assists private companies, government agencies and non-government organizations and individuals • Develops solutions that take into account long term energy issues and the needs of the target audience

Chapter 5. Recounting Progress: the Pilot Phase

In this Chapter…….

Technology development phase….

Piloting at Kanheiput….

Major outcomes of the pilot phase ….

5.1 The Technology Development Phase

The starting point and the core of phase 1 of the LIBERA project was the development of a biomass gasifier based 100% producer gas engine power system appropriate for application in small, remote tribal communities of rural Orissa. Up to this time, power gasifiers ran predominantly on a mix of both diesel and biomass (dual-fuel systems), with the gas produced in the gasifier mixed with air before entering into the engine. This approach had proved easier to develop than systems running entirely on producer gas. Principally this was because it avoided a number of issues to do with the means of ignition and with impurities in the gas damaging the engine in 100% producer gas engine gasifier system.

Over the decade or so prior to LIBERA, TERI had developed a number of dual-fuel systems and, through this work, explored many of the issues of 100% producer gas systems. After the preliminary groundwork of the LIBERA project was done, it became clear that because of severe limitations in the availability and access of diesel, diesel dependent systems were not a valid alternative for many remote communities. The first design parameter for the technology was thus established.

Design parameters for the LIBERA gasifier

- The technology should be 100% biomass based and require no (or minimal) external or secondary fuel inputs;
- Generation plants should be small, yet of a size sufficient for meeting village requirements for domestic power, and for supporting electric irrigation pumps and powered cottage industries such as small mills;
- When fully developed, the technology should be operable by trained locals who should also be able to carry out the necessary general maintenance duties;
- Consumable maintenance materials should be low cost and locally available, to the extent possible;
- During the pilot phase of the project, standardized monitoring and documentation systems should be put in place and integrated where necessary into the system design. These would look at the load profiles for newly electrified villages with various attached rural industries; the costs and benefits of the various operation and maintenance duties; and the effectiveness of alternative management regimes.

The research and development work carried out by TERI for the LIBERA project was built on its previous, ongoing work. What was innovative about the technology development process under LIBERA was the collaborative approach, and the close involvement of a number of other parties in the process.

- Gram Vikas' involvement in the technology development process was initially limited to giving inputs on what constituted appropriate design parameters and ensuring that TERI and Sorane SA clearly understood the conditions in the target villages and the limitations these would place on the technology. As the design process progressed, however, and the prototype lab-system developed, they were able to provide more specific and actionable feedback on its expected operability. As the project progressed towards a final pilot design, Gram Vikas then turned to mobilizing resources to ensure that everything was ready on the ground for when the system arrived.

- Sorane SA's specific contribution was provision of technical guidance in technology development process. This included identification of system parameter testing techniques and methodologies, design modeling and the identification and assessment of design options. It also involved the identification of suitable partners for technical collaboration and it was through these efforts that DTU was identified as a potential partner.

- The Biomass Gasification Group (BGG) from the Danish University of Technology (DTU) was brought in to provide skilled, technical peer review that would benefit the design process and reduce the time needed for technology development. TERI, Sorane SA and DTU signed a tripartite agreement that saw DTU become officially involved in the design and testing of the prototype system in Gual Pahari.

- Over the course of the project, TERI established an MOU with Kirloskar -and subsequently Cummins Engine Division. These MOU's were established to explore and expedite the development of an industry produced, certified and guaranteed 100% producer gas operable engine, suitable for use with TERI gasifiers. This was necessary, as at that time, there were no commercially available small gas engines.

Starting in late 2002, TERI's gasifier team working on the LIBERA project had begun looking at both wood-based and charcoal-based systems and over the first six to nine months of 2003, both options were tested and trialed. By mid 2003, long hours in laboratory had produced positive results for both wood-based and charcoal-based systems. There remained, however, some outstanding issues with both systems and slightly more with the wood system. The TERI team anticipated that the expected time required to develop a working wood-based system would be long, while the charcoal-based system, a simpler technology, could be developed in a much shorter time. The charcoal based system would also be easier to manage under field conditions due to cleaner gas with charcoal gasification. Given this, and in order that the LIBERA project is able to maintain its momentum, it was decided to go ahead with the option of charcoal based gasifier system for the initial pilot. At this stage, it seemed imperative to get a pilot (of either wood or charcoal) into the field as quickly as possible as it would:

- provide valuable operating data for feedback into consequent development activities;
- provide a means by which to test a range of other accessories (such as electronic governors), also applicable to wood systems;
- allow load profile data on a newly electrified village to be gathered;
- give Gram Vikas the opportunity to familiarize itself with power gasifier technology;
- provide an opportunity to build the capacities of the technical teams of both Gram Vikas and TERI in field operation and support;
- serve as a demonstration unit to various interested public, government and funding bodies.

The charcoal-based system was regarded as an intermediate technology whose establishment and field piloting would allow the project to move ahead with its other, non-technology related work. It was also intended to provide useful operational data that would assist in the subsequent development of the wood-based system, which was clearly the long term option.

The cleaning train issues: wood vs. charcoal based system

In a gasifier, the raw gases produced have to be cleaned before being admitted into an IC engine. The tar must be washed or 'scrubbed' from it and the dust fraction filtered.

How best to do this and the degree to which it needs to be done continues to baffle the research community. At present, the most widely used system for cleaning producer gas is through the use of a cyclone, a wet scrubbing system and a filter of some kind. A wet scrubbing system involves the spraying of water into the gas stream, which cools the gas and promotes the condensation of tar which is then washed away with the water along any remaining dust particles. Although effective, this process results in the constant production of hazardous tar-laden wastewater that needs to be disposed of. It also introduces new moisture into the gas that itself then has to be removed, using a final filer.

The other approach to the problem of tar involves reducing the initial load of volatiles introduced into the system. And this is what is achieved through a charcoal based system. Charcoal is pyrolized wood - wood that has had the majority of volatile matter or tars already driven out of it. With such an approach, the cleaning-cooling train can remain dry and need only to remove dust and particulates and to cool the gas which can be achieved through a series of cyclones, dry filters and an indirect cooling system. The benefits of this system are multiple:

- the cleaning-cooling train remains simple and easy to maintain
- no wastewater is produced and the system has very low water consumption
- negligible effect of tar on the engine

Although effective, this approach comes with a cost: charcoal must be made; introducing new demand for skills, labour and hardware. Also, the net efficiency of the system is reduced as some of the energy in the wood is lost during its conversion to charcoal.

The design of low tar gasifiers is a major area of research. The Biomass Gasification Group (BGG) at DTU (the Danish Technical University, Denmark) has come up with a two-stage gasification process for producing clean producer gas. In the first stage of this system the biomass is pyrolized and converted into gas and charcoal and then is gasified in the second stage at high temperature, resulting in a low tar producer gas. At TERI, efforts are on to develop a low tar gasifier by supplying preheated air into the gasifier at two different layers; the supply of preheated air helping to better premix hot volatiles & air so that cold pockets can be eliminated.

….After looking at the difficulty to rapidly develop a reliable 100 % wood gas system, and comparing results with charcoal (tar level), the charcoal option was seriously considered as a short-term option. The parallel tests run, have shown a great difference on tar levels as well as on moisture content of the gas. A number of issues to be solved with wood as a fuel are resolved by the use of charcoal. In addition, a charcoal gasifier is "like" the second stage of the DTU gasifier, which means that all the work done on the gas cleaning/cooling and the engine remain essentially valid for the development of a two stage gasification 100 % wood gas system. In order to fast-track field tests at Gram Vikas, it was decided to develop a system working with charcoal as fuel. It allowed going for a dry cleaning system…..

Internal discussion note, TERI, and Sorane SA, November 2003

After numerous months of lab work, a reliable 100% producer gas engine based biomass gasifier power plant of 10-25 kWe capacity suitable for rural electrification was successfully developed at TERI's Gual Pahari campus. The technology development phase can be divided into two sub-phases:

Why a charcoal based gasifier:

- The use of charcoal, with relatively cleaner (low tar) gas, allowed for an easier gasifier operation in general and reduced the unknown variables in the system when it came to testing design changes.
- A charcoal system had potential application as a stand-alone system in itself.
- The use of charcoal simplified the requirements of cleaning train considerable
- The use of charcoal allowed the study of a dry cleaning train, with potential reference back to how it could be achieved in a second stage of two-stage wood system

5.1.1 Long Duration Testing of Existing "Mark 1" System

During the start up phase, between October 2002 and February 2003, the existing "Mark 1" prototype unit was operated for about 250 hours for monitoring its performance and assessing maintenance requirements. This system configuration was based on the team's past experience with 50 kWe dual fuel gasifier power system. The system consisted of downdraft throat-less gasifier with preheated air entry through 8 nozzles (4 each in two layers) with firebox insulation till the fuel grate. Hot gases pass through the cyclone separator to remove dust particulate in hot condition. In the existing prototype, the air pre-heater heat exchanger, and the SS wire-mesh filter (40 micron size) are enclosed in one large cubical MS insulated chamber. The top portion of the heat exchanger has a 40 micron size SS wire mesh filter. The heat exchanger had a water seal pond at the bottom. The gas is then passed through series of filters consisting of packed bed scrubber (bed of rasching rings), a mesh type mist separator, fabric filter (1 micron size) followed by a safety paper filter (police filter) before it enters the engine.

The system was operated daily for about 8 hours with maximum output of 8 kWe. During system performance monitoring, several shortcomings were identified in the existing design from point of view of its suitability for remote target areas.

- High heat loss due to large surface area of combined air pre-heater and hot gas filter assembly, low gas to air heat transfer due to low gas velocity on air tubes.
- Evaporation of water from waterseal pond due to direct exposure to hot gases and its condensation on air pipe reducing preheated air temperature, and causing frequent clogging of SS wire-mesh filter.
- Direct water-hot gas contact cleaning in packed bed scrubber causes vapour formation and condensation in components down the line.
- High cost of SS wire mesh, hot gas fabric filter etc may not be economically acceptable for remote rural areas for maintenance (spare part availability, cost)

5.1.2 Development of "Mark 2" System

In order to critically review the performance monitoring data of "Mark 1" system, and to get insight for developing improved gas cleaning-cooling train, a team of consultants was brought in, who debated on whether to continue with wet system (in which gas and water comes in direct contact with each other) or go for dry system (indirect cooling of gas). It was finally decided to develop a dry system instead of the wet system for cleaning-cooling of gas in order to arrive at improved "Mark 2" system.

Also, since the target locations are far remote, inaccessible, un-electrified villages where no conventional energy source is available, following factors were taken into consideration while re-designing the gas cooling-cleaning train:

- Low capital cost investment
- Use of local available material and simplicity in repair at local level
- Simplified system operation

- Less water use, minimal waste water generation for disposal
- Minimizing power consumption in gas cleaning-cooling train so as to
  - o Minimize parasitic load and maximize net output power
  - o Low starting power backup (SPV battery, biogas genset, paddle blower)

Salient features of the gasifier and gas cooling-cleaning system:

- Improved raw gas quality due to preheated air supply to `Mark 2' gasifier using in-built effective air pre-heater located inside gasifier shell. Tar content in raw gas was reduced from more than 5,000 mg/Nm$^3$ (in `Mark 1' gasifier without preheated air) and more than 2,000 mg/Nm^3 (in `Mark 2' gasifier without air preheating) to below 500 mg/Nm$^3$ (in `Mark 2' gasifier with preheated air)
- Use of indirect gas cooling system for preventing direct contact of air and cooling water thereby minimizing
  - Maintenance requirements
  - Wastewater generation
- Simple and effective gas cleaning system consisting of
  - Dust settling chamber, large cyclone for dust removal in hot condition
  - Small cyclone and gravel bed filter for removing finer particulates
  - Gas cooler and foam filter for tar-moisture condensation and removal
- Paper filter which is cheap and easy to maintain as safety filter to remove finer remains, if any.

In May 2004, the actual system was installed and commissioned in Kanheiput, a tribal village nearby to Gram Vikas's headquarters in rural southern Orissa. This system however was not an ideal solution and further work was required to develop a wood system.

5.2 Piloting at Kanheiput

Once the gasifier system was developed and tested at Gualpahari by TERI, it was time to shift it to a village for piloting /pre-testing in the field situation. Specific objectives of the pilot phase were:

- To test the chosen system reliability, operation & maintenance requirements.

- To provide opportunity for capacity building of the technical team involved with its design, redesign, and operation.
- To study a biomass supply system in operation
- To gather load profile data on a newly electrified village.
- To act as a demonstration unit to the various interested bodies (public, government and funding bodies)

5.2.1 Selecting a Site for the Pilot

The first major decision in the pilot phase that GV and TERI had to take was the selection of a site for the pilot. Proximity to Gram Vikas and accessibility were identified as the major requirements for a site; to allow for quick and easy access by staff to ensure due oversight and data collection; and for easy access to visiting government dignitaries and other interested parties. The three short-listed sites were:

- On-site at Gram Vikas' head office campus,
- Kanheiput village, and

Kanheiput: the pilot site for the gasifier

Kanheiput village is a small tribal village at the foot of the Kerandimal hills, roughly 15 km from Berhampur city in Southern Orissa. Kanheiput was established in late 1980's when with encouragement from Gram Vikas, the people of the village moved from the Kerandimal hills into the nearby plains, to escape from chronic water shortage they faced in the hills. With Gram Vikas as guarantor, the people took loans to purchase land for houses and eventually built new, *pucca*[1] homes.

Initially, none of the people could afford to purchase any agricultural land. It is only recently a few have been able to do so. Most households have continued with traditional *bogodo,* or slash and burn agriculture, in the nearby hills to ensure a minimal level of food security. Their primary means of livelihood has been labouring jobs in the local area and collection and sale of firewood from the nearby forests. To improve their employability and basic wages, Gram Vikas has trained many of them, including a number of women, in masonry.

Since the village's establishment, the people of Kanheiput have constructed a gravity flow water supply system, sourced from a spring in the hills and a toilet and bathroom each for every household. Gram Vikas has also helped them to establish and improve a large water harvesting structure, which the people use for irrigating their crops (those without land work on a share-farming basis), and for sale of irrigation water to other farmers in the area. A village development society was formed to manage the development activities including the village school, the community pond and forest.

An unnamed optimal village in which the gasifier could operate under ‘real’ conditions. (This third option was presented for reflective purposes as the practical issues involved with such an approach made it generally untenable.)

	Gram Vikas	Kanheiput
Positives	• Ease of access it allowed for the technicians • Ability to manipulate and create a range of loadings on the system • Availability of an adequate biomass supply (in its forestry plantations) • Ease with which the whole experiment could be managed • Accessible point for demonstration and dissemination of the technology.	• Close enough to head office for easy access by technicians and for system monitoring • Represented a tribal village with access to a relatively limited biomass supply • Far enough away from Gram Vikas campus for it to seem like a *real village* for demonstration purposes • Long involvement and understanding with Gram Vikas, useful given the experimental nature of the project • Ready availability of supplementary biomass (from the local wood market)
Negatives	• Being a campus, its inability to reproduce actual field conditions, load patterns or management issues • No opportunity to study a real biomass supply system in action • Too similar to lab conditions for it to be worthwhile from a demonstration point of view	• Small size (12 houses), the load supply would be small and possibly an issue with a gasifier of the designed size. • Representative capacity as a tribal village (many villagers worked at Gram Vikas and there was a significant GV presence in the village). • Risk of Kanheiput’s proximity to GV influencing the project outcomes

Pros and cons of piloting at Gram Vikas campus and Kanheiput

In the end, the decision to go ahead with Kanheiput was endorsed by all project partners. Initially, due to the expected time-lag between this decision and the development of a pilot system, no formal commitment was made with the community. It was only in early 2004 that Gram Vikas began to work with the Kanheiput community. Mobilizing a community to agree to experiment with a technology completely alien to them on the one hand, and preparing itself for the experiment required a confidence building process, this phase involved many important steps for GV.

5.2.2 Social Mobilization: Preparing the Community

Kanheiput was a village where Gram Vikas had a presence for many years, and involved in a range of activities. Partly as a result of this, and partly through a community mobilization process, Gram Vikas was able to convince the villagers about the potential of electricity in improving the quality of life and in income generation activities. The feeling of positive anticipation was further heightened when some of the villagers traveled to Delhi to be trained on the gasifier and shared their views with the rest of the village upon their return.

As the gasifier system being installed was a pilot technology, it was important to ensure transparent communication with the villagers about the aims of the installation, the support Gram Vikas would provide and what mechanisms were in place for dealing with any problems that may come up. A management committee was established in Kanheiput, responsible for organizing the monthly tariff collection and for organizing labour for odd jobs as the shifting of charcoal from storage to the gasifier shed and site cleaning.

In early July 2004, discussions were held with the village to finalize the tariff amount and means of payment. It was expected that the villagers might want to pay the tariff in the form of wood (which could be used in the gasifier). However, contrary to expectations, the villagers expressed their desire to pay only in cash as the majority of them worked as labourers and the wood they collected was for their own personal consumption and sale. They did not want to spend any more time collecting wood than they did already as it would impact on their ability to take part in paid labour. A monthly tariff of Rs. 50/household was agreed upon. As the system was experimental, Gram Vikas agreed to pay this money into a Village Development Fund, jointly managed by the village committee and Gram Vikas. For all night power supply, an additional flat fee of Rs. 200 was agreed upon.

Collection of the tariff has continued smoothly with only one household defaulting on payments due to severe ill-health of the breadwinner. He was approached by Gram Vikas a number of times to see if there was a means for him to contribute and for a while he did help at the gasifier, however this could not be sustained. The village committee was approached to see if the problem could be resolved but no consensus was reached as people were generally not inclined to contribute any further money on his behalf. No complaints arose regarding this situation and every household bar this one continues to pay.

Gram Vikas also supported the training of community members in system operation and maintenance. Two villagers were trained in operating the system and worked for some time, side-by-side with the Gram Vikas technicians. One of these pulled out a few months after starting, but the other continued on for more than a year before pulling out[2]. During trial system, before supplying to power to village, they were trained on the system on

[2] The first operator pulled out for a general lack of interest and commitment. Ravi, the other trainee, withdrew primarily because this was only a part-time position and offered limited

- how to start and shutdown LPG genset used during starting of the system
- how to ignite the gasifier, flare the gas for testing its flammability and how to divert it to engine
- how to start 100% producer gas engine: how to adjust air and gas valves for given load and how to maintain frequency
- how to shut down the gas engine and also gasifier and what care needs to be taken during the shut down process
- Various precautions to be taken during starting, operation and shut down (sequence in which various tasks needs to be done)

5.2.3 Building Capacities of GV Staff

Being a field based NGO, it was quite a challenge for GV to get staff with sufficient electrical and/or mechanical skills and/or capacities to be able to undergo training with TERI technicians. The availability of such skills in the organization was quite limited, and in order to build its basic capacities in this area, Gram Vikas set about putting potential staff members through a series of training courses. During the months building up to the installation of the Kanheiput system, Gram Vikas sent two staff members for training at SELCO (the Solar Electric Light Company) in Bangalore for a month, and to WIDA (an NGO in southern Orissa implementing a rural energy programme), also for one month. In addition to this, one of these staff members was sent to Delhi for training with TERI staff at the prototype system in Gual Pahari.

Once the system was installed, this staffs were then assigned full-time to the gasifier to carry out the day-to-day operation and maintenance and to undertake the necessary system monitoring and community liaison work. To ensure that Gram Vikas built requisite skills to provide supervisory support, the TERI technicians who carried out the commissioning, remained at Gram Vikas for couple of weeks, after the system was up and running. The duration of this orientation training was intentionally left open and it was terminated only when both TERI and Gram Vikas felt confident that local capacities were adequate to the task of safely operating and maintaining the system. This process of training continued at every visit by TERI staff to the site and where possible and when needed, through over-the-phone direction.

5.2.4 Ensuring Raw Material for the Gasifier

To begin with, the procurement of charcoal for the Kanheiput gasifier involved contacting local producers to deliver large quantities on a regular basis. As time passed, however, Gram Vikas began to explore ways in which it could produce the required charcoal from

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remuneration. For regular operation of the system, it also required him to be present at the gasifier every single night.

wood produced on its own campus. This had the twofold purpose of seeking to make the system more 'environmentally transparent' by being able to account for the wood it used; and as a means of better understanding the labour requirements of the biomass supply process.

Beginning in mid 2004 then, Gram Vikas constructed and trialled a range of different charcoal kilns, in an effort to understand their efficiencies and labour requirements and to make cost comparisons with the charcoal being purchased from the local market. This was also expected to provide insights into the labour and other requirements associated with the supply of biomass, once a gasifier was established in a remote community.

5.2.5 Fabrication, Transportation, Installation and Commissioning of the System

The Kanheiput gasifier was fabricated in Mumbai by 2M industries in around two months. It however took another month to transit across the country to Orissa. Both of these procedures took longer than expected for a number of reasons, some of which reflect the difficulty in commercializing new technologies and others that reflect the general difficulties faced in the dissemination of these technologies.

Gasifier system assembled for trial testing at Mumbai

- *Industry expertise to fabricate the system:* The first hurdle was the difficulty 2M Industries faced in fabricating the gasifier. 2M had a long history of fabricating; installing and commissioning gasifiers designed by TERI, also holding a license to manufacture and install the TERI designed thermal gasifiers. They had also been closely involved in the final design of the system. In spite of this, they found it difficult to decipher the design drawings and finally, a TERI technician had to personally supervise and direct the work, before the system could be fabricated.

Inauguration, a proud moment for Kanheiput

- *Bureaucratic hurdles:* The second and most unexpected hurdle faced was getting the system shipped and into Orissa, a state in which taxes are high and exemption for charitable purposes difficult to secure. As a non-for-profit, community development organization, Gram Vikas has rights to claim tax exemption from the government for state tax. However, while good in theory, the process to claim this exemption proved to be an extended nightmare involving a slow and often unwilling bureaucracy, which delayed the commissioning considerably.

- *Transporting heavy equipment:* The practicalities involved in moving some of the incredibly heavy components was not realized initially. It was fortuitous that Kanheiput has easy roadside access, which made it possible to employ a large Hitachi digger to lift a number of the heavier components into place, including the central section of the gasifier (the heavy, concrete encased firing zone) and the engine-alternator rig. However, if the system had instead been transported into a remote village in the hills, as was intended with future systems, the whole process would prove to be very difficult indeed.

The Kanheiput gasifier: system description

The Kanheiput gasifier system consists of about 100 kg capacity hopper mounted on top of a throat-less, downdraft gasifier of a 50,000 kCal/hr capacity (equivalent to a maximum power output of about 20kW), with a movable grate at the bottom. Two rows of tueres (gas pipes) circle the gasifier, feeding air that has been preheated in the lower portion of the gasifier, into the pyrolysis and oxidation zones. The producer gas is drawn off at the bottom near the grate and goes to a dust settling chamber (essentially a large empty box) where the majority of the dust and ash is deposited. From here, it passes through two small cyclones and a gravel bed filter before making its way through an indirect water cooler. This water cooler is a series of winding, large diameter tubes constantly drizzled with water allowing for heat to conduct out of the gas and away. After the water cooler, the gas is little warmer that room temperature and passes through a foam filter (a stack of different density sponge foam), then a common diesel generator air (paper) filter; the gas then moves into a large 'buffer' tank for mixing to ensure it maintains a consistent quality when entering the engine. From the buffer tank it passes through one more paper filter, and then to the engine via an electronic governor, which controls the gas-air mix. The engine is a modified 25hp kirloskar diesel engine with spark ignition and a number of other modifications. The alternator is a brushed 12kW 3-phase alternator. Electricity from the alternator is fed through a control board and main switch before transmission to the village where a 4-pole fuse is fitted and the individual house-lines are taken off. For the purpose of system monitoring and data collection, pressure gauges, and temperature probes were fitted at various points along the cleaning and cooling train.

Technical specifications of the Kanheiput gasifier

Gasifier design	TERI's downdraft throatless (Patent No 183935 of year 1991)
Gasifier Model	Mark-2 (G-50) with water seal
Fuel consumption	15-20 kg/hr
Fuel storage capacity	100 kg
Fuel feeding interval	5-7 hrs
Biomass feeding system	Manual
Ash removal system	Manual
Gas cooling,-cleaning train	Specially design cooling-cleaning train consisting of dust settling chamber, pair of cyclones, gravel bed filter, indirect gas cooler, foam filter, paper filter, gas buffer storage tank, police paper filter
Blower type	Centrifugal blower (0.5 HP)
Blower rating	25 Nm^3/hrwith static pressure of 200mm of WG
Pedal blower	Specially made for gasifier starting
Engine Model	Modified Kirloskar make 3R1040 engine (water cooled, three cylinder, CR 14:1, 28 bhp at 1500 RPM)
Alternator make and capacity	Kirloskar or equivalent, (15 kVA, 3 phase, 415 volt, 1500 RPM, 50 Hz, 0.8 PF)
Auxiliary power consumption	0.6 kWe
Net Power output	10 kWe
Type of load control	Manual ball valves along with speed control device, auxiliary load bank for compensating sudden drop in load
Instrumentation & Control	Panel with manometers and digital auto-scanner temperature indicators for monitoring static pressures and temperatures at various locations in air and gas flow path. Engine control panel: Meters for measuring: current, voltage, frequency, load, PF and energy meter (kWh)

Subsequent to its successful installation, the system was subject to a range of tests on the gasifier and the associated electrical system. After several rechecks, the system was officially commissioned and began operation on the 11th May, 2004.

5.2.6 Livelihood improvements through biomass energy in Kanheiput

May 14, 2004 was a first in the lives of the people in Kanheiput village – for the eleven families living there, to have light in their houses. For long they had seen the lights in the neighboring villages. Their village was small and not viable for electrification unless they made a large deposit. They learnt that electricity would be a luxury available for five hours every day, from 5.30 pm to 10.30 pm. That did not diminish their joy in any way. Their only request was that occasional exceptions be made, like when they wanted to watch movies or celebrate during festivals. They agreed pay a monthly rental of Rs.50 and additional Rs.200 when they ran the system all night.

The final and perhaps most challenging activity which Gram Vikas had to work towards was the establishment/installation of 'real' productive loads with which to test the system. Based on the identified needs of the people of Kanheiput and the resources available to them, potential productive applications for which the power could be used were:

- Water pumping from the local well during the dry months when the spring that feeds the gravity supply system fails (~2-3 months of the year)
- Water pumping for irrigation – this was thought to be an ideal opportunity to develop a community business selling water to farmers in the area
- Hulling of rice and grinding of local millets like *ragi*
- Evening lighting to facilitate productive activities such as grass broom binding
- Lighting for evening education.

Once the system had passed its initial period of operation and both the people and Gram Vikas were satisfied with its reliability, initiatives were begun in these areas.

After due consideration, it was realized that for the first three of the identified activities, 3-phase machinery would be required. 3-phase machinery loads each phase equally[3] whereas single-phase machinery only loads a single phase. In a 3-phase alternator, when one phase is loaded more than the others, it can overheat, become damaged and even completely burn out. With no load balancing equipment, the use of large single-phase loads was therefore not possible. With this in mind, the first task was the replacement of the petrol-kerosene water pump with a 3hp electric pump. This pump has since been used to pump water from the local well, up into the community overhead water tank for supply to the village. The gasifier system easily handles the pump load with only a small amount of operator supervision necessary during pump start-up.

Installation and commissioning at Kanheiput

The second activity undertaken was to establish a huller and flour mill. For economic, legal and administrative reasons, this was not established as a commercial venture, but as a demonstration unit. Over many months, a rice huller and flour mill, powered by a 5HP, 3-phase motor, were installed in the storage room next to the gasifier. Trials were conducted to see how the system responded with only the mill as a load

[3] Most electricity produced is 3-phase electricity, each phase being a separate line of current. The term refers to specific characteristics of the generating technology. Essentially 3 phase means three lots of current being produced in three wires from three copper coils in an alternator. Each line of current is slightly different from the other and each one is called a phase. The red, yellow and blue wires you see in the street are the three phases of three phase power. The black wire is neutral, which is common to all three.

and with the mill and domestic supply connected at the same time. After a little experimentation, the system operators learned how to manage both of these situations. However, the large load fluctuations that occurred with the entry of grain into the huller or grinder proved to be too much for the electronic governor to handle on its own. To handle this, a skilled operator needed to be present to monitor and manually adjust the gas-air mix accordingly. The close proximity between the gasifier and the mill helped in facilitating communication between the mill and the gasifier operators. As of now, the flour mill is used occasionally by the people of Kanheiput to process their grains. The rice huller is used only rarely as no blower system has yet been installed to clean the chaff from the rice.

The third activity identified, of selling water for irrigation, had the potential to be a real income-generator for the village and more importantly, for the system. Unfortunately however, this did not take off. The Kerandimals is an area naturally low in rainfall, with long dry summers and regular drought. Combating water shortages was what led Gram Vikas to first help the people of Kanheiput construct the water harvesting structure behind the village. By late summer in 2004, when the gasifier was installed, the water in this structure had dropped dramatically and was barely sufficient to meet the irrigation needs of people's own fields let alone have excess for sale. The summer of the following year was almost as dry, the structure had not filled and no pumping for sale could take place. Given an adequate water supply, however, there is little doubt that the system could have supported it and real income realized.

5.2.7 The Feedback-Development Loop

The installation and commissioning of the Kanheiput system did not signal an end to the research and development work in LIBERA. Once commissioned, the Kanheiput system became the hub of an intensive R&D process, revolving around two simultaneous processes: (a) further fine-tuning and refinement of the technology and (b) instituting operational and maintenance processes for systematic performance monitoring. The data and observations collected were analyzed and fed back into the technology development cycle. Sorane SA and DTU continued to play an important role during this time, analyzing data, reviewing design changes and making suggestions as to way forward with the development process.

Monitoring equipment at Kanheiput gasifier

A core activity was the collection of system operation data using the various meters and gauges installed. Monitoring systems were established whereby data on pressure drops across components, operating temperatures at various critical points, quality of the electricity produced and total load were collected every 15 minutes of operation. Data on daily fuel consumption, regularity of filter cleaning and any other maintenance work was also logged. Over time this information has built up into a valuable record by which the system can be assessed for efficiency, running costs (including required operator attendance times), and long duration performance. The regular collection of this data was also important in the more short-term management of the system, as Gram Vikas' technical staff slowly learned. For instance, gradual increases in the drop in pressure across cleaning train components invariably indicated the clogging up of the filter and the eventual need for it to be cleaned.

5.3 Major Outcomes of the Pilot Phase

5.3.1 Technological Innovations

An important outcome of the pilot phase was the ongoing assessment of the technology's 'appropriateness' to the conditions in which it was expected to operate. Not all of the design parameters of the system had been met fully prior to installation. Two areas that needed immediate attention were: Reducing and preferably eliminating the reliance on secondary fuels; and easy operation and simple componentry to facilitate operation by trained villagers.

By the time the Kanheiput gasifier was installed, the first had not been fully achieved and an LPG generator had to be used to run the blower during start-up. The replacement of this by a non-powered alternative had been deferred until post-installation: it was expected that it could be addressed by a fairly simple retrofit of new components and/or changing of old.

The second, however, was a much more complex issue which ultimately was likely to be resolved only after a number of villagers had been trained and had operated the system for some time. That said, simple operation had remained a key design parameter throughout the development process and the use of low cost filter materials such as gravel, and bed foam are examples of how this was achieved.

Once the system was installed, a number of changes were made to the system to improve its operability.

- The most notable of these was the replacement of the LPG generator with a pedal powered blower. This reduced the use of any secondary fuels in the system to the kerosene used during firing and the engine battery. In terms of securing battery reliability, the simplest solution identified was to install a solar power trickle charger, and although this has not been done the technology is well proven and could be added at any time. Various means of replacing the kerosene were also proposed, however, no work was done on developing these.

- An electronic governing system and automatic grate shaker were other innovations, that greatly improved system performance and manageability by reducing the amount of human intervention required and more importantly, by allowing the system to run with less unknown variables. For example, prior to the installation of the electronic governor system, changes in electrical load had to be accommodated for by a manual adjustment of the gas-air mix – a delicate operation requiring a skilled operator. If this was not done promptly, short-term frequency and voltage spikes and dips could occur due to the engine over or under-reviving and electrical components and household appliances could easily be damaged. The electronic governor automatically adjusted fuel flow through to the engine ensuring higher quality and more reliable power supply and reducing the chance of system shut-down through operator error or absence.

5.3.2 Technology Demystification

Training of field staff

One of the principle objectives of the pilot plant in Kanheiput was to allow Gram Vikas to familiarize itself with the gasifier technology to the extent that it was comfortable enough to install and support it in a real field environment and to build its human capacities to do so.

For the community members, even after having been trained, handling a rather complex technology was a process of trials and errors. The operators were neither from highly educated backgrounds nor did they have any formal training in mechanical or electrical engineering. This is a reality of the working environment of the state and as such was a test of the 'appropriateness' of the technology package.

In general, the operation and maintenance of the system was readily learned by the operators. Once the practicalities of each job were learnt, all it took was some degree of experience to learn how to do it well. The development of these basic capacities, however, was not always backed by a complete understanding of how the system worked, and there was an underlying fear of breaking or damaging the system. This absence of ownership and confidence proved to be a real issue in the technology transfer process as it led both to acts of misjudged rashness as well as complete inaction. Of the four barefoot engineers trained, only two showed enough self-confidence and natural ability to overcome this problem, and even then they continued at times to be rash where in fact they should have been careful, and vice versa. As a result, at least in the initial months, the trouble shooting process was long, and a process of trials and errors. As time went on and the technicians became more confident, they began to show the initiative needed to connect what they already knew with observations they made.

Learning to tinker with clinkers

One of the first problems faced by the Gram Vikas field staff with the Kanheiput gasifier was the sudden erratic and intermittent supply of gas. This started to occur after about 50 days after commissioning of the system. The gasifier started to 'pop' or 'cough' with a loud bang, or the engine would stutter and lights would flicker. Usually the system recovered but sometimes it did not, however it could usually be started again without much difficulty. When this first bang sounded, the whole village ran over to the shed to see if the whole thing had blown up!

Valves and connections were checked and bolts tightened until eventually, when trying to flare the gas at start-up (a process always done to check gas quality before starting the engine), no flare was to be seen. After a call to TERI, the Gram Vikas staff dug down to the bottom of the gasifier and discovered a large grey, rock-hard blob of …clinkers, covering nearly three quarters of the grate. It had accumulated over time until it had grown large enough to almost completely block the gas flow. This was prized away and the system went back to normal, healthy operation.

Over time the staff learned to estimate how often the grate needed to be checked for clinkers depending on the quality and cleanness of the charcoal being used. When the charcoal was clean, the system only needed checking every 2 months. On the other hand, when it was not, the system needed cleaning every 2 – 3 weeks. Once understood though, the problem was merely a maintenance issue and dealt with in a routine manner.

The system breakdown due to genset problem in Kanheiput system was an eye opener for the team, and brought home several lessons, relevant to technology dissemination in rural areas:

- It highlighted the difficulty in accessing spare parts for the system in small towns and rural areas. Time and again, assumptions about the availability of parts either in Berhampur, the nearest city or even Orissa as a whole were proved misplaced.

Light at home at Kanheiput

- Prior to this crash, GV, at its level, had been able to rectify most technical problems, with little intervention from TERI. The crash however raised a critical question of how long a system needed to be trialed before it can be deemed reliable and how long before any problems that arise can be considered simply operational problems and not design problems. Once the system had reached the one-year operation mark, it was generally considered to have settled down, but this new set of problems arose, and this proved a valuable lesson to all the partners in just how long the technical hand-holding period might need to be in the field

The learning continues – Kanheiput generator breakdown

In late 2005 the Kanheiput system suffered a serious engine breakdown. As an exercise in seeing just how good the technical capacities of the local team were, it was decided that Gram Vikas would try to remedy the problem with only minor input from TERI.

..Local engine mechanics were identified and brought on site and troubleshooting began. After trying different configurations, replacing parts and checking gas quality, the system started, only to stop working again after a day or so.

..TERI was called in and they identified the engine as the probable problem. The local engine mechanic was called in, the spark ignition system replaced, the system worked for a short while. New components and parts came from Delhi and they worked for a time only to fail.

…Eventually a system technician from TERI was called in and along with the local engine mechanic set about getting the system up and running. The system ran for a number of days and satisfied, he left. Not long after however the system went down again. This was a crisis situation, with the system, after 18 months of near trouble-free operation puttering into erratic, unpredictable operation!

5.3.3 Perceived Benefits by the Community

Kanheiput today has an electric fan, a number of radios - which are also used on batteries when power is not supplied – and one television. All of the houses have bright, high quality lighting in all the rooms and there are pole mounted street and area lights in and around the village.

For the first few months, the system was run for only three to four hours in the evening, after which the people requested that power be supplied for longer into the night to allow them to work until later. During the

Watching television at home

harvesting season, farmers were able to continue crop threshing under the lights. Some commercial activities also take place in the evenings now, where previously the people would simply have gone to bed. The main livelihood activity of Kanheiput continues to be firewood selling, followed by some weaving and other NTFP processing. One effect of the street lighting has been the deterrence of tiger attacks on the herds of goats, a benefit the community is quick to point out when requesting further lighting near their cattle shelters.

Chapter 6. Recounting Progress: Scaling up Through Second Generation Plants

The LIBERA project envisaged that the rural energy provision model developed by Gram Vikas and TERI would be disseminated to a large number of remote tribal villages in Orissa and, eventually, throughout Central-Eastern India. For this to happen the technology had to be developed and a strategic plan by which the dissemination process could be coordinated, put together. This chapter looks at the thinking behind scaling up of the experiment, the preparations made for it, the various factors influencing the project and the ensuing outcomes.

In this Chapter…….

Preparing to scale up….

Charting the upscaling phase….

Final decisions….

6.1 Preparing to Scale up: Development of a Village Selection Protocol

It was realized quite early in the project that the kind of intensive pre-project assessment (discussions, feasibility visits etc.) that was carried out for Kanheiput had been possible only because it was a done for a single location. This would not be feasible if the experiment were to be replicated in many locations, with limited resources, manpower and time. This necessitated a village selection protocol that is simple, quick to administer by typical NGO staff, and yields reasonably accurate results. Given the project's focus on developing livelihoods (and not simply electricity supply), the protocol also needed to (a) analyze the status of a village's livelihoods and food security, (b) estimate the natural, human and financial resources locally available by which these could be improved, (c) assess whether a village had the resources necessary to sustain a biomass gasifier and (d) estimate the potential impacts a gasifier could have.

In the June 2003 LIBERA meeting, a basic two stage selection process was outlined for identifying and selecting villages best suited to take the second generation pilot plants. This process involved identifying, followed by ranking (in importance and relevance) all factors that would be significant in ensuring the achievement of LIBERA's goals. It was further refined in a two day workshop at Gram Vikas in August 2004. Experts from diverse fields, joined hands to complement the skills and experience of the project partners: the MS Swaminathan Research Foundation, (MSSRF) on food security; TERI on GIS mapping; and BASIX on livelihoods. This exercise proved to be a highly stimulating activity with the discussions dissecting each factor and clarifying some of the project's intermediate goals and potentials. The first cut selection hierarchy for the village selection protocol then was:

- Biomass availability

- Direct need (lack of physical access to grid electricity)
- Institutional suitability
- Potential local and regional impact for dissemination and demonstration
- Evaluation of expected base load demand and consequent biomass demand
- Potential to improve livelihoods and food security using a power gasifier as the central intervention tool.

After revision, the final document, the framework protocol, was divided into five main parts:

- Initial selection/disqualification round – An elimination round, using the criteria of electrification status, biomass availability, nodal status and institutional suitability. This was to be applied to the whole pool of 200 potential villages.
- Loads, demands and biomass – For the short-listed villages, this involves estimating the base load (domestic demands and water pumping) and based on it, the minimum biomass reserves required to meet this.
- Ranking for short-listed villages – Using more detailed data, this step involves drawing up selection matrices for both livelihoods and food security with weighted criteria to rank villages according to their suitability for the LIBERA model. These were designed to estimate a village's ability to improve food security and livelihoods through the utilization of electrical and other related energies from a gasifier, based on the resources available to them.
- A more thorough load/demand assessment and estimate of village biomass requirement - using field based observations and information.
- Final determination of required biomass resources - This involves an in-depth, on-ground estimation of a village's biomass reserves available for use in a gasifier system.

6.2 Charting the Upscaling Phase

At the July 2004 review meeting in Mohuda, representatives from SDC, DTU, Sorane SA and the TERI technical staff involved with the LIBERA project came together to brainstorm on how to proceed from the pilot stage. The meeting was organized at Kanheiput so that the presence of the working Kanheiput gasifier would serve as a reminder of the progress made and the importance of maintaining the momentum of the work.

At this stage of the project, a number of other pressures surfaced, both internal and external to the project, which stressed the project by either emphasizing the critical need for progress, or dramatically sucking momentum from the project. Thinking among the various project partners and the decisions made were contingent all these factors, which are summed up in the following paragraphs.

6.2.1 Biomass Availability in Gram Vikas Villages

In more ways than one, the starting point for the LIBERA project was the understanding that 200 odd GV villages had established biomass plantations, and atleast a sub-set of these had more than adequate biomass resource to support a gasifier. It was expected that a rough validation would be sufficient to establish biomass availability in these locations. Gram Vikas records on these plantations along with the earlier field assessments carried out by TERI (some years earlier) supported this approach. It was taken for given that the project could get on with working out technology and implementation issues, and not worry about biomass supply issues.

In early 2004 when the project was gearing up for the upscaling phase, it came up against its greatest hurdle, which was the realization that most of the social forestry plantations it had expected to utilize were either non-existent or not available; and the figures and estimates on which this assumption was based were no longer correct. In most cases, the plantations had been broken up into individual holdings and consisted of only fruit and cashew trees. Where plantations did exist, grid-electricity was now, suddenly and amazingly being established, and hence there was no need for electrification through gasifiers.

In order to understand just why this change took place, it is important to view it in context of the rampant deforestation going on in most tribal belts of Orissa. In fact, many Gram Vikas staff members were concerned that in such conditions, the introduction of a biomass gasifier might actually end up increasing the pressure on already overburdened local forests. Without due verification of the sustainability of the biomass resources necessary to support the gasifiers (and the project), there was the risk of losing critical support within the organization, including key field staff. In this background, it became imperative that before selecting any village for upscaling, it be established conclusively that the available biomass resources were of a quantum and quality sufficient for sustainably supplying both the needs of the gasifier and people's traditional needs.

6.2.2 Institutional Arrangements Between TERI and GV

One of the cornerstones of the LIBERA project was its multi-partner approach. Even though no formalized agreement between TERI and GV was envisaged in the beginning of the project, the potential of a partnership became evident with passage of time.

As work in LIBERA expanded into various fields (charcoal production and biomass assessment being two examples of these), the need to extend the partnership to new initiatives became evident. It was expected that at some stage, the partnership would culminate into an MOU signed between the two organizations, standardizing cooperation between them in current and future energy initiatives. With encouragement from SDC, a draft MOU was prepared, which laid out the basic framework within which the two could work together over a range of rural energy initiatives.

Unfortunately, by the time the MOU was drafted, a number of other initiatives were already underway or under consideration, which necessitated project specific working arrangements. The MOU eventually fell by the wayside in favour of more project-specific agreements which Gram Vikas and TERI agreed to develop as and when necessary.

6.2.3 Technology Ownership

Gram Vikas, as an organization, is firmly rooted in ground realities, and the staff has to deal with real issues of abject poverty and hunger, alarming levels of deforestation, lack of productive resources, and ill health, on a day to day basis. From the very start of the LIBERA project, there was certain disconnect between the technology and some of the GV staff members. In spite of the very explicit commitment by the top management, there was disquiet among the staff about the promotion of a biomass based energy system, given the levels of deforestation in operational areas. The difficulties faced in procuring wood/charcoal for the Kanheiput gasifier, and the severe deforestation in the Kerandimals did not help this perception. This was recognized at the highest levels, and to address this, GV organized a number of visits to the gasifier for its staff, explaining its operation in the context of a wider effort to improve communities' natural resources and how the establishment of a gasifier could help spur and direct such work. While people were impressed with the direct benefits of the system (lights and power in a tribal village), the lack of a working biomass supply system led many to infer that it was good but just not applicable in their areas of operation. What was really needed was a system working in the field with all of the related biomass and community management structures in place and resource interventions under way. This had been planned with the second-generation systems, but unfortunately did not take place.

As a result of this phenomenon, the gasifier technology within Gram Vikas remained rather individual-centric. While the few people were extremely committed, and deeply involved in the technology development process, the rest of the GV staff remained outsiders to LIBERA. Some of the key people moving out of the organization created a temporary vacuum, and contributed to the loss of momentum of the project.

6.2.4 Demands Placed by External Factors

A number of other pressures existing at the time contributed to the situation. In a large measure, this was created by TERI being awarded funding for a gasifier dissemination project under the auspices of the World Bank's India Development Marketplace Programme (IDMP). Under this project, TERI had to have in place a working wood based power generation system within a limited time. This project originally stemmed from the perceived need by TERI and GV to identify new funding opportunities jointly and to take a strategic approach formulating new activities in the area. The newly awarded IDMP project, which had a very tight set of deadlines for completion, imposed a great strain on the LIBERA project, and more specifically, on TERI (who submitted the proposal). It also meant that a fully operational gasifier had to be installed within a fixed timeframe, something that the partners had been unable to agree on under LIBERA.

A further, though less surprising low, was the inability of the partnership to convince MNRE, the protagonist of VESP, to include the LIBERA project as one of the VESP case studies. VESP was in the making during this period, and both TERI and GV had considerable interactions with the Ministry at the highest levels, including hosting of a national workshop on remote rural electrification. It was expected that the VESP programme would most certainly include LIBERA in its initial portfolio of case studies, which were expected to provide direction to the national programme. Unfortunately, this did not materialize, most likely because the project lacked a fully implemented and working 'real' system and as such was not yet able to sufficiently prove itself as a workable model. Another roadblock came when due to the grim bureaucracy of the state, Gram Vikas proved unable to secure the requisite certificates and authorizations it needed to proceed with these projects. In particular it could not secure the necessary non-electrification certificates from the local electricity distribution company.

6.3 Final Decisions

Decisions made towards the upscaling phase of the project were influenced by all the above compulsions. At the project level, two critical decisions had to be made: how to proceed with upscaling in other villages, and what direction should the technology development efforts take?

How to proceed with upscaling in the field?

Prior to widespread dissemination, the project needed to identify a number of villages in which the second-generation technology could be established. Whereas the pilot system was established primarily as a means for testing the technology, this second round of field trialing was planned as a means of capturing information and feedback on the performance of:

- the village selection protocol;
- processes for the development of a sustainable biomass supply system;
- processes for the development of community ownership and system management; and
- the uptake of productive, energy dependant activities by target villages

In order to successfully demonstrate the potential of the LIBERA project, it was decided that the wider scale dissemination would take place in two stages:

- Initial round of dissemination would take places in villages that were least food secure and with the fewest livelihood options, but in which there was adequate biomass reserves and the greatest opportunity to improve these through the productive application of energy. This would provide a critical test for the project, and help prove (or disprove) its central assumption that linking energy to livelihoods was a sure way of relieving poverty.

- Once the initial pool of such villages was exhausted, villages with marginal biomass resources would be taken up. For such villages, the selection protocol would have to be modified to include a much more stringent biomass assessment process. Such assessments would then allow for appropriate biomass establishment and management plans to be drawn up in villages that did not have sufficient resources.

Ultimately, after an extended period of consultation, reflection and debate, the project partners accepted that in most villages, there was simply not enough biomass available. Energy plantations would have to be established prior to or concurrent with the establishment of a gasifier. Further, in the interim period before these plantations reached maturity, demands for wood would have to be met by offsets in domestic demand achieved through:

- the introduction of improved cook-stoves, and

- the establishment of Joint Forest Management (JFM) agreements with local forest departments to give legal access to local reserve forests for the collection of fallen timber

How to proceed with the technology development process

At the July 2004 meeting, a thorough review of the Kanheiput system was made, especially in terms of at what lessons could be learned from the charcoal gasifier technology in relation to the further development of a wood based system, as planned originally. In choosing the charcoal system for the pilot, the project had avoided a number of difficult issues relating to the use of wood in a 100% producer gas power gasifier; issues that now needed to be resolved and yet proved difficult to do so.

Faced with this situation and the pressures created by the World Banks India Development Market Place Project to come up with a ready-to-install system quickly, TERI decided to go ahead with the system configuration that they felt was most likely to succeed, deferring to a more conventional approach. This decision however did not find full support within the LIBERA project. This was principally because TERI's approach did not pursue some of the other, more progressive options put forward that had the potential to produce a much better system, although at considerably higher risks. In the end though, the decision was TERI's and the design of the wood gasifier subsequently developed by them reflected their chosen approach.

In essence, the two main options put forward were:

- To work further on the current configuration, which used a conventional wet scrubbing system to remove tar, and try to improve it further through different filter materials and maintenance regimes; or

- To pursue a hot gas system; which sought to do away with wet scrubbing in favour of stopping the tar in the gas from condensing by keeping the gas at a higher temperature in the cleaning train so it could be fully combusted (catalysed) in the engine combustion chambers.

This second option represented a marked divergence from the traditional approaches undertaken so far in gasifier R&D in India and would clearly have involved a significant amount of costly research, trial and development. Furthermore, there was no assurance that it could be made to work under remote target village conditions. The first option on the other hand, involved adopting an approach that was, by that time, much better understood and with a greater apparent likelihood of success. As of today, TERI has a number of wood based systems developed under this approach that are successfully being operated and managed (though still requiring lot of maintenance) in the field and which vindicate, to a great extent, the decision made by them at this time.

The LIBERA project came to a close in 2005 for a combination of reasons, as elucidated above. The reality of non availability of villages with established plantations; difficulty in identifying alternative villages with such resources; the lack of consensus over the development of a second generation technology; and an inability to identify an acceptable means of assessing biomass resources finally combined to bring the project to a close. Different strategies for addressing these were put forward by the various involved parties, each quite different from the other and difficulties were experienced in reaching a consensus as to the best way forwards. It was because of this range of pressures that the LIBERA project closed before a wood based gasifier was developed. The work done during the project did, however, lead directly to the subsequent development of just such a system by TERI, subsequently installed in remote villages in other parts of the country. It also provided an impetus for further developing the energy programme of Gram Vikas.

Section 3. Synthesis and Lessons Learned

In this Section…….

Chapter 7. Achievements of LIBERA

> **In this Chapter…….**
>
> **Prototype model….**
>
> **Technology development….**
>
> **Collaborative model….**
>
> **Project management….**
>
> **Creating a forum….**
>
> **Enhanced visibility….**

The LIBERA project was innovative in the way it was conceptualized, in the way biomass based energy service provision was visualized as something more than 'electricity supply, and in the way it brought several key players together to collaborate and pay serious attention to this resource. The realities of what happened to the LIBERA project should not detract from its key principles, or from the overall LIBERA concept. It failed to reach its potential not because of a defect in its design or conceptualization, but because of a number of internal and external compulsions and miscalculations. As such, it still stands as a sound model for the delivery of improved energy services to remote community and the development of energy based village livelihoods. Its collaborative and partnership-based approach should be promoted in all fields of work and something that makes LIBERA stand out from other development projects undertaken in the country to date. Even though it appears that much of what LIBERA achieved could not be put to meaningful use within the project, it certainly paved the way for future work in the sector. Key achievements of the project are discussed in the following paragraphs.

7.1 A Prototype Model of Rural Energy Service Provision

The LIBERA project provided a model for energy service provision to remote rural areas, a model that brings biomass to center-stage as a fuel, that goes beyond electricity provision and addresses core issues of rural poverty by linking energy service provision with productive applications, and that is community-driven.

The project contributed, to a large measure, to the national policy and programme development in the early 2000s, when the government was re-looking at the rural energy policy, which finally culminated in the launch of the VESP programme. The lessons from LIBERA are particularly relevant in the VESP context, and the fact that there are more than 25,000 villages that require power supply of 5–25 kW daily, but are located in areas too remote for grid supply to be financially viable. Community managed, and decentralized biomass based gasifiers could be a viable option for these.

The Kanheiput power gasifier is essentially a technology demonstration under actual field conditions. Although the financial viability of the Kanheiput system is yet to be established, it has clearly shown that a 100% producer gas power gasifier can generate electricity for low-demand applications, and that it can be operated by the local community with some training. The average daily demand for electricity in the village is around 4–5 hours.

However, the system can run for 7–8 hours continuously at full load on one full fuel charge. Thanks to the power gasifier, children in Kanheiput are now able to study by the light of electric lamps. Each household pays a sum of Rs 50 per month for electricity. On festive occasions, an additional Rs 200 is paid to run the system throughout the night. The challenge that persists is to find ways to make the power gasifier system affordable to poor communities.

7.2 Technology Development in Biomass Based Power Gasifiers

In technology development for biomass gasifier for power generation, the LIBERA project claims several achievements.

- More than 250 hours of long duration performance monitoring of TERI's existing prototype
- Development of a charcoal based power plant package of 10-15 kW capacity
- Fine-tuning of system to make it suitable for remote areas, by addressing issues of
  - Inadequate preheating of air going into gasifier, resulting in higher tar content in raw gas
  - High maintenance requirement due to sticky tar deposit formed due to direct gaswater contact and condensation of tar.
  - Wear and tear of engine piston rings-cylinder due to impurities in cleaned gas
- Introduction of a pedal operated starting system, negating the use of diesel
- New testing facility developed in TERI's RETREAT gasifier installation building in Gual Pahari
- Simple, easy to maintain alternate dry system configuration was developed consisting
  - In-built effective air pre-heater located inside gasifier shell
  - Dust settling chamber, gravel bed filter, cyclone for removing particulate in hot gas condition
  - Dry gas cooler (water film outside gas carrying duct and water is re-circulated and cooled using desert cooler concept)
  - Charcoal bed for tar adsorption
  - Simple foam filter to absorb mist as well as very fine dust and safety paper filter

Pedal operated blower

- Development of standardized comprehensive tar dust content measurement protocol and apparatus
- Detailed tar and dust content measurement was carried out to systematically evolve final gas cleaning cooling configuration so as to reduce tart-dust content to minimal possible level with keeping system configuration low cost and simple.
- Standardization of engine parameters for 100% gas engine operation based on trial testing with existing 2-cylinder 100% gas engine
  - Procurement and modification of 3 cylinder gas engine of 15 kWe capacity
  - Development and trial testing of engine governor and speed control mechanism
  - Long duration testing of system with 2 and 3 cylinder gas engine with charcoal as fuel

In particular, the development and testing work during the project provided very useful inputs for the designing of wood based power system. Eventually, TERI developed a modified wood gasifier system, which was demonstrated in many other locations.

Meeting technical challenges

To find a way by which air required for the gasifier could be supplied without using any external energy source

Initially, during the trial runs, the project used a 1-kW generator set based on LPG (liquefied petroleum gas) to run a blower supplying air to the gasifier. Within a few months, the project successfully developed and installed a pedal operated blower for air supply. This manually operated blower has freed the villagers from dependence on fossil fuels like LPG, diesel, and kerosene, which are not only expensive but often difficult to procure in remotely located villages.

To find a way to periodically remove ash deposits from the gasifier grate

Initially, the grate had to be shaken manually every half-hour or so to ensure smooth and continuous operation of the gasifier. In 2005, TERI designed a simple grate-shaking mechanism with a timer for automatic ash removal at periodic intervals. This device obviates the necessity for constant supervision by an operator. Later, an electronic governor was also successfully installed to take care of load fluctuations.

7.3 A Collaborative Model of Rural Energy Service Provision

SDC facilitated and brought together a complementary set of skills vested in a number of organizations, each dedicated and expert in its own field. The project forged new partnerships e.g. TERI–DTU-Sorane SA and strengthened the existing partnerships e.g. TERI-GV. The signing of a tripartite agreement between TERI, Sorane and DTU provided an opportunity for a systematic peer review of the technology by DTU.

The collaboration brought many good tidings to the projects jointly, and to each of the institutions involved. It provided an opportunity to exchange knowledge and deliberate on future R&D directions. Increased interaction at various levels (top, middle and field level) between the two organizations and a genuine appreciation for each other's work helped in the strengthening of TERI-GV partnership. The mutual trust and open communication meant that the project meetings were frank, honest, informative and productive and most of the set-backs and delays experienced by the project were able to be readily accommodated and worked through.

Another process by which closer ties were achieved was the active pursuit of joint-lobbying activities. Though these did not always involve both Gram Vikas and TERI being present, it meant that when LIBERA was presented to government officials, both partners stressed the collaborative nature of the project, the parts played by the various partners and the strengths of the project for this being so.

A renewed interest in thermal gasifiers: A LIBERA spin-off…….

An activity that occurred as a result of the TERI-GV collaboration was the re-piloting of thermal gasifiers in Gram Vikas, which began late in 2004 but actually happened after the closure of the LIBERA project in 2005. During this activity, the two organizations took similar roles as those under LIBERA, with Gram Vikas playing the implementing organization and TERI the technology developer and service and support provider. The difference here was that this was a Gram Vikas-led initiative; however, the support that TERI provided went beyond the parameters of a simple service provider, and this to a large extent, was because of the work done under LIBERA and the institutional ties created there-in.

At a programme level, this meant that the activities, particularly those in the field, were carried out effectively and there was both good capacity transfer and communication between staff. For both TERI and Gram Vikas, LIBERA enabled them to build their individual capacities through skills and experience sharing between staff working closely with one another in the field.

At an individual level, each institution was able to use this project effectively to build their individual capacities, and contribute to the national debate on the subject of rural energy.

Taking LIBERA work forward

TERI

- Increased focus on decentralized distributed generation (DDG)
- Provided an impetus to restart work on development of small capacity (10-20 kW) biomass based power systems
- Formation of a core team for undertaking power gasifier technology development work
- TERI technicians developed a clear understanding of the realities in the field

Gram Vikas

- First project dealing with biomass power generation
- Provided intensive exposure to the management and technical team working on village electrification
- Creation of a technical team of technicians and engineers for operation and maintenance of village level power gasifier system
- Enhanced technical capacity to support not only a gasifier, but other electro-mechanical energy systems as well

7.4 Efficient Project Management Systems

As there were a number of project partners, mechanisms had to be set up to ensure that a consensus approach was retained at every stage of the project. The principle mechanisms by which this was achieved were:

- regular all-partner, project review and planning meetings;
- the establishment of open and accessible channels of communication between partners; and
- a participative planning and decision making process.

Beginning in 2001, well before the project for formally launched, project review and planning meetings started as a means by which the project partners shared views and experiences and planned for the future. Taking place variously in both Delhi and at the Gram Vikas Mohuda campus, the format and conduct of these meetings was egalitarian; no one party held greater influence over the discussions, and decisions were made by consensus.

The aim was to achieve a consultative process whereby inputs from a variety of actors with different skills could be elicited, understanding on an issue achieved and the best decisions made.

Beyond the project review meetings themselves, the two means by which project communications were achieved was through the establishment of the on-line LIBERA FTP site and close, direct working relationships between key individuals across partners. Due to the long distances separating the partners, these meetings occurred only every few months or so. In the interim periods, much work was done either individually or together. Most of this work consisted of planned activities, however, some was not. Either way, it was important to have mechanisms for regular information sharing. Only significant issues and decisions were funnelled through to the project review meetings.

Project review and planning meetings

… taking stock of the progress made

…critically reviewing the work to date

…exploring options as to how to proceed

…assessing the current policy environment with an eye to further involvement

…debating and deciding on a future course of action

…Drawing up Action plans, identifying activities and responsibilities for each partner

The FTP site was set up by TERI in August 2003. Accessible by all partners, the site contained all the reports produced by the LIBERA project as well as the logged operational data from the various gasifier systems in place (Kanheiput and the lab systems) when they were running. It contained information on the technology, the project concept note and related project planning reports and some promotional material created for the project.

The FTP site was intended as a means by which information could be shared between all partners. In practice, however, the realities of the poor state of rural communications often precluded Gram Vikas from accessing it from its campus. For the other partners however, the site continued to be the primary means by which they kept in touch. With TERI regularly posting system performance data, Sorane and DTU was able to download this, conduct modeling exercises and other analyses and provide feedback.

The FTP site was where 'fixed' information was stored and shared. Discussion, feedback, and debate on day-to-day activities and decisions took place beyond its borders in emails and telephone conversations.

7.5 Creating a Forum for Serious Discussion on the Subject

LIBERA project's single most important achievement was that it contributed immensely to knowledge on the subject of biomass gasifiers for remote, rural electrification, lending a never- before visibility to the technology.

With the passing of the Electricity Act of 2003, and the subsequent government initiatives aimed at developing rural energy infrastructure, such as the 'Rural Energy Supply Technology' (REST mission) and the 'Remote Village Electrification' (RVE) in 2003, and the subsequent launch of the VESP in 2005, the LIBERA partners found themselves well placed to lobby for positive and much needed change to the country's rural energy policies. The passing of the Electricity Act meant that these policies needed to be revised and reformulated so as to be in line with the statutory obligations laid out by it. To assist in achieving this, the government then began a process of consultations, at which the LIBERA concept was presented as a replicable model for rural energy supply.

Some of the significant changes in the government policy the LIBERA project partners aimed to see included:

- Specific inclusion of government support for activities and initiatives that linked the supply of energy to its productive application for village livelihoods development;
- A move away from a rigid, one-size-fits-all approach to a more flexible format in which the specific conditions of a village (and not just population) would determine the level of funding and support provided;
- A recognition that the financial models being promoted were based on the assumption of a minimum level of wealth in a village; wealth which was not always there; and so a move towards a higher level of subsidization to meet the initial capital costs involved: and
- A recognition of the need for the government to provide ongoing financial and managerial support to communities for a number of years post-installation, to ensure the community was fully capable of managing the energy systems as a means of ensuring system and programme sustainability.

For Gram Vikas and TERI, as well as SDC, effecting positive change in government policies relevant to their areas of work has always been a major aim. As with all such efforts, this work incorporated activities ranging from concrete demonstrations of the integrated approach they would like to see (the LIBERA project itself) as well as more traditional face-to-face discussions with officials.

TERI has historically been involved in advisory and advocacy positions with the government on matters related to energy and environment, extending this to the realm of rural energy was natural. TERI and SDC took the lead in interactions with the government, exploiting their proximity and leveraging their contacts in the ministries to gain access to and involvement in consultative proceedings. For Gram Vikas, with its headquarters in a remote area of rural Orissa, direct and frequent engagement with the government was relatively more difficult.

Within the project framework, TERI was very active in disseminating information and keeping its partners up to date. Time was set aside at every project meeting for a review of government activities and discussions on how the LIBERA partnership could be better promoted. It was through this process that the decision was made to seek funding from MNES to hold a national workshop on "Remote village Electrification and Village Energy Security" at Gram Vikas.

The 'National Workshop on Remote Village Electrification and Village Energy Security'

In November 2004, Gram Vikas and TERI organized the 'National Workshop on Remote Village Electrification and Village Energy Security' at Gram Vikas's campus in Mohuda, Orissa. Financial support was provided by the Ministry of Non-Conventional Energy Sources (MNES), Government of India. Involving around 75 people from community groups, NGOs, R&D institutes and government, the workshop shared experiences with establishing and managing community based energy systems. Headphone translation services ensured the community representatives could participate in the discussions effectively, which helped immensely to focus discussions on ground realities, a point so often lost in large city, hotel conferences. It was an event enjoyed both for the honesty of exchanges and the communal spirit in the face of common challenges. It also provided a neat summary of all of the key problems faced by the various stakeholders in their efforts and clear indicators to government on what they need to do to solve these.

As a means of promoting the ideas of the LIBERA project and the work being done under LIBERA, the workshop was a great success. Key lessons that emerged from the workshop were:

- It is essential to intensify the implementation of village electrification projects.
- It is essential to ensure sustainability in terms of resource availability, economics, and more importantly, long term community management.
- While village electrification projects provide opportunities for developing income-generating activities that can aid system sustainability and promote the economic growth of the villages, this needs to be recognized as a slow process. However, the contribution of energy in meeting basic survival and livelihood needs such as lighting, water-lifting etc. should never be discounted.
- Experiences with village-based, community-managed energy systems are relatively new and the lessons are only now emerging. Most of this lies in the field of micro hydro, and very little in biomass gasifiers.

- Village–based, community-owned power systems are a complex business and need considerable time, effort and iterative learning from the community and a huge amount of intermediation from the external agency.

A number of field visits to the Kanheiput gasifier were organized. The siting of the first pilot system in Kanheiput, at a distance of 3 km from Gram Vikas, had been deliberate in order to make such excursions possible. From mid 2004 through to the end of 2005, a number of exposure visits were made by external groups and individuals, including staff from other TERI groups and divisions, community members from remote tribal villages elsewhere in the state, representatives of other research organizations and officials from the state government, including the State Minister for Panchayati Raj. Gram Vikas actively promoted and supported these visits, during which all aspects of the LIBERA project were explained.

TERI, on its part, promoted the LIBERA concept by demonstrating the research and development work underway at their Gual Pahari facility. The proximity of Gual Pahari to Delhi, coupled with its high quality facilities for hosting workshops and meetings meant that Gual Pahari was often visited by government officials. Together, Gual Pahari and Kanheiput demonstration sites did a lot for the cause of promoting the LIBERA concept, the project activities and the standing of both Gram Vikas and TERI.

Visits by government officials

In November 2003, Shri A M Gokhale, Secretary, MNES visited TERI's Gual Pahari campus on becoming Secretary MNES, which represented a high for the lobbying process. During this visit, the `Mark 2' gasifier system was demonstrated and presentation on LIBERA project made. He was impressed by the LIBERA frame work diagram to the extent that he sought permission to use it and the Joe Pierre diagramme was displayed within MNES.

The second important visit was by the State Minister of Orissa for Panchayat Raj to the Kanheiput system in late 2004. Prior to the visit he was a known skeptic of Gram Vikas and its work, yet by the end of the tour he was a changed man and a great supporter of not only the gasifier technology but the wider development approach of Gram Vikas. Furthermore, all of the project partners made formal presentations on LIBERA to ministry officials (including to the Secretary himself), which were very well received.

Subsequently, under the chairmanship of Secretary MNES, a four member team of MNES was constituted along with two resource persons from TERI for preparing an approach paper to formulate VESP. Series of discussions were held with various stakeholders to conceptualize this program approach paper. Further brain storming sessions and consultation meetings were held with TERI, other policy makers and other stakeholders such as DRDAs (District Rural development Agency), Forest Departments, SNAs (State Nodal Agencies), and local NGOs, technology developers and manufacturers, to discuss various issues relating to the conceptualization of VESP scheme based on biomass.

At the time it was launched, VESP was a landmark proposal for two reasons: First, it sought to create an integrated approach to meeting village energy needs; and secondly, it clearly linked the supply of energy to the development of village livelihoods. This was the most significant programme released during the LIBERA project and much effort was made by the project partners to support it. It is somewhat difficult to clearly spell out the direct impact LIBERA had on government policies, however some of the policy developments that did occur and which were in line with the goals of LIBERA included:

VESP: An integrated approach to rural energy

The VESP program aims at meeting total energy requirements of cooking, electricity, water pumping through locally available biomass resources. The strategy focuses on utilization of available biomass resources and their production through plantations, which is quite similar to the LIBERA concept. The energy production system could comprise of biogas plants for cooking energy needs, biomass gasifiers for decentralized power generation using 100% gas engines, and biofuels for energizing pump sets instead of diesel. The systems set up under VESP are envisaged to be owned and managed by local community. VESP is an ambitious government program which is proposed to take up about two lakh villages consisting of 173 lakh villages on the forest fringes and about 25,000 remote un-electrified villages with a total investment of over Rs 40,000 crores.

- The clear and specific inclusion of livelihoods development as a specific goal of energy provision (in both the RVE and VESP)
- The development of integrated 'energy security' programmes that targeted energy service needs as opposed to focusing on the supply of a specific energy technology
- A rise in the level of subsidization proposed by the government
- The promotion of power plants sized to demand (In 2003 MNES began to promote smaller scale gasifier systems, more in line with the needs of smaller villages)

7.6 Enhanced Visibility and Recognition of TERI and GV as Organizations with Competency on Rural Energy

Finally, the activities initiated under the LIBERA project proved to be very positive for both Gram Vikas and TERI as they raised their image with the government as organizations actively working in rural energy. At this stage there were just a few organizations MNES regarded as capable of implementing pilots for its new programmes. The work done by Gram Vikas and TERI promoting the LIBERA concept and lobbying for its inclusion in the VESP document as a case study helped convince MNES that these were among the few who could successfully carry out the piloting of the VESP. It was a real high of the project when it came out that their preliminary proposals had been accepted and Gram Vikas and TERI were on the list of preferred organizations to carry this out.

Chapter 8. Building on LIBERA: Way Forward

8.1 Lessons Learnt

In this Chapter…….

Lessons learnt….

Way forward….

8.1.1 The complexities of livelihood improvement through energy services in rural areas

The stated goal of the LIBERA project was to improve livelihoods through provision of energy services. During the project, efforts were made to gain a better understanding of livelihood and food security issues, and devices such as water pump, flour-mill were tested in Kanheiput. After three years of electricity availability however, power in Kanheiput continues to predominantly be used for lighting, televisions and some water lifting. The LIBERA framework envisages a very comprehensive model, with energy being used as a service, for a variety of applications addressing both subsistence and productive needs. In this respect, what has been achieved in Kanheiput terms of *use of energy service* still has some way to go.

Kanheiput continues to remain a poor, tribal village on the margins of society, despite its close proximity to the large city of Berhampur. Its people have low levels of literacy and their main interaction with society at large is through their work as labourers. They know about electricity, have seen it – in fact can see it from their village as the main power line runs half a kilometer from them – but they have never had access to it, until the biomass gasifier was installed. Like many other interior, tribal villages with whom LIBERA proposed to work with, they are first time electricity users. Gram Vikas estimates that the lag period between energy supply and its productive use is likely to be two years or more in such villages.

Analyzing why electricity is still not used in Kanheiput for a variety of applications, as originally envisaged under the project, provides valuable lessons for rural energy service provision, and throws light on the following questions:

- Do new energy services improve access to income-earning opportunities?
- Can improved energy services reduce poverty by enabling livelihood diversification?
- What is the impact of energy services on human capital (health, education) and social capital?
- How can energy services be adapted to promote positive impacts that are relevant to the livelihoods of poor households and women?

- What are the community-level processes for decision-making on energy services?

Need for complementary inputs

All communities and all people need and use energy, yet how much they need and what they use it for is determined first by their immediate subsistence requirements (cooking, heating etc.), then by the livelihood opportunities and resources available to them. This equation is then further influenced by the availability of and access to, infrastructure such as roads and communications, social services such as medical facilities and schools, levels of wealth, education and health, to name a few. Expectations of energy should, hence, be realistic and tempered by these parameters.

Energy by itself is capable of making only a beginning in rural transformation and poverty reduction. As seen in Kanheiput, beyond that, other inputs are necessary to bring about more profound changes, especially the elimination of poverty altogether. In particular, two kinds of inputs must be ensured, if energy services are to be optimally utilized:

- Physical inputs, such as transport infrastructure, communication facilities and access to markets

- Inputs to develop human and institutional capacities of villagers (education, skills training, exposure, vision building, community organization)

Only in combination can such activities achieve concrete and sustainable increases in village livelihoods and economies.

First time electricity users

It needs to be recognized that the time-scale for effecting sustainable transformation at the village level is greatly affected by people's familiarity and prior exposure to modern energy and technology. In newly electrified villages, plans for the establishment of income-generation and entrepreneurial activities cannot be over-ambitious. In most cases, it is unrealistic to expect people from such villages to become overnight, or even over a few years, highly effective and efficient entrepreneurs when they are in fact, first time users of modern energy services. Careful and conservative goals such as increased cropping and value addition to agricultural and forest products (as compared to large economic gains from new improved income generating activities) may be more realistic in the initial stages.

This is a significant fact that needs to be realized and appreciated. In conjunction with low levels of education, it recognizes that there is a low level of awareness about the wide range of potential benefits of electricity, beyond the obvious applications of lighting, milling and water pumping. The fact that the people of Kanheiput have not as yet embraced the full potential of evening lighting to further the education of their children – or indeed themselves – is reflective of this phenomenon. Other cultural factors, which do not stress an importance for organized education, are also affecting this attitude and it is indeed a long-term project to change these.

8.1.2 Investments required in demystifying technology

The LIBERA model places the control of the energy services provided in the hands of the users themselves. This can be a mixed blessing, as it also means that unlike grid electricity, the burden of operating and maintaining the service falls squarely on the users. Kanheiput was a pilot case, where Gram Vikas was available at close proximity, and the TERI technicians were ready to provide trouble-shooting services as and when required. Over time, as GV technicians and the village operators learnt the ropes of handling the gasifier, the need for TERI's involvement reduced. However the experience does bring out that it takes a long period of sustained investment and handholding for a rural community to build their skills sufficiently to handle a power gasifier confidently. As such, the dissemination of these systems is best done with the involvement of an NGO or community-based organization, which would take on the task of building skills to install, operate and maintain such a system.

The LIBERA project further highlighted the complexities of implementing biomass energy projects, in terms of issues of handling the technology, management of biomass supply, and community issues at the field level. It also brought to the fore organizational issues related to competence pooling, handling inter-disciplinary teams, and the logistics of providing high quality service at remote locations.

Currently, the Government of India has launched major initiatives for rural electrification, with biomass as one of the important energy sources. It is clear that such a programme will require massive efforts in building capacities of different actors, e.g. local governments, communities, technicians etc. In addition it will also require supply of standard off-the-shelf biomass power generation packages. Thus standardization of the technology package and transfer of technology to manufacturers and setting up of quality control and assurance systems would be crucial for large-scale application of the technology.

8.1.3 Availability of biomass and management of biomass supply in tribal villages for biomass based power generation

The LIBERA project started with a premise that sufficient quantity of biomass is available with the tribal communities (at least in those villages where social forestry programme is in place), later this premise proved to be wrong. The availability of a reliable and sustainable biomass supply is a sine qua non for biomass based energy systems. In the absence of established coordination among different actors in the biomass supply chain, gasifier users have to develop their own supply linkages that add to the transaction costs of switching over to this technology. The obvious lesson here is to ensure, by very stringent measures, that biomass availability is reliable and sustainable in the future.

8.2 Way Forward

The LIBERA project provided an impetus to the ongoing work on rural energy, in a big way. Apart from contributing to the ongoing national debate on remote, rural electrification, both

TERI and Gram Vikas used it as a basis for their further work in the area. Specific areas which benefited from this project include: Generating further experience on the technology through implementation projects, shaping the rural energy work of TERI and Gram Vikas, and finally, defining future direction of technology development in gasifiers.

8.2.1 Generating a body of experience through implementation projects

Post LIBERA, TERI has undertaken a number of pilot projects on gasifier-based decentralized power generation for rural electrification in collaboration with other institutions. The first such experiment was undertaken in Orissa. TERI installed a prototype pilot system of 10 kWe capacity, in collaboration with OREDA (Orissa Renewable Energy Development Agency) at village Deodhara in Komna Block, Nuapara district. The project was supported under UNDP-GEF.

The Komna gasifier proved to be the harbinger for several others, each with further adaptations to the local context, and technology improvements. These included one at village Jamera, Korba in Chhatisgarh, and another at village Bhaogarh, Anta district, Rajasthan, both implemented in collaboration with the NTPC (National Thermal Power Corporation). Under another project with the Forest Department, Government of Madhya Pradesh, two pilots under VESP program will be set up at villages Jambupani and Dawaniya (in district Khandwa). The project includes two 10 kWe gasifier systems, with a 100% producer gas engine, along with a civil foundation and shed, biogas plants (including all accessories and civil works), and 122 biomass gasifier cook stoves designed by TERI. Another biomass gasifier-based power plant, with a capacity of 290 kWe (2 x 145), is being set up in Sri Lanka. The power plant aims to meet the electricity requirements of a tea estate and will be eventually connected to the grid. The system will use locally available wood, Gliricedia as feedstock. Each of these pilots represents a step forward from LIBERA, and further builds on the LIBERA principles of systematic site selection, community organization, adapting technology to local needs, using electricity for productive use and local capacity building.

8.2.2 Building Gram Vikas's rural energy portfolio

Since LIBERA, Gram Vikas has been actively implementing community-based energy programmes using bio-diesel, biogas, micro hydro, smokeless chulhas, and solar photovoltaic applications. As envisaged in LIBERA, Gram Vikas views energy as a service and a means to development, and promotes integrated solutions to address rural energy needs, where each project is directly linked to one or more of the core programmes. Gram Vikas' interventions in the energy sector help communities develop and extract value from their natural resources in a sustainable manner, and create overarching institutional arrangements to manage systems and installations at the local level. Each project incorporates values of inclusion, social equity, gender equity, sustainability, and cost sharing. In all projects, people identify their own energy needs, assess the technical and social feasibility for technology selection, contribute financially, and participate in the implementation. A significant contribution of LIBERA was the technical capacities built within Gram Vikas, which gave it the confidence to venture into areas such as micro hydro. Indeed, several of the operators trained moved onto the micro hydro plants in the interior, remote locations of Kalahandi and have been managing these since.

8.2.3 A roadmap for gasifier technology development

As discussed in the previous sections, the LIBERA project made many technological strides, including development of a charcoal based power plant package of 10-15 kW capacity, and its field-testing in a village, which provided useful operating experience and data for assessing technical and economic viability of the system.

Specifically, it led to initiation of R&D work on:

- Low tar (like two-stage) wood power gasifier. The idea was introduced by the DTU team and TERI has initiated preliminary work on the concept.
- The need for efficient charcoal making process was realized during the field demonstration at village Kanheiput. This has led to initiation of work on efficient charcoal making systems including turbo-stoves.
- Collaborative work is being initiated with corporate bodies like Siemens (for capacities below 50 kWe) and with GE (for higher capacities) for developing low tar gasifiers and needed power electronics (governer and grid synchronization systems), which can help in mainstreaming gasifier based power generation

Annex 1. Gasification Technology: the Basic Principle

Gasification is a thermo-chemical (chemical and heat) process in which a solid fuel is converted into a gaseous form. In a gasifier, a solid fuel (wood, charcoal, rice husk etc) is converted into a gaseous fuel called producer gas by a series of processes including drying, pyrolysis, oxidation, and reduction. Drying is the removal of moisture, while pyrolysis is the thermal decomposition of biomass at high temperatures (greater than 200°C) in the absence of air. The end product of pyrolysis is a mixture of solids (char), liquids (oxygenated oils), and gases (methane, carbon monoxide, and carbon dioxide) with proportions determined by operating temperature, pressure, oxygen content, and other conditions. If atmospheric air is used as the gasification agent – which is the normal practice - the producer gas will consist mainly of carbon monoxide (CO), hydrogen (H_2), methane (CH_4), and carbon dioxide (CO_2). The first three of these are combustible gases. A typical composition of the gas obtained from wood gasification on volumetric basis is as follows:

Carbon monoxide	:	18% - 22%
Hydrogen	:	13% - 19%
Methane	:	1% - 5%
Heavier hydrocarbons	:	0.2% - 0.4%
Carbon dioxide	:	9% - 12%
Nitrogen	:	45% - 55%
Water vapour	:	4%

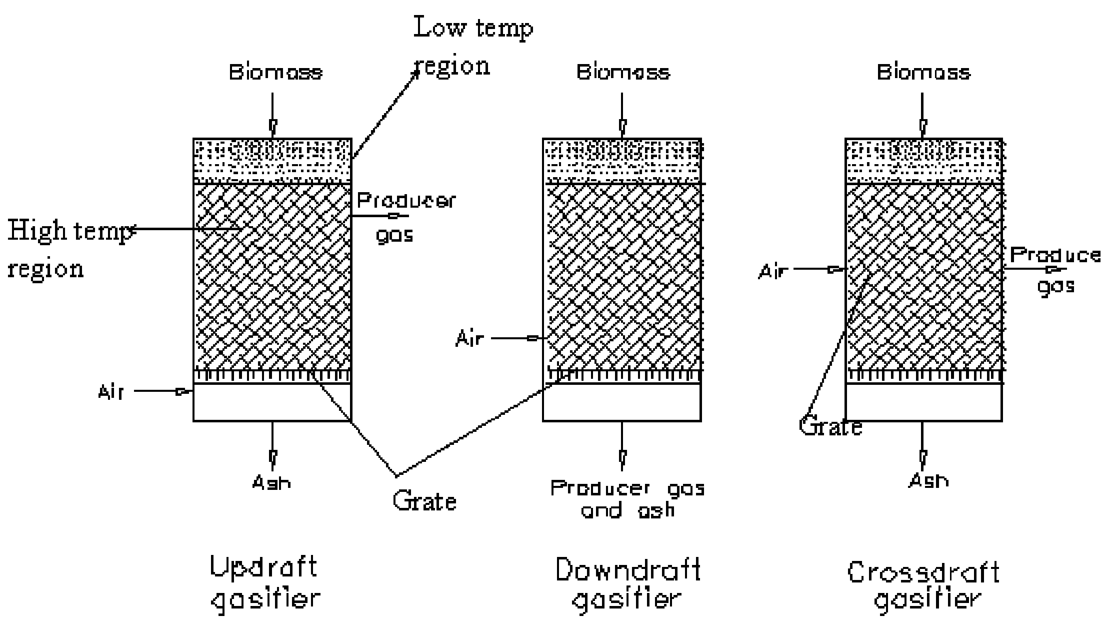
The calorific value (the quantum of energy per given mass) of the producer gas is about 1000 – 1200 kcal (kilocalories)/m^3. To put this in perspective, natural gas, or LPG has an equivalent calorific value of ~10,000 kcal/m^3, while biogas (from cow dung and roughly 60% methane by content) has 4500-5500 kcal/m^3. Approximately 2.5 Nm^3 of producer gas is obtained from the gasification of one kilogram of woody biomass using atmospheric air as gasifying agent.

Producer gas can be used for the generation of motive power either in dual fuel engines (where gas and diesel are mixed and combusted together in the engine) or in diesel engines that have undergone some modification. Engines operating on a spark-ignition system (e.g. petrol engines) can be made to run entirely on producer gas, whereas those using compression ignition (CI) systems (e.g. diesel engines) can be made to operate with about 60% - 80% diesel replacement by the gas. A rough performance ratio for electricity produced from gasifier-based systems is:

- ~ 0.9 - 1.1 kg of biomass/kWh in the dual fuel-mode of operation
- ~ 1.5 - 1.8 kg of biomass/kWh in 100% producer gas engine operation.

Producer gas can also be burnt directly in air, much like LPG gas and therefore finds useful applications in cooking, water boiling, steam production and food and materials drying. In general, the fuel-to-electricity efficiencies of thermo-chemical processes such as gasification are much higher than those of direct combustion. Where gasification converts approximately 35-45% of embodied energy, combustion converts only 10-20%.

In all gasifiers, the gasification of solid fuels containing carbon, such as wood, takes place in an air-sealed chamber, under a slight vacuum or pressure. The fuel column is ignited at one point and exposed to a continuous air blast during operation, with the producer gas being drawn off at another location. Depending upon the positions of the air inlet and gas withdrawal, three broad types of gasifiers have been designed and operated to date: (i) updraft; (ii) downdraft; and (iii) cross-draft gasifiers.



Annex 2. A summary of the Recent Major Rural Energy Initiatives in India

1986: MNES[4] launched a research, development, and demonstration programme on biomass gasifiers which saw over 1000 small gasifier coupled irrigation pump units installed across the country. This programme, which subsidized both gasifier and pump, suffered from widespread technical issues and with significant modifications, exists today as the 'Biomass Gasifier programme', administered by the MNRE.

2002: The Government launched the Rural Electrification Supply Technology Mission, or REST Mission, with the objective of *accelerating completion of all villages progressively by 2012 through local renewable energy sources and decentralized technologies,* along with the conventional grid connection. The REST mission document sought to create a unified approach to the task of electrifying India's villages. Most significantly, it revisited the entire information gamut on rural electrification, redefined what passed for 'electrified' to mean 10% of all households in a habitation. [5]

2003: The Electricity Act 2003 was adopted by the Government of India, which provides the overall policy and regulatory framework for the industry. The Act provides policy provisions for strengthening distribution infrastructure and rural electrification.

2003: The MNES released a framework document for a new and ambitious, "Programme for Electrification of Remote Census Villages and Un-electrified Remote Hamlets of Electrified Census Villages through Non-Conventional Energy Sources." This programme (also called the Remote Village Electrification or RVE programme) aimed to deploy renewable energy technologies such as solar photovoltaics, small hydro, biomass and hybrid power systems for the electrification of remote villages and hamlets which were unlikely to get covered through grid extension in the near future.

2003: MNES began work on the Village Energy Security Programme or VESP. VESP was an improvement over the RVE concept as it went beyond just electrification and sought to address communities' total energy requirements for cooking, electricity, and motive power through, primarily, various forms of biomass energy technologies and, where these were not feasible, other renewable energy technologies. The VESP outline plan was prepared by the Ministry in association with forestry officials from the Ministry of Environment & Forests and the States.

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[4] MNES (Minstry of Non-conventional Energy Sources) has, since then been rechristened as the MNRE (Ministry of New and Renewable Energy).

[5] This was in contrast to the previous approach which defined a village as electrified if there was a single connection present. Quotes from the 'Proposed approach paper, REST Mission, Ministry of Power, GoI,' circulated 26-Aug-2003.

2005: The Government of India came out with the **National Electricity Policy (NEP) 2005**, which laid down the policy goals and programmes for rural electrification and mainstreaming of renewable energy power generation. NEP 2005 also states that the focus of the power sector development is to provide electricity to all including those in the rural areas as mandated in Section 6 of the Electricity Act 2003.

2005: The "Rajiv Gandhi Grameen Vidyutikaran Yojana – Scheme of Rural Electricity Infrastructure and Household Electrification" was launched by the Central Government with the goal of *delivering electrical connections to rural households through the creation of electricity infrastructure in rural areas.* Activities laid out included the establishment of:

- a Rural Electricity Distribution Backbone (REDB) with at least one 33/11 KV (or 66/11 KV) substation in each block.
- Village Electrification Infrastructure (VEI) with at least one distribution transformer in each village/habitation.
- Decentralised Distributed Generation (DDG) Systems where grid supply was not feasible or cost-effective.

The scheme provides for free of cost connection to all rural households living below the poverty line and aims at a *qualitative transformation of the rural electricity infrastructure* that will *facilitate the delivery of modern health care, education and application of information technologies. This is aimed at accelerated rural development, employment generation and poverty alleviation.*

2006: The Government of India notified **Rural Electrification (RE) Policy 2006,** which aims at (i) Provision of access to electricity to all households by year 2009; (ii) Quality and reliable power supply at reasonable rates; and (iii) Minimum lifeline consumption of 1 unit per household per day as a merit good by year 2012. RE Policy 2006 provides the overall framework for the implementation of the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY), including setting out the role of *Panchayati Raj* Institutions in managing the implementation of the programme. The RE Policy 2006, addresses the issue of management of electricity distribution through Franchisees, preferably input based franchisees, appointed either through bidding route on bulk supply tariff or through negotiated bulk supply tariff based on the consumer mix. It also provides policy provisions permitting stand alone systems based on renewable energy for rural areas.

Annex 3. System Profile: Kanheiput

Capital costs	
Capital cost of system (gasifier, engine and accessories):	Rs 550,000
Cost of gasifier shed (100sqft):	Rs 150,000
Transmission and distribution cost:	Rs 6,500
Housewiring *(Community contribution)*	Rs 4,200 *Rs 5,500 (Rs 500 per household)*
Community wiring and streetlights	Rs 12,900
Mill (5hp motor, no. 4 huller & flour mill):	Rs 37,000
3hp pump	Rs 12,500
Total capital cost	Rs 7,80,000
Operational modalities	
System staff:	2 Gram Vikas barefoot engineers, later reduced to 1 1 trained villager (paid)
System operating capacity:	25kVA modified diesel engine coupled to 12kW, 3-phase alternator
Engine hrs completed	1260 hrs upto 16/02/05
Units of electricity produced:	4983 kWh (metered), ~1214 kWh for first 65 days of operation (estimated un-metered production) ~ 6200 kWh total production upto 16/02/05
Charcoal consumption to date	2969 tins or 8907 kgs equivalent
Average fuel consumption.	1.24 kg/kWh (ranging from 1.1 – 1.4)
Average hrs operation per day:	5 hrs (5:30pm – 10:30pm)
Average fuel consumption:	36 kg/day
Total days operational	253
Total downtime (system non-operational)	12 days
Economics	
Tariff	Rs 50/household/month
Purchase cost of charcoal:	Rs 5.0/kg
Average fuel cost per kWh -	Rs 6.45 per kWh
Average cost per kWh (fuel & operators wages – no annualisation or depreciation):	Rs 23 per kWh[6]
Total cost of charcoal purchased	Rs 48,873
Stipend for village technician	Rs 6,625
Total expenditure on operation & maintenance consumables	Rs 1350[7]

[6] This figure is large due to the inclusion of wages paid to Gram Vikas' own staff; an amount far in excess of what would be paid to village level operators/technicians

[7] This does not include a number of items supplied directly or paid for by TERI, including the rewiring of the alternator exciter coils, which, as they were burnt during testing, were not considered a real maintenance cost; something a result of normal operation.