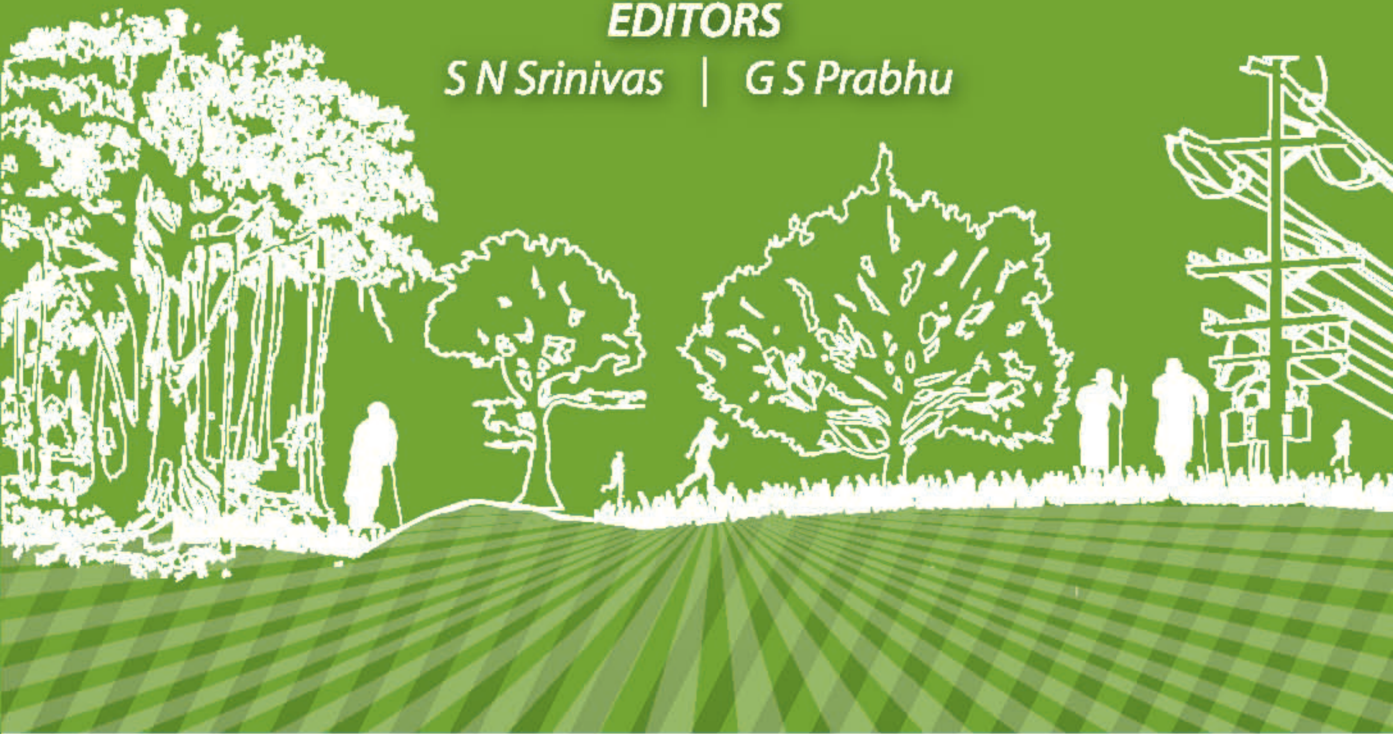
BIOENERGY FOR RURAL INDIA

Demonstration of decentralized sub-megawatt-level power generation using biomass gasification technology

EDITORS

S N Srinivas | G S Prabhu



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ABBREVIATIONS/ACRONYMS

ASTRA	(Centre for) Application of Science and Technology for Rural Areas
BERI	Biomass Energy for Rural India
BERIS	Biomass Energy for Rural India Society
BESCOM	Bangalore Electricity Supply Company
BUG	Biomass User Group
CBA	Cost Benefit Analysis
CGPL	Combustion, Gasification, and Propulsion Laboratory
FYP	Five-Year Plan
GEF	Global Environment Facility
GHG	Greenhouse Gas
GoK	Government of Karnataka
ICEF	India Canada Environment Facility
IISc	Indian Institute of Science
KERC	Karnataka Electricity Regulatory Commission
KSCST	Karnataka State Council of Science and Technology
LPG	Liquefied Petroleum Gas
MNRE	Ministry of New and Renewable Energy
NGO	Non-governmental Organization
O&M	Operation and Maintenance
PAC	Project Advisory Committee
PEC	Project Executive Committee
PLF	Plant Load Factor
PMU	Project Management Unit
PPA	Power Purchase Agreement
PSC	Project Steering Committee
QCBS	Quality Cost-based System
RDPR	(Department of) Rural Development and Panchayati Raj (Karnataka)
RET	Renewable Energy Technology
RGGVY	Rajiv Gandhi Grameen Vidyuthikaran Yojana
SFC	Specific Fuel Consumption
SHG	Self-help Group
SUTRA	Sustainable Transformation of Rural Areas

TBF	Tree-based Forestry/Tree-based Farming/Tree-bund Farming
TERI	The Energy and Resources Institute
TSU	Technical Support Unit
UNDP	United Nations Development Programme
USD	US Dollar
VBEMC	Village Bio Energy Management Committee
VFC	Village Forest Committee
WUA	Water Users Association

PREFACE

India has a considerable interest in reducing its dependence on fossil fuels and promoting the use of renewable energy options to provide access to energy. This can significantly contribute to secure an annual economic growth rate of eight per cent and stability in domestic energy resources provisions. The Biomass Energy for Rural India (BERI) project assumes significance in this context.

BERI is a joint project of many funding partners, with the Department of Rural Development and Panchayati Raj (RDPR), Government of Karnataka, as the implementing agency. The project idea was inspired by a number of successful research, development, and pilot projects by the Combustion, Gasification, and Propulsion Laboratory (CGPL) of the Indian Institute of Science (IISc) in the early 1990s. BERI aimed to develop and implement a bioenergy technology package to reduce greenhouse gas (GHG) emissions and to promote a sustainable participatory approach in meeting rural energy needs.

The project was implemented in 2001 in a cluster of 24 villages of Tumkur district in Karnataka with original project implementation duration of 5 years from May 2001 until May 2006. This was extended to 31 December 2012 to enable the project to complete all its activities. During this time, the project has successfully demonstrated sub-megawatt biomass gasification and provided valuable lessons for future action plans for small scale biomass power generation plants.

This book recounts the BERI experience, and attempts to situate its relevance in the national objective of increasing the share of renewable energy, specially for biomass-based power in the national energy mix. Chapters I and II contextualize the project – narrating the confluence of interests that led to the design of the project, and the subsequent organizational structure that was set up to implement the technology. The actual implementation of BERI on the ground is covered at length in Chapter III. Key milestones in the project such as the change in project design from off-grid micro-power plants of 20 kW_e each to the eventual commissioning of a grid-connected 500 kW_e power plant, the development of biomass plantations through community support, and the project's irrigation and biogas initiatives are detailed in this chapter. The impact of 10 years of project implementation is encapsulated in Chapter IV. This being one of the first experiences of sub-megawatt power generation through biomass gasification, the lessons from the project are invaluable, and will inform significantly to replication attempts. Replication of the project's model is discussed in the final chapter, where the project's own attempts to facilitate sustainability of the project is discussed within the larger context of BERI's implications for rural electrification in India.

It is our hope that this book will lead to greater awareness, discussion, and eventual adoption of sub-megawatt biomass gasification technology as a means to provide tail-end electricity support to India's villages.

As editors, we acknowledge and highly appreciate the efforts of all those who were involved in this project. In this regard, our special thanks are due to Mr N Rangaraju, Project Officer, BERI, and Ms Chitra Narayanswamy, UNDP.

S N Srinivas, UNDP
G S Prabhu, BERI Society, Government of Karnataka

CHAPTER I

AN INTRODUCTION TO BERI

THE ENERGY AGENDA

The quest for universal access to modern energy is still a distant goal in the developing world. Globally, it is estimated that about 1.4 billion people (i.e., 20% of the world population) have no access to electricity, and a further 3 billion (almost 43% of all people) rely on inefficient and crude fuels for cooking.[1] In the Indian context, it is estimated that almost 700 million people do not have access to modern energy sources such as liquefied petroleum gas (LPG) and rely solely on firewood, dung or kerosene for cooking.[2] Likewise, it is estimated that about 400 million people do not have access to electricity and rely on kerosene as the primary source of lighting.[3]

How to ensure adequate and affordable energy to meet the cooking and lighting needs of their communities have occupied the attention of every developing country, and India is no exception. Moreover, as access to modern energy has a proven impact on education, health, and employment generation, countries understand the significance of modern energy access in achieving broader human development goals. But with conventional sources of energy (coal, oil, natural gas, mega hydro power projects, and nuclear power) proving to be increasingly unviable due to depletion (and consequent manifold increase in costs) and disruptive environmental implications, the struggle to bring all of humanity into the glow of modern energy is also an exercise in harnessing alternative energy sources that are renewable, sustainable, affordable,

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1 UNDP. http://www.undp.org/content/undp/en/home/ourwork/environmentandenergy/focus_areas/sustainable-energy/universal-access/

2 The World Bank. 2011. http://www.indiawaterportal.org/sites/indiawaterportal.org/files/India_Biomass_for_Sustainable_Development_World_Bank_2011.pdf

3 Balachandra P. Universal and Sustainable Access to Modern Energy Access in Rural India: an overview of policy-programmatic interventions and implications for sustainable development. *Journal of the Indian Institute of Science* **92**(1) (January–March 2012)

and practical. Consequently, solar, wind, hydro, and biomass energy are today emerging as exciting new energy options that together possess the potential to greatly advance the quest for universal access to modern energy without compromising environmental imperatives.

A REVIEW OF BIOENERGY IN INDIA

Biomass energy or bioenergy is lush with potential in a country such as India. As organic matter derived from wood, agricultural residue, or animal waste, biomass is an abundant, naturally occurring source of energy, and one that is also carbon-neutral, i.e., it generates an equal amount of carbon dioxide that it consumes. While biomass energy in the form of fuelwood and dung have had a long history of fulfilling humanity's basic lighting, heating, and cooking needs, its potential as a source of electricity has been steadily developed since the oil crisis of 1973.

Biomass pieces processed for firing in a gasifier

Bioenergy is produced either through *combustion*, where biomass is burned to generate heat that is, in turn, used to generate steam and then converted to electricity (much like coal is used in thermal power stations); or through *gasification*, which is a thermo-chemical conversion of biomass into a combustible gas mixture (producer gas) that fires in engines or in turbines generating electricity. Typically, power plants with installed capacities of 2 MW and above produce electricity through combustion. Gasification to electricity, on the other hand, is a relatively newer development that also opens up possibilities for small-scale (a few kilowatt- to megawatt-scale) biomass power projects.

While the technology of gasification is not new, its application to produce bioenergy has been pioneered in large part by Indian scientists and entrepreneurs. Yet while Indian solution providers are implementing biomass gasification projects in many countries in Asia and Africa; in India itself, biomass-based power generation is still at the margins of the country's power generation pie, currently dominated by coal (Figure 1).

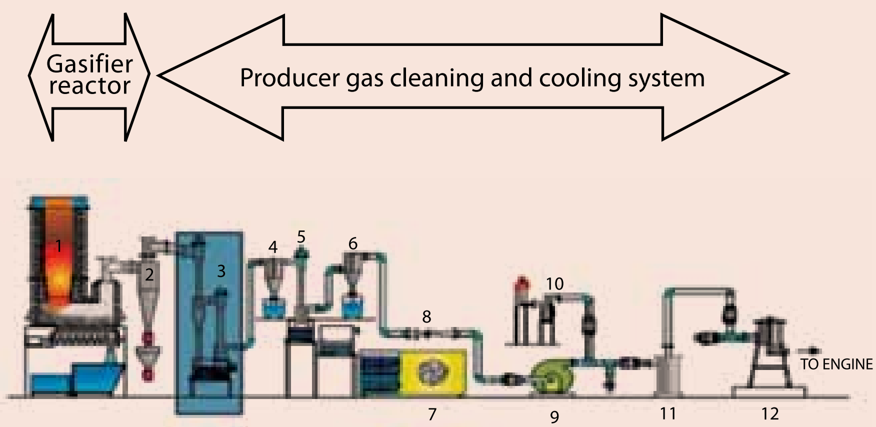


Figure 1 *Schematic representation of a biomass gasifier system*

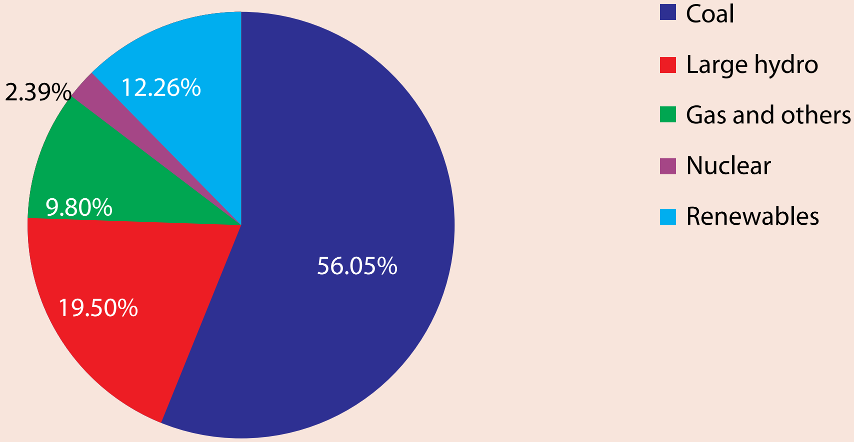


Figure 2 *Share (%) of energy sources in total installed power generation capacity in India (as on 31 March 2012)*

Out of a total of 199,877 MW of installed capacity in the country, biomass accounts for 3095 MW. This includes 1952 MW of grid-connected cogeneration from bagasse, and 1143 MW of biomass-based power from agro residues. A bulk of this capacity is from combustion technology. Power generation through biomass gasification contributes 148 MW, chiefly in off-grid rural and industrial settings.[4] Clearly, when contrasted with its estimated potential of 18,000 MW annually, bioenergy is some distance from achieving its promise in India.

This under performance is due to a number of barriers – technical, institutional, regulatory, and financial. One of the biggest hurdles has been the continued absence of demonstrated operational feasibility and financial viability. The lack of a large-

[4] Srinivas S N, Reddy P R, and Iyer S. 2012. Biomass Power: business opportunities for sub-megawatt-scale biomass power generation. In: Business Opportunities in Biomass Power and Energy-Efficient Technologies in Manufacturing Units, edited by S N Srinivas, Srinivasan Iyer, and P Ramana Reddy. New Delhi: United Nations Development Programme.

scale success story inhibits manufacturers, service providers, and end-users from embracing bioenergy. The bioenergy sector has also been unable to achieve standardization of technology, which has affected the reliability of bioenergy packages. Adding to the technical barriers inhibiting the development of bioenergy, there has been little progress in building the technical and managerial capacities needed to run bioenergy systems. Village-level institutions, in particular, do not possess the skill-sets required to operate or maintain gasifier technology, nor have made efforts to raise awareness about the technology.

All this has meant that bioenergy technology has not elicited significant interest from investors, curtailing the flow of funds for development and replication. It does not help that bioenergy has to eventually compete in an energy market against subsidized grid electricity and fossil fuels. This has placed bioenergy at a competitive disadvantage, which has further acted as a barrier to its widespread adoption.

Inside a biomass gasification plant

Removing such barriers is the first step towards creating an eventual biomass revolution in rural energy generation – a development that can be the key to India's aspirations of extending the reach of modern energy to all its rural communities. It is now widely believed that 100% rural electrification requires solutions beyond grid electricity, which is always going to be diverted first to serve the ever hungry urban and industrial clusters. The environmental cost of this is an added concern, considering the majority of grid power in India is generated through coal use. In such a scenario, bioenergy – which is carbon-neutral, amenable to off-grid power generation, and operable at sub-megawatt capacities – is an eminently viable solution. Because energy demand in villages is characterized by dispersed and low load density, and with adequate potential for biomass plantations, bioenergy seems tailor-made for rural energy requirements.

Launched in 2001 in Tumkur district of Karnataka, the Biomass Energy for Rural India or BERI project aimed to address the technical barrier to wider use of bioenergy by demonstrating a viable biomass-powered sub-megawatt electricity generation system to serve rural consumers. In the process, it sought to create a model of rural electrification that enabled decentralized operation and maintenance of power plants by local community groups (as opposed to large power utilities). In essence, a model where rural communities are not just consumers, but also producers as well as distributors of electricity.

BERI – VISION

Environmental sustainability, poverty reduction, and inclusive growth – these are the agendas that define the mandates of BERI project partners Global Environment Facility (GEF), United Nations Development Programme (UNDP), India Canada Environment Facility (ICEF), and the governments of Karnataka and India. BERI's vision statements reflected these concerns, and were described as:

- Ensuring energy access to rural India through cleaner technologies
- Promoting decentralized modes of power generation from biomass fuels to cater to rural energy demand
- Building capacity in local institutions to manage demand and supply of rural integrated energy systems
- Reducing greenhouse gas (GHG) emissions

A more detailed description of BERI's objectives and strategies to meet them is given in Table 1.

Table 1 BERI: objectives and strategies

OBJECTIVE #1	DEMONSTRATE A VIABLE BIOENERGY END-USE SYSTEM
ACTION ITEMS	1.2 MW of woody biomass gasifier-based systems with a potential to generate 4800 MWh of bioelectricity annually
	120 kW community-run biogas and biofertilizer systems generating 346 MWh for lighting and drinking water availability
	24 biogas-cum-biofertilizer systems in 24 village settlements with a total capacity of 4000 m^3/day (range 25 to 100 m^3/day) for cooking gas and biofertilizer production
	Establish 452 ha of short rotation forest plantation, 371 ha of agro-forestry systems, 271 ha of community forestry, 471 ha of orchards, and 113 ha of high input forestry
	Create multiple delivery modules of energy service packages to villages
OBJECTIVE #2	**STANDARDIZE BIOENERGY TECHNOLOGY PACKAGES**
ACTION ITEMS	Develop gas engines based on local resources and needs
	Prepare detailed technical specifications
	Prepare draft standards for bioenergy technologies for wider replication

Table 1 contd...

Table 1 Contd...	
OBJECTIVE #3	**ENHANCE INSTITUTIONAL AND FINANCIAL CAPACITY**
ACTION ITEMS	Facilitate the participation of women in planning and management of bioenergy packages
	Establish infrastructure for manufacturing and service support
OBJECTIVE #4	**ENHANCE INSTITUTIONAL AND FINANCIAL CAPACITY**
ACTION ITEMS	Train entrepreneurs, village institutions, and non-governmental organizations (NGOs) to manage the project
	Create investment opportunities in the form of venture capital and revolving funds
	Demonstrate financial viability and willingness to pay among rural households to investors
OBJECTIVE #5	**COMMUNICATE, INFORM, INSPIRE**
ACTION ITEMS	Create robust information dissemination and awareness generation models
	Develop audiovisual tools for community outreach
	Engage policy makers through workshops and seminars
	Prepare case studies, success stories, and technology reports for peer review and replication

Taken together, the impact of these objectives would be felt in 2500 households in 24 villages. 2000 farmers were expected to benefit from better irrigation, made possible by electric pump sets powered by bioenergy. Women in particular were envisaged to attain new avenues of employment and social mobility with the availability of electricity and biogas cookstoves. Beyond local concerns, BERI hoped to advance the global sustainable development agenda by adopting carbon-neutral technology to meet rural energy demand. In addition, the plantations it planned to raise would create sinks for carbon sequestration and aid afforestation.

CHAPTER II

CHARTING THE COURSE

PROJECT IMPLEMENTATION STRUCTURE

BERI was launched in 2001, with the expectation that the project would complete all its targeted objectives by 2006.[1] To ensure smooth implementation of the project, a robust organizational structure was envisaged that pulled in expertise and experience from several local-, state-, and national-level institutions (Box 1). Initially, the project proposed the involvement of 19 experts and 16 sub-contractors only, working with a small team of regular staff led by a project coordinator. However, this arrangement was found to be unsuitable on the ground and consequently, a more elaborate organizational structure was designed.

BOX 1 BERI STAKEHOLDERS

- Department of Rural Development and Panchayati Raj (RDPR), Government of Karnataka
- Karnataka State Council for Science and Technology (KSCST)
- Indian Institute of Science (IISc)
- Tumkur *Zilla Parishad* and district-level forest division
- Equipment suppliers
- Technology developers
- Consultants
- Non-governmental organizations (NGOs)
- *Panchayats*
- Village community institutions such as village forest committees (VFCs), self-help groups (SHGs), and water users associations (WUAs)

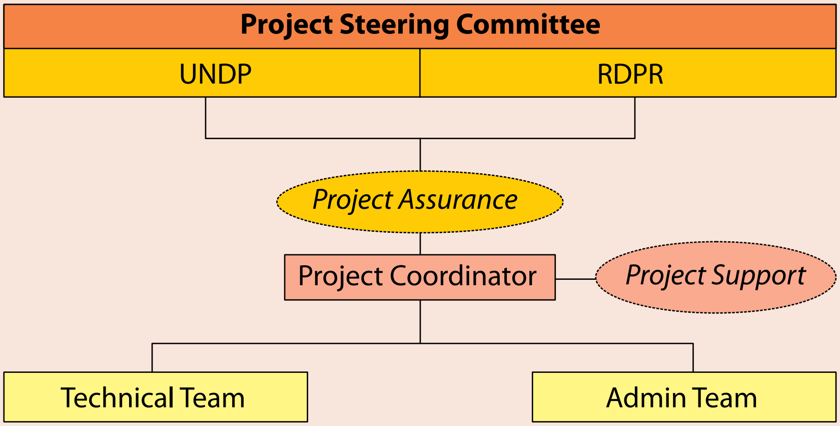
The guiding principle behind creating an institutional framework for the project was an acknowledgement that BERI must stay true to its vision of decentralization and community empowerment. Accordingly, it mooted the creation of a local implementation agency to launch project strategies

[1] Due to various factors described later on in this book, this was later extended to 2012.

in conjunction with community groups, NGOs, *panchayats*, technical institutions, and consultants. The KSCST was proposed to be this agency. Within the KSCST, the project proposed the creation of a Technical Support Unit (TSU), responsible for the recruitment of experts and consultants to help the project implement its technical objectives. The TSU was also expected to prepare technology packages and guidelines for implementation, manage and monitor project progress, facilitate capacity building, and undertake a host of information dissemination activities.

It was proposed that the KSCST create a dedicated Project Management Unit (PMU) as the centre of the BERI organizational structure. The PMU was headed by a Project Coordinator, a position occupied by a senior officer of the state government. Although initially proposed to operate out of Tumkur, the PMU was eventually headquartered in the state capital Bengaluru, about 70 km north of Tumkur. It was described as the engine of the project – the nodal point for project implementation, monitoring, and reporting. Its responsibilities also included project financial management, recruitment of staff and procurement of equipment, and coordinating the activities of all project stakeholders.

To monitor the activities of the PMU, and to give global direction to the project, an office of the Project Director was created, who was to be a secretary-rank officer in the Department of Rural Development and Panchayati Raj, Government of Karnataka. To aid the Project Director, three empowered committees were mooted – a Project Steering Committee (PSC), a Project Executive Committee (PEC), and a Project Advisory Committee (PAC) – at the local level. However, the PEC was subsequently wound down with the PSC and the PAC taking over its supervisory functions.

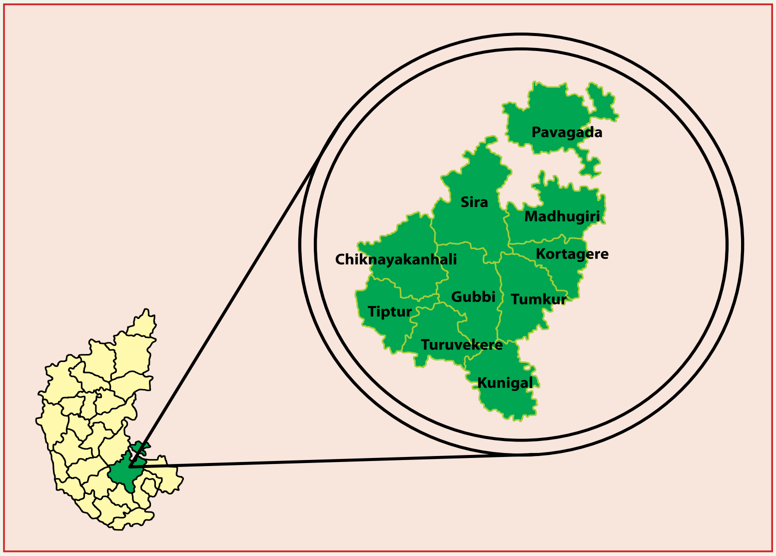


BERI Project Implementation Arrangements (2012)

An important component of this organization structure was the IISc, Bangalore. The technology that made the BERI project possible was originally conceived and developed by the IISc's Centre for Sustainable Technologies (then known as the Centre for ASTRA or Application of Science and Technology for Rural Areas). The Centre has considerable experience working in the project villages, and had established linkages with NGOs, *panchayats*, and other community organizations in the area. ASTRA had implemented projects around 'Rural Energy Centres' as a partner in the Sustainable Transformation of Rural Areas or SUTRA project. These energy centres generate power from small biomass (gasifier, biogas, pongamia) for rural end uses of lighting, powering agriculture pumpsets, powering flour mills and combined with improved cooking devices, improved ovens for jaggery making, etc. As such, the Institute was co-opted into the project as the lead technical partner. Apart from developing and designing the technologies that would power BERI, the Centre – through its Combustion, Gasification and Propulsion Laboratory (CGPL) – was expected to take the lead in capacity building initiatives, documentation of technical benchmarks, and periodic technical monitoring of the project's energy assets.

THE PROJECT GEOGRAPHY

The BERI project was designed to be implemented in 24 villages in Tumkur district. Located in the south-eastern corner of the state, the 10,597 sq. km district is the second largest in Karnataka, with the district headquarters in the city of Tumkur. It is divided



into 10 *talukas* or sub-divisions, and 321 *gram panchayats*. The district is home to 2.6 million people of which 78% reside in rural areas.

With the majority of the people living in villages, the district's main economic interests lie in agriculture. Paddy and Ragi (millet) are widely grown in fields fed mostly by the monsoons. Farmers are also engaged in the cultivation of groundnut, which is the main commercial crop grown in the district. Besides agriculture, mining is an important component of the local economy. The district is rich in iron ore, granite, manganese, and limestone. The exploitation of these minerals – often using obsolete and destructive methods – has deep ramifications for public health and the local environment, even as it provides employment to a considerable section of the working population. The district also has a sizeable presence of small- and medium-scale industries. The Government of Karnataka reports that the district is home to 21,854 such units, engaged in industries such as machinery components, coir products, and food processing.[2]

Tumkur district's human development indicators are a mixed bag when compared to other districts in Karnataka. It ranks 15 out of 28 districts in overall human development. While the district is ranked ninth in the Health Index, 31% of its population is estimated to be living in endemic poverty.[3] The district reported a per capita income of ₹ 20,000 in 2008, lower than the state's overall per capita income of ₹ 25,585.[4] However, Tumkur performs better on literacy and gender indices. The district has a gender ratio of 979, higher than the 968 recorded by the state of Karnataka as a whole, and at 74%, its literacy rate is only marginally lower than the state's overall literacy rate of 76%.[3]

BERI chose Tumkur as the project location for a number of reasons. Over 40% of rural households in the district did not have access to electricity, and where available, grid electricity was unreliable and prone to chronic shortages. The lack of reliable power supply forced farmers to buy diesel pumpsets for irrigation needs. Bioenergy could easily lower the costs of running pumpsets by ending farmers' dependence on expensive fuel oil. Further, a bioenergy-led intervention made eminent sense in a region possessing over 400,000 hectares of waste land, comprising nearly 34% of its total area. This

2 Government of Karnataka, Tumkur District Profile. *http://pppinindia.com/pdf/karnataka/District%20Profiles/Tumkur.pdf*

3 Comptroller and Auditor General of India, District Rural Social Sector Audit. 2012 *http://www.saiindia.gov.in/english/home/Our_Products/Audit_Report/Government_Wise/local_bodies/Tabled_Legislature/Karanatka/10_11/Chap_2.pdf*, last accessed on December 16, 2012

4 Shiddalingaswami H and Raghavendra V K. 2012. Regional Disparities in Karnataka: a District-level Analysis of Growth and Development. CMDR Monograph Series No. 60.

indicated a substantial potential for the cultivation of biomass feedstock. Tumkur district has also seen the steady erosion of its forest cover due to mining and quarrying, and this has left it with a forest cover of only 4.2% of the total area. Growing biomass feedstock was also seen as a viable strategy to achieve afforestation objectives. The project team also noted the abundant mulberry and coconut plantations in Tumkur district, which could be yet another source of biomass feedstock.

IDENTIFYING PROJECT BENEFICIARIES

In the project design phase, BERI had identified six strategic components to achieve its objectives (Box 2). Ranging from technology standardization to capacity building, these strategies were geared to deliver project benefits to three key groups of people within the larger beneficiary communities. These three groups were:

1. Women and children
2. Small and marginal farmers
3. Landless households

BOX 2 THE STRATEGIC COMPONENTS OF BERI

- Technology package standardization
- Bioenergy proof of concept and system demonstration
- Capacity building to overcome institutional barriers
- Enabling activities to overcome market barriers
- Information dissemination
- Removal of financial barriers

Women and children

Even as women have traditionally played a central role in rural energy production and use, they typically find themselves excluded from energy programmes. BERI, on the other hand, recognized the centrality of women in any successful rural energy programme, and tailored its strategies to include women. BERI aspired to empower women in the production of bioenergy by reserving 30% of all positions in village committees for women. The project's emphasis on biogas for cooking aimed to end their daily drudgery associated with hunting for firewood, freeing their productive capacities to engage in economically fruitful activities. Further, smokeless cookstoves as envisaged by the project sought to reduce respiratory illnesses among women and dependent children.

Small and marginal farmers

It is estimated that 80% of all agricultural holdings in India are small or marginal, that is, between 3.4 acres (1.38 hectares) and less than 2 acres (0.81 hectares).[5] Yet their number is by no means indicative of their share in agricultural inputs such as irrigation, fertilizers, and knowledge. Small farmers in India do not easily get access to quality irrigation and agricultural technology. BERI hoped to redress this by providing modern irrigation facilities powered by bioenergy to at least half an acre of land held by every farmer in the project villages. The project sought to supplement this with capacity development initiatives focusing on improved agricultural practices.

Landless households

The socio-economic milieu of an agrarian economy places those without land at the bottom of the ladder. Families that do not possess agricultural land tend to be relegated to the margins of the community, their problems and aspirations seldom addressed by the larger community. BERI sought to empower this group by creating the provision of a trade-able 'water right', which would be equivalent in value to the land-

[5] Dev M S. 2012. Small Farmers in India: Challenges and Opportunities. Mumbai: Indira Gandhi Institute of Development Research. (Can be accessed at <http://www.igidr.ac.in/pdf/publication/ WP 2012 014.pdf>

holding members of the community. This mechanism – it was hoped – would give landless households an equal say in matters relating to energy development. Landless households were also represented in various village-level institutions involved in the management of bioenergy services. Further, employment opportunities created for communities through servicing and maintenance of energy systems and forestry activities were expected to improve the economic conditions of this group of beneficiaries.

UNDERSTANDING RISKS AND PROJECT SUSTAINABILITY

A project of BERI's scope comes with attendant risk factors, an analysis of which is vital to the project's preparedness to tackle hurdles in the way of smooth project implementation. The BERI project studied potential hazards to itself and concluded that external risks to the project – such as a sudden reduction in oil prices, which may negatively impact cost-effectiveness of bioenergy or an unfavourable change in government policies towards renewable energy – were present but unlikely to manifest themselves. However, the project identified several risks internal to it, which may derail its objectives. These are listed in Table 1, along with measures to mitigate them.

Table 1 POTENTIAL RISKS AND MITIGATION MEASURES

Risk	Risk level	Mitigation measures
Non-participation of local communities	Medium	Create a stake in the project by: ▪ Empowerment of village committees and participation of communities in decision making ▪ Awareness creation and transparency in functioning ▪ Assured supply of good quality energy services that improves the quality of life and increases incomes

Table 1 contd...

Table 1 contd...		
Risk	**Risk level**	**Mitigation measures**
Poor recovery of costs of good quality energy services provided	Medium	Create capacity to pay for energy services by: ▪ Increasing incomes through irrigation drives ▪ Providing employment to the landless ▪ Inking prior agreements with end-users ▪ Ensuring adequate information flow ▪ Establishing institutional mechanisms for recovery
Low performance of system and reliability of services	Low	Ensure technical excellence by: ▪ Continuous and rigorous technical performance monitoring and reporting ▪ Signing maintenance contracts with service providers for quick remedial action during breakdowns ▪ Training local operators, service staff, and local entrepreneurs ▪ Undertaking continuous R&D to improve the technology
Limited government commitment	Low	Ensure sustained cooperation from government agencies by: ▪ Participation of senior government decision makers in the Project Management Unit, Project Advisory Committee, and Project Steering Committee
Lack of land availability for biomass plantations and low productivity	Medium	Create sustainable raw material supply chains by: ▪ Diversifying biomass sources to include crop residue and plantations on farm land ▪ Inking long-term supply contracts with farmers ▪ Improve yields by using quality seedlings and modern silvicultural practices.

BERI also applied itself to envisage a post-implementation scenario – a situation where the project partners exit the project after creating the infrastructure and operating mechanisms. It was mooted that to ensure sustainability after the end of the project's life cycle, the private sector and/or NGOs would be invited to take over operations and maintenance of the project's bioenergy assets. It was hoped that private entrepreneurial spirit would create a self-sustaining model where profits from the sale of energy would be invested in replicating the BERI model elsewhere.

CHAPTER III

ON THE GROUND

THE POWER PLANTS

At the centre of BERI's intervention in Tumkur district were three biomass gasifier plants. These plants were built in three villages of Korategere and Madhugiri *taluka*s – Kabbigere (installed capacity 500 kW_e), Borigunte (250 kW_e), and Seebanyanapalya (250 kW_e). Of this installed capacity of 1 MW, 900 kW_e is 100% biomass producer-gas-based, while one 100 kW_e system in Kabbigere is powered by a dual-fuel engine, where the second fuel used is diesel. The power plants run on biomass gasification technology developed at the CGPL, within IISc, Bangalore, and have been built by private vendors who have got the licence for manufacturing gasifiers. They were selected through an open tender process.

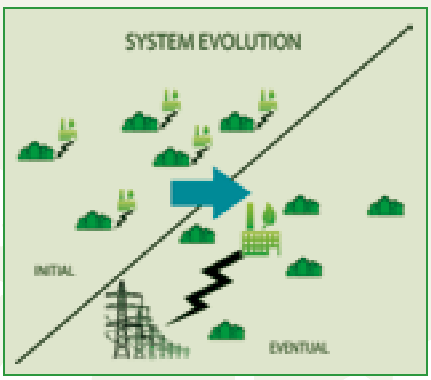
BERI's Kabbigere power plant

These systems have together generated 1.34 million units of electricity from June 2007 to December 2012, and contributed to the reduction of 1058 tonnes of CO_2. Almost all of this output is from the 500 kW_e Kabbigere power plant, which has been operational since 2007, even as the power plant at Borigunte has already undergone performance guarantee test runs and the plant at Seebanyanapalya is in the process of being commissioned.

The gasifier at the 250 kW_e Boriguntc power plant

System evolution

The original BERI project design did not envisage the construction of three power plants. On the contrary, the project's original idea was to set up 60 power plants of 20 kW_e each (totalling 1.2 MW). These decentralized stand-alone plants were to provide electricity to the project villages. Such a model was in tune with the prevailing context, as exemplified by the national-level Village Energy Security Programme (VESP), implemented by the Ministry of New and Renewable Energy Sources in 2004/05 to provide electricity in remote villages and hamlets through 20–40 kW_e stand-alone gasifier systems.



BERI's original vision was, however, modified to the existing larger capacity plants for technical, financial, and administrative reasons, even as the aim of creating a bioenergy grid delinked from the primary electricity grid was retained. Yet soon, it was realized that villages had a power demand that was too low to make the 500 kW_e Kabbigere plant – the only operational power plant – cost-effective to run. As this imperiled one of the core objectives of BERI, i.e., successful demonstration of the technology, the PMU, in consultation with BERI's PSC and PAC, took the decision to link the plant to the main electricity grid. In effect, the project underwent a course correction from promoting a stand-alone bioenergy grid to bioenergy generation and distribution through the existing grid. Yet again, this move was mirrored a few years later by VESP, which also came to the realization that the mismatch between generation and load made stand-alone systems untenable, and consequently larger capacity plants connected to the grid was mooted as a solution.

The power generated by the Kabbigere plant is today evacuated to the grid by a 11 kV dedicated line, at a tariff of ₹ 2.85 per kWh (with a built in 2% annual escalation) as per the power purchase agreement signed between the Tovinakere *Gram Panchayat* and the electricity utility BESCOM (Bangalore Electricity Supply Company).

Technology performance

BERI marked the first outing of the IISc-developed gasification technology through a community approach in a rural set-up at this scale and with grid evacuation. The project's core technical objective was a successful demonstration of the technologyat the sub-megawatt scale. Hence, the performance of the Kabbigere plant was keenly monitored. A controlled operation was conducted by technical teams on the 100 kW_e capacity Genset III of the power plant to gauge system performance and set benchmarks. The system was allowed to run for 1035 hours – a run completed in 45 days – and its performance monitored. It completed its run with grid synchronization of 951 hours. On most days, the system functioned continuously on a 24-hour cycle, with occasional interruptions caused by issues such as non-availability of the grid. Analysis of data also revealed that the system consumed a total of 111 tonnes of biomass, exporting 56,500 kWh to the grid. These and other key performance parameters are listed in Table 1.

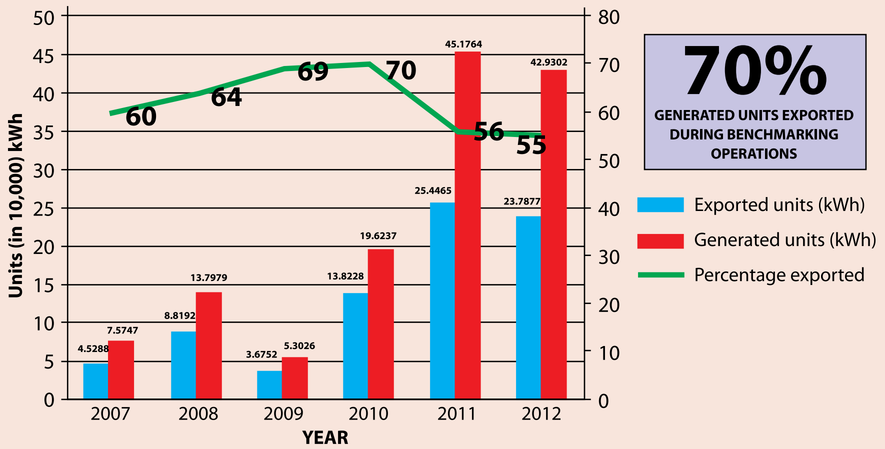
Table 1 Key performance parameters of Kabbigere plant

Parameter	Details
Gasifier operation	1035 hours (h)
Engine operation	1022 h
Grid synchronization	951 h
Total biomass consumption	111 t
Average biomass consumption	107 kg/h
Moisture content of biomass	15% or less
Specific fuel consumption (SFC) (calorific value 15 MJ/kg)	1.36 kg/kWh
Best recorded SFC	1.2 kg/kWh
Total energy generated	80,600 kWh
Net energy exported to grid	56,500 kWh
Average load factor	85 kW of electrical energy (kW_e)
Peaking load factor	100 kW_e
Rated capacity of engine	120 kW_e
Overall efficiency biomass to electricity	18%
Overall efficiency producer gas to electricity	25%
Cold gas efficiency	77%
Estimated efficiency for 500 kW_e	25% to 30%

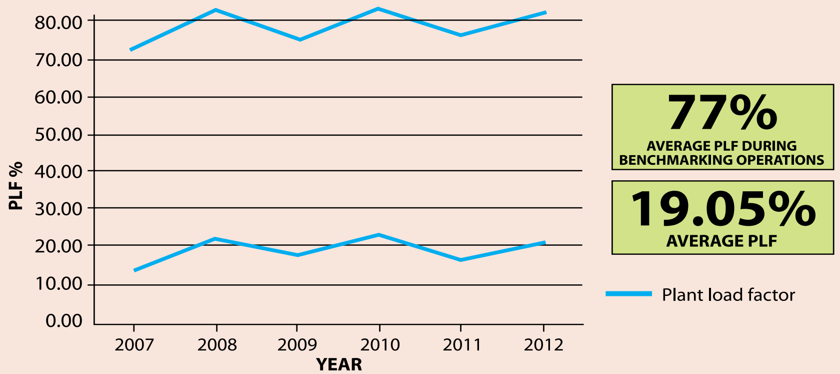
The average plant load factor (PLF)[1] of the Kabbigere plant was calculated at 19.05%. This was lower than the 77% achieved during the benchmarking operations.[2] The weighted PLF,

[1] The PLF for a power plant is the ratio of the actual output of a power plant over a period of time (say annually) to its potential output if it had operated at full guaranteed capacity for that period. For example, the Kabbigere plant of 500 kW_e as per tender specifications was guaranteed to operate at a PLF of 68.5%.

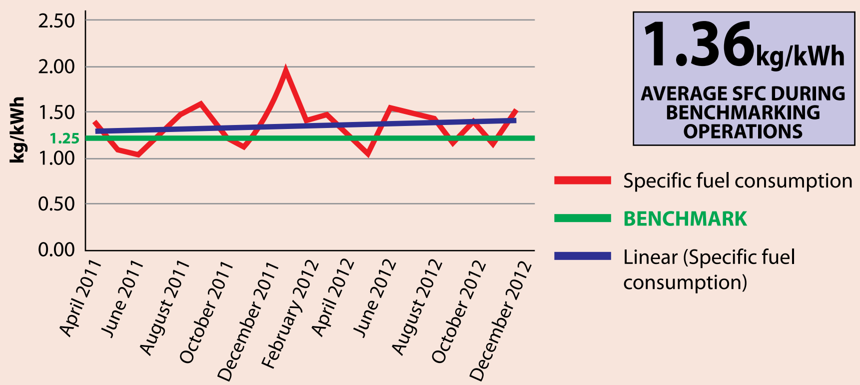
[2] Benchmarking operations were conducted for 1000 hours under the guidance of CGPL-IISc.



Annual data of units generated and exported at the Kabbigere plant (500 kW_e)



Plant load factor - Kabbigere Plant (500 kW_e)



Specific fuel consumption (kg/kWh) - Kabbigere Plant (500 kW_e)

calculated by the cost-benefit analysis (CBA) study of the plant, was even lower at 15%. These low numbers are reflective of the frequent forced outages due to maintenance and repair of engines and non-availability of grid supply that have dogged operations, issues compounded by the skill sets of the plant operators, procedural delays in receiving approvals for servicing and replacements, etc. However, the PLF of the plant is expected to increase and stabilize as the plant matures and operation and maintenance (O&M) modalities are refined and improved.

Cost of power

While various studies commissioned during the course of the project estimated the cost of exported power achieved by BERI, the most authoritative source for the cost of electricity generation remains the IIM Bangalore-conducted CBA report on BERI, published in 2012.

Costs of electricity generation are a function of fixed or capital costs and variable costs. To determine the fixed cost, a 12.25% interest on capital on the ₹ 70 lakh (USD 130,000) spent on building a 100-kW_e biomass gasifier system was assumed. It was further assumed that the system is operational for 6000 hours out of the total 8760 hours in a year, giving it a PLF of 78%. Fixed cost calculation also took into account a capacity utilization factor of 85%, based on the assumption that a 100-kW_e engine delivered an average load of 85 kW_e. Taking into account these assumptions, the fixed cost of electricity is estimated to be ₹ 1.08 per kWh.

To arrive at the variable cost – which includes the cost of fuel (biomass in this case), operation, consumables, and maintenance and repair costs – the CBA report considered specific fuel consumption at 1.36 kg per kWh. With the cost of processed biomass at ₹ 2.75 per kg, the cost of fuel is estimated at

₹ 4.00 per kWh. Added to this are labour costs, consumable costs, and costs of repair and replacement. Taken together, these costs give a variable cost of electricity generation of ₹ 5.31 per kWh.

Added to the fixed and variable costs of biomass power generation is auxiliary consumption loss. This is arrived at by calculating the difference between electricity generated and electricity exported. Data from 1000 hours of operation of one 100-kW_e producer-gas system revealed total electricity generation of 80,600 kWh, of which 56,500 kWh was evacuated to the grid. The balance 24,100 kWh, or 30% of the total, is the electricity consumed by machines used for biomass processing and for running the power plant. Thus the auxiliary consumption loss is estimated at ₹ 1.84 per kWh.

Taking fixed and variable costs together with auxiliary losses, the total cost of power generation is estimated to be ₹ 8.23 per kWh.

Yet when it came to setting tariff, the project found that it was hamstrung by prevailing guidelines governing its power purchase agreement (PPA) with the Bangalore Electricity Supply Company in 2005 for sale of power. The BERI project had to consequently not only agree to comply with the existing tariff of ₹ 2.85 per kWh, but accept an agreement term of 10 years (making BERI ineligible for possible upward revisions of biomass tariffs). Although a 2% annual escalation was built into the PPA, the tariff is still significantly lower than the cost of electricity generation, requiring the project to support the gap.

THE ENERGY PLANTATIONS

Biomass requirement for the power plants was calculated by first considering the optimal annual electricity generation of a

A eucalyptus grove in a BERI plantation

100-kW_e system (operating for 4800 hours or 300 days annually) as 480,000 kWh of electricity. As each kilowatt-hour of electricity requires 1.35 kg of biomass as input, the annual biomass requirement was determined as 648 tonnes. On the supply side, assuming 1 hectare of land yields 4 tonnes of biomass annually, it was found that 162 hectares of land needs to be harvested to run a 100 kW_e system every year. However, new methods of plantation with protected irrigation can increase the yield 10 times in which case only 16 hectares of land is sufficient.

Creating a supply chain of biomass for the power plants was one of the entry-level activities of the project, and by the time the Kabbigere power plant was ready for operations in 2007, the biomass needed to power the plant was ripe for harvesting. The project had launched tree plantation campaigns covering 2930 hectares of land, which included 1983 hectares of forest land and 946 hectares of agricultural land (through tree plantations along bunds). *Panchayat* land and other private plots were also utilized for plantations. Although over 5000 tonnes of biomass was produced annually in these largely unprotected plantations,

Biomass awaiting processing at the Kabbigere plant

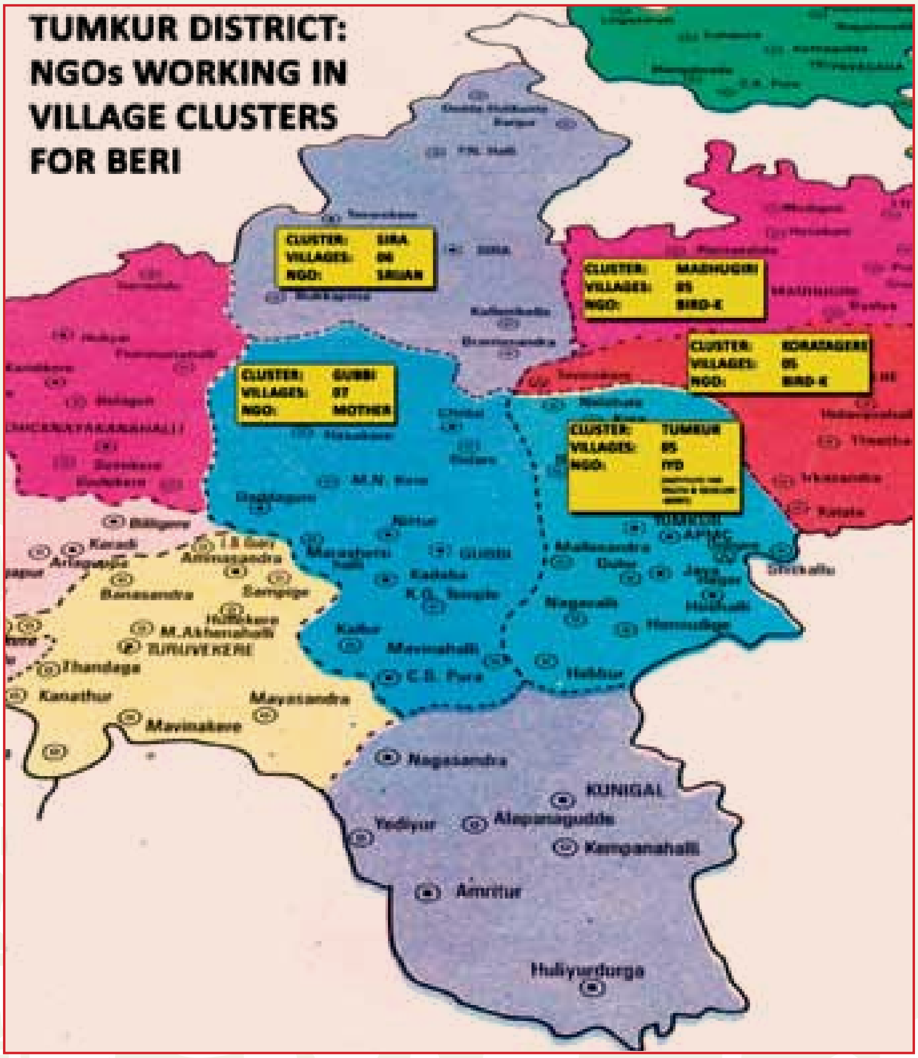
these could not be made available to the Kabbigere plant on time. Hence to ensure operations run smoothly, the project team started to procure biomass from private partners.

Tree plantation has also yielded additional benefits, such as an annual sequestration of carbon dioxide by up to 26,500 tCO_2. Community mobilization was a key strategy to boost tree plantation activities. One of the most popular plantation campaigns launched by BERI was *Hasiru Habba* (Green Festival). Developed by the project partner, the Institute for Rural Development (Karnataka), *Hasiru Habba* gave a festive and spiritual dimension to the act of tree plantation. The annual event involves large-scale plantation

Community celebrations during Hasiru Habba activities, rallies, and public events, and sees enthusiastic participation by local communities.

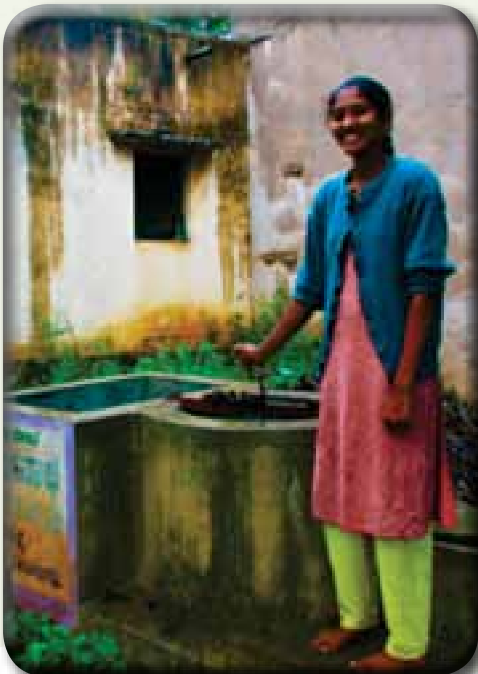
COMMUNITY PARTNERSHIPS

The participation of local communities was integral to the project design, and BERI sought to engage with communities through NGOs working in the project area. Four such NGOs (see map) were identified to raise awareness about the project.



Subsequently, communities were organized to participate in activities such as construction of biomass plantations, drip irrigation systems, borewells, and biogas plants. These community activities saw a high participation of women.

Communities were formed into several organizations, each with its specific agenda. Households with access to cattle and living in proximity to biogas plants were organized into biogas users' groups (BUGs). These groups were trained in operating a biogas unit, and were also responsible for supplying dung for processing into biogas. The biogas generated was then fed into homes through pipes. The households paid a monthly maintenance charge for using the gas, which was kept in a common account. By 2007, 51 BUGs had been formed, involving 175 households with a population of 843.



A member of a BUG at a biogas plant

To propel its plantation drives, the project encouraged the setting up of village forest committees (VFCs). These were organized to oversee tree-growing activities in order to raise sufficient biomass for the plants. The VFCs worked to achieve afforestation of village common land, raising of seedlings in decentralized nurseries and implementation of tree-based forestry (TBF) activities with the participation of the local community.

By 2005, it was reported that VFCs had been formed in 28 project villages, with 100% of households enrolled as members of VFCs.[3] Households are charged ₹ 10 (USD 0.18) as a monthly membership fee. A president was elected from among the members of a VFC, and so was an Executive Committee of 12 members. Additionally, the Forest Department deputed an officer as a Member Secretary.

The third kind of community organization fostered by partner NGOs was the Self-help Group (SHG). These SHGs typically comprised 20 women each. The groups encouraged members to meet regularly, have a platform to discuss various financial needs, maintain books of records and access loans to take up or augment existing livelihoods.

But, perhaps, the most critical community initiative of the project was the Water Users Association (WUA). Set up in project villages, these associations had a simple aim – to systemize water distribution in order to make access to water adequate and equitable. Under this initiative, 32 bore wells were dug in the project villages, and then connected with drip irrigation systems on farmland. A WUA was formed out of households in the vicinity, and these were entrusted with operating and maintaining the irrigation systems, receiving adequate training and guidance to fulfil their mandate. In return, each household received power for irrigation on 0.5 acre (0.2 hectare) of land at tariffs mutually agreed upon by all stakeholders. With each WUA comprising three to four households, the micro-irrigation systems benefitted 127 farmers in all. The community irrigation initiative also had an inclusive charter, where each WUA consisted of at least one landless household. Such families would receive water to irrigate half-an-acre of land, which they could lease from land-holding households in the WUA.

[3] Jayakumar P. 2005. Mid-Term Evaluation Report. Eco Ltd for BERI PMU.

Farmers in a BERI project village laying drip irrigation lines

The bore wells installed by the project were initially connected to existing electricity lines, with the expectation that BERI biomass power plants would eventually supply electricity to them. While the plants eventually supplied power to the grid, the community irrigation initiative made a considerable impact in augmenting existing livelihoods, generating income, and improving the socio-economic condition of poor farmers. The bore wells have resulted in increased crop intensity – with more than two crops per year now possible – which, in turn, has increased farm income at least by 20%-30%. Further, the WUAs (and indeed the VFCs, BUGs, and SHGs) were instrumental in cultivating an awareness culture that was conscious of rules and norms and the idea of fee for service.

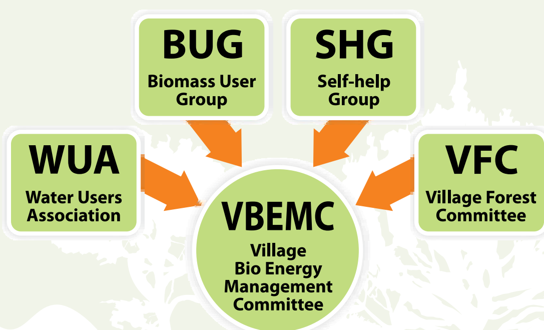
Together, all these community organizations formed the Village Bio Energy Management Committee (VBEMC). One VBEMC was established per village as a sub-committee of the local *Gram Panchayat*, operating with a 15-member committee. Thirty percent of committee members are women, and other members include *Gram Panchayat* members of the respective villages, members of WUAs, BUGs, and representatives from

BERI's irrigation initiatives have allowed farmers to engage in floriculture activities

SHGs. These committees were expected to act as an umbrella organization at the village level to address all bioenergy-related policy issues and also to implement and manage bioenergy-related programmes.

CAPACITY BUILDING

With communities forming the main axis of the project on the ground, enhancing their capacity to handle their new duties was also an integral part of the project design. Several training programmes were held to facilitate implementation of each



Community ownership: institutional structure at the village level entry-point activity, with a particular focus on increasing the involvement of women in the planning and management of bioenergy systems. Women formed 58% of all participants in the project's capacity-building programmes.

The training programmes facilitated by the project covered conceptual, managerial, and operational aspects of bioenergy systems such as gasifier maintenance and biomass handling. In all, over 124 courses were organized, attracting over 3700 participants. In addition, 159 courses provided management skill development, while 68 programmes focused exclusively on

Insights on O&M being shared with local staff at the Kabbigere plant

awareness generation and promotion of bioenergy. The project also organized 109 field trips to enable a better understanding of bioenergy, and over 2800 people participated in these trips. Technical courses offered by the project focused on operations and management of bioenergy packages, nursery development and tree plantations, book-keeping and accountancy, management of micro-credit, development of biomass sites and efficient agricultural practices (Table 2).

Table 2 BERI CAPACITY BUILDING PROGRAMMES

Managerial and skill	Technical	Exposure visits	Promotional events
1. VFC book-keeping 2. Rural energy services 3. Project orientation 4. SHG book-keeping 5. Leadership training 6. *Yuvachethna* 7. VBEMC account maintenance training 8. Forest management 9. Orientation on federations 10. Orientation to SHGs on government programmes 11. Workshop on gasifier maintenance and biomass procurement	1. Herbal medicine preparation 2. Nursery raising techniques 3. Vermicomposting methodologies 4. Biogas plant operation and maintenance 5. Crop management techniques 6. Pest and disease management techniques 7. Vermi wash preparation technology 8. Village health guide training 9. Bee keeping techniques 10. Tree-based farming systems (TBF) 11. Organic farming systems 12. Fodder development techniques 13. Micro irrigation systems 14. Pressed bricks-making techniques 15. Construction of improved cookstoves 16. Vegetable cultivation techniques 17. Biomass cutting techniques	1. TBF 2. Vegetable growing 3. Income generation activities 4. *Krishimela* 5. Flower show 6. Model village 7. Bioenergy 8. Bee keeping 9. Vegetable nursery 10. Horticulture fair 11. Organic fair 12. Vegetable outlet	1. Video show on *Hasiru Habba*, TBF, nursery raising, livestock development 2. Organic farmers' meet 3. World Environment Day celebration 4. Health camp 5. *Padayatra* 6. Family Day celebration 7. *Hasiru Habba* celebration 8. *Shrmadana* 9. World Women's Day celebration 10. Seed sowing and Seed collection *jatha* 11. Awareness programme on herbal medicine 12. *Krishi Sammman Divas* 13. School awareness programmes 14. *Kashaya* camp 15. NSS camp 16. *Sneha sammelana* 17. Eye camp 18. Legal awareness programme


CHAPTER IV

PROJECT
IMPACT AND INSIGHT

The lasting legacy of BERI is the demonstrated viability of biomass power generation at sub-megawatt scales, generating 24/7 electricity to meet the energy needs of rural India. By taking the technology from the laboratory to the public domain, testing and benchmarking it in actual working conditions, and disseminating its findings, the project has provided a direction for the wider adoption of bioenergy in the country, and indeed throughout the developing world.

While the technology demonstration was able to only partially meet project expectations, a review of BERI's impact, and the insights attained from its implementation, shows that the project has succeeded in making a tangible contribution to emerging alternative options to achieve rural energy access. Presented below are some of the important achievements of the project, as also a review of issues that need further scrutiny to enable replication of the BERI blueprint.

TECHNOLOGY DEMONSTRATION

BERI's core technical objective – testing a technology hitherto confined to the laboratory or closely supervised industrial set up in actual ground conditions – has been achieved with over 1.34 million units of electricity generated by the Kabbigere plant thus far. Further, once the power plant was made grid-interactive, it marked the first time that a sub-megawatt system had successfully connected to the grid. However, this achievement is tempered by the fact that the plants faced repeated forced outages and suffered from recurrent unscheduled grid interruptions. This resulted in a low PLF of 19.05%, indicating the technology could have performed much better if conditions were optimum (for instance, a PLF of 77% was recorded during the 1000-hour benchmarking operation).

One of the reasons identified for the low performance of the plant has been persistent teething issues with the gas cleaning system and engine. Staff at the power plant estimate that 70%–80% of all operating problems could be traced to the cleaning system. It was observed that producer gas with high tar content (as a result of biomass that is too moist) regularly caused malfunctions in the carburetor. This issue can be remedied by better storage of purchased biomass. In addition, continued development and demonstration of low-tar technology can further improve the quality of producer gas.

The quality of gas apart, breakdowns caused by human error was a persistent issue. Local operators found themselves on a steep on-the-job learning curve, considering the novelty of the technology, and this affected the duration of outages. Moreover, manufacturers of the systems were also caught unawares by the sub-megawatt scale of the technology. The manufacturers contracted by BERI were large-scale fabricators

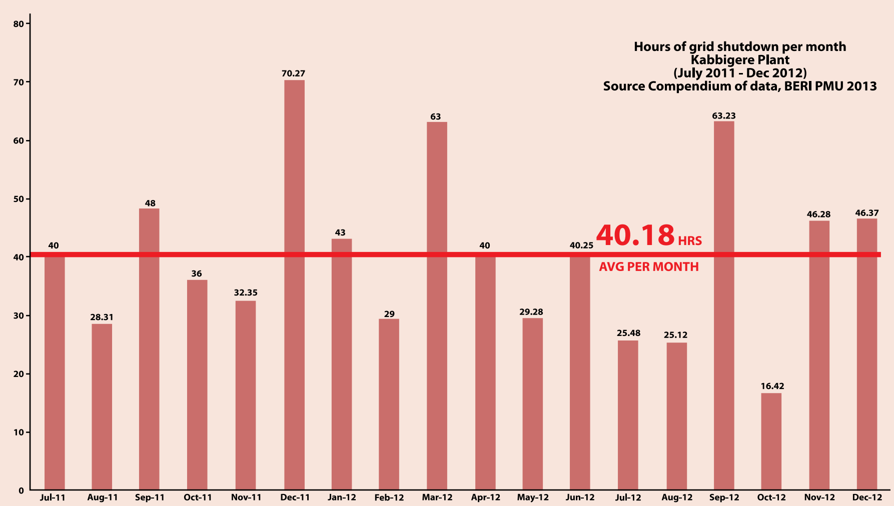
Conducting repairs on equipment at the Kabbigere plant and had little turnkey experience of the requirements and limitations of a sub-megawatt project. During the construction phase, contractors were found to be lax in meeting technical specifications, delaying operations. Once operational, the plants were dogged by the slow response of contractors supplying parts to the plants, which increased down-times.

What further intimidated service providers were the stringent performance guarantee tests for the gasifier systems. Benchmarks included continuous running the gasifier-based units for a period of 300 hours, running at rated capacity of 95% (240 kW for 250 kW_e system), and achieving specific energy consumption of 1.25 kg per kWh. The turnkey agent conducted performance guarantee tests twice but fell short of the prescribed performance standards. Consequently, the PMU was compelled to expand its role to running the units, with the support of the CGPL, IISc.

In the context of service providers, BERI processed gasifier tenders through established state government norms, which stressed on an 'L1' principle, i.e., after technical qualification, the least-cost bidder receives the award. Assessing the performance of contractors selected through this route, the project recognized that such an approach may not be valid for projects testing new technology. An 'L1' system is perhaps ideal when the technology involved is mature and there are established technical standards. But the success of new technology on the ground is critically dependent on the quality and capacity of service providers, rather than on their presumed financial prudence. A QCBS or Quality Cost Based System followed by many multilateral organizations is an alternative that could be considered instead for projects aiming to demonstrate new technology.

The other major technical hurdle impacting the power plants' performance was the tenuous availability of the grid. As the generators are directly synchronized with the grid, any grid collapse or sudden voltage fluctuations lead to immediate automatic disconnection from the grid, bringing operations to a halt. Apart from a loss of generated power into auxiliary consumption due to long hours of outage, the fluctuating quality of voltage/frequency results in lost time as plant staff seek manual intervention by BESCOM. In addition, biomass processing, which depends on electric cutters and saws, is also interrupted during unscheduled power outages. Grid unavailability was a frequent phenomenon throughout Kabbigere plant's operations, with an average of 40 hours of grid shutdown recorded per month.

On the whole, despite being dogged by technical issues, BERI's power plants have operated long enough to generate over a million units of electricity, and the data and insight attained as a result have provided a template as well as a technical road map for sub-megawatt biomass power projects.



Hours of grid shutdown per month

REDUCTION IN GREENHOUSE GAS EMISSIONS

As per the project proposal, BERI's objective was to achieve annual saving in CO_2 emissions to the tune of 47,879 tonnes through the course of the project.[1] Apart from savings achieved by generating bioelectricity and biogas, energy plantations for biomass feedstock was expected to contribute a bulk of this target. At the end of 2012, however, the BERI project reported annual CO_2 savings of over 27,000 tonnes per annum, achieving a cumulative saving of 161,860 tCO_2 over the duration of the project. The delayed start of operations in the plants is cited as a major reason for missing this target.

The project's afforestation and plantation activities made the bulk of the contribution to the emission reduction. Innovative interventions like tree-bund farming and mass movements like *Hasiru Habba* augmented the extensive plantations raised in forest land.

ENHANCED LIVELIHOODS, EMPOWERED LIVES

Long before the power plants were commissioned, BERI had launched a number of entry-point activities to inform, motivate, and involve local communities. This ensured that by the time the plants were ready, biomass to power them was ready for harvesting, and there was significant goodwill and support for the project. The partnership struck between BERI and NGOs operating in the area was instrumental in creating awareness, enthusiasm, and participation for the project, and they offer valuable insight into community participation in large-scale projects.

One of the first things the project did was launch an extensive irrigation initiative. This fulfilled an urgent agricultural need in

[1] GEF APR (Annual Project Review)/PIR (Project Implementation Report) 2012. 'Progress Towards Meeting Development Objectives'

a semi-arid region dependent on rainwater for cultivation. A total of 56 borewells powered by IP sets were dug, benefitting 267 households across the project villages, grouped into water users associations (WUAs). Drip irrigation systems were also built simultaneously, and many farmers began harvesting the bounty of irrigated fields for the first time.

Most significantly, the irrigation initiative successfully demonstrated a unique model of participatory irrigation management that also included the landless. By giving each landless household in WUAs a half-acre worth of water (i.e., water to irrigate half an acre of land), the project facilitated the economic and social empowerment of the poorest of the poor in rural society, while presenting a fresh approach towards more inclusive irrigation interventions.

Even as the project could not take its irrigation initiative to its logical conclusion by powering the borewells through the biomass power plants (currently, these borewells are powered by grid electricity), the initiative was successful in increasing income from agriculture, and in creating awareness and support for BERI in the project area.

Farmer incomes were also augmented by tree-bund farming – BERI's attempt to use the fallow land bordering fields to grow biomass for its power plants. These narrow but lush plantations of fast growing species such as eucalyptus enabled farmers to earn an additional ₹ 720,000 a year (2009/10) by selling nearly 600 tonnes of biomass to the gasifier plants.

The project design had placed women at the centre of its community engagement initiatives, and with the help of partner NGOs, BERI facilitated their participation in the project through adequate representation in organizations such as VFC, WUA, and VBEMC. The project also supported 81 women's self-help groups, providing – in many cases for the first time – avenues of meaningful livelihood and empowerment to 240 women. The groups encouraged members to meet regularly, have a platform to discuss various financial needs, maintain books of records, and access micro loans for income generating activities. Their contribution proved significant to the plantation activity, and they together raised 1 million saplings in 24 decentralized nurseries, earning them over ₹ 1 million in just six months. Some of these newly empowered women have used their earnings to initiate other livelihood activities. In addition, six women have been employed in the gasifier plants, responsible for biomass feedstock preparation.

Women were also the chief beneficiaries of the project's biogas plants, with the 175 beneficiary households receiving improved cookstoves that eliminated the health risks associated with cooking with traditional fuels. In 2006, BERI commissioned The Energy and Resources Institute (TERI) to conduct indoor monitoring of particulates (PM_{10} and $PM_{2.5}$) and carbon monoxide

A woman staffer of the Kabbigere plant, employed as a biomass cutter in 21 households selected from 7 villages representing all the 5 clusters where biogas units had been installed. The study results showed that the average value of PM_{10} concentration was 117.77 μg/m^3 in biogas users, as opposed to 1120.78 μg/m^3 in traditional fuel users.

In the context of BERI's biogas initiative, the project had initially targeted 24 biogas/biofertilizer systems with a cumulative capacity of 4000 m^3/day. After receiving positive feedback from users, the project built 51 community biogas-cum-biofertilizer plants by 2006, covering 175 households in 31 villages, with an installed capacity of 400 m^3 per day.

However, the biogas initiative eventually did not meet BERI's expectations, and in late 2012 only four of the 51 units were being operated. Analysing the biogas initiative, project officials have identified two significant barriers that eventually torpedoed what was a progressive solution to cooking energy needs. One was a frequent shortage of animal waste, which was an unexpected problem considering the abundance of domesticated cattle in the villages. Yet with most animal

A newly installed biogas unit in a project village waste being diverted for use as manure, the biogas units were chronically short of animal waste. The second impediment to the success of the biogas programme stemmed from the design of the technology. Being a group biogas plant project, gas is supplied by a plant to all BUG members (i.e., five households on an average). However, the systems served gas to users without any controlling mechanism to determine how much gas is being used by each member of a BUG. On a daily basis, this meant that users who accessed the gas from the unit first got the lion's share of the resource, leaving little or no gas for the other members of the BUG. This soon demotivated users from using the units, and they consequently fell to disrepair. A technical response to this issue could have been the installation of valves or meters that distributed gas more equitably and monitored usage. Studying other community biogas projects in India and elsewhere in the developing world could present viable solutions to this conundrum.

The unsatisfactory outcome of the biogas initiative, however, cannot mask the fact that community organizations such as BUG and WUA brought in and put in place platforms for discussions, discipline, awareness, and rules and norms, which bound the larger community. These served a larger purpose of community ownership and a spirit of working together.

Once the project was re-configured to sell electricity to the grid, community involvement turned lukewarm, but there was still a sense of pride and achievement that the *panchayat* in Kabbigere was perhaps the first *gram panchayat* in the country to sign a power purchase agreement with an electricity utility.

CAPACITY DEVELOPMENT

Against the project's objective of enabling communities to acquire the skills to run a bioenergy system, BERI had

The formal transfer of the Kabbigere plant to the Gram Panchayat *in 2007 was held in a colorful public function*

The symbolic cheque received by the Tovinakere Gram Panchayat *from BESCOM*

envisioned setting up a centralized training centre that would impart technical and management skills to local residents. This model was later jettisoned for a more diffused structure where a number of capacity building programmes were held in training

THE ROLE OF *GRAM PANCHAYATS* IN DECENTRALIZED POWER GENERATION MODELS

An important insight gained by the project was the nature of decentralization that could be realistically expected on the ground. In 2008, staying true to its vision of decentralization and community ownership, the project had transferred O&M of a 100-kW_e gasifier to the *Gram Panchayat*, but the institution was unprepared for the levels of involvement and diligence required to run a power plant efficiently. They could run the unit for about 500 hours. As a result, BERI PMU took back O&M responsibilities, and the consensus that has emerged is that while *Panchayats* can supervise and govern sub-megawatt plants, they may not be equipped to take over actual O&M. A suggested solution is a model where the *Gram Panchayat* can take on a supervisory role, while outsourcing management of the plants to the private sector.

nodes – situated in project sites as well as in the laboratories of CGPL, IISc.

The project succeeded in imparting advanced training to a group of 15 local persons in plant O&M. However, while training is continuous for shop-floor technicians and attracts the interest of educated youth, attrition levels are high as better pay in other small-scale industries weans away skilled technicians from the project's plants.

In all, over 10,000 people participated in the project's skill development, technical and awareness generation programmes, of which 58% were women. These capacity building workshops gave communities substantial vocational training and focused on practical application of bioenergy, demystifying many aspects of bioelectricity generation and bridging the gap between the community and the technology.

However, despite the range and reach of BERI's capacity development initiatives, technical capacity to run the plant remained weak, indicating a review of training methods, material, and remuneration to plant operators for projects of this nature is in order.

POLICY ADVOCACY

While BERI demonstrated the viability of bioenergy technology, it identified a gap in setting tariff for sub-megawatt-scale biomass projects. The project found that while it was producing power at ₹ 8.23 per kWh, it was bound to sell power at the established tariff of ₹ 2.85 per kWh (with 2% annual escalation) as per the power purchase agreement signed with BESCOM. The disparity was bridged by funds from the project, which also sought at the same time changes in policies governing biomass tariffs to make bioenergy a viable investment option.

As Table 1 shows, Karnataka's tariff for bioelectricity is still lower than most other states at ₹ 4.13 (due to its agreement with BESCOM fixing tariff at ₹ 2.85 per kWh with 2% annual escalation, BERI's power is bought at an even lower tariff of ₹ 3.66). It is also lower than other renewable energy sources (solar tariff by comparison is ₹ 7.49 per kWh). One of the reasons for this could be that biomass tariffs are possibly set based on benchmarks of large (over 5 MW) combustion-based units. This has put electricity generated by sub-megawatt biomass gasification at a disadvantage in the tariff structure, even though small rural power projects bring with them substantial intangible benefits to communities and villages. Additionally, the BERI project could not leverage the Renewable Energy Certificate (REC) system to bridge the gap between cost and tariff due to the fact that BERI's power was exported to the main power grid, and not technically replacing conventional energy use. Likewise, its rural biogas plants were deemed to have replaced not conventional cooking energy but woodfuel.

Table 1 Tariff announced by regulatory commissions for biomass power and cogeneration projects in different states in India (as on 1 November 2011)[2]

State	Tariff fixed by commissions
Andhra Pradesh	₹ 4.28/kWh
Bihar	₹ 4.17/kWh
Chhattisgarh	₹ 3.95/kWh for old projects ₹ 4.15/kWh for new projects
Gujarat	₹ 4.40/kWh with accelerated depreciation
Haryana	₹ 4.00/kWh with 3% escalation with base year 2007/08
Jharkhand	₹ 5.53/kWh with 3% escalation variable cost (air cooled) 2011/12 ₹ 5.31/kWh with 3% escalation variable cost (water cooled) 2011/12
Karnataka	₹ 3.66/kWh (PPA signing date) ₹ 4.13/kWh (10th year)
Kerala	₹ 2.80/kWh escalated at 5% for five years (2000/01)
Maharashtra	₹ 4.98/kWh (2010/11)
Madhya Pradesh	₹ 3.33 to 5.14/kWh for 20 years with escalation of 3 to 8 paise
Odisha	₹ 4.8/kWh with 3% escalation variable cost (2011/12)
Punjab	₹ 5.12/kWh (2011/12) escalated at 5%
Rajasthan	₹ 1.72/kWh for water cooled (2010/11) ₹ 5.17/kWh for air cooled (2010/11)
Tamil Nadu	₹ 4.50 to 4.74/kWh (2010/11) escalation of 2%
Uttaranchal	₹ 3.06/kWh (2010/11)
Uttar Pradesh	₹ 4.29/kWh for existing ₹ 4.38/kWh for new with escalated 4 paise per year, base year 2006

[2] Srinivas S N, Reddy P R, and Iyer S. 2012. **Biomass Power: business opportunities for sub-megawatt-scale biomass power generation.** In: *Business Opportunities in Biomass Power and Energy-Efficient Technologies in Manufacturing Units*, edited by S N Srinivas, Srinivasan Iyer, and P Ramana Reddy. New Delhi: United Nations Development Programme.

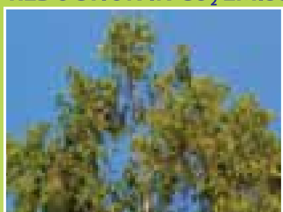
BIOMASS ENERGY FOR RURAL INDIA

ACHIEVEMENTS AND CHALLENGES

TECHNOLOGY DEMONSTRATION

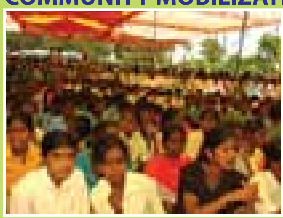
Achievements	Challenges
1.05 MW cumulative installed capacity (900 kW 100% producer-gas based)	Low PLF due to unscheduled grid outages and operational inefficiencies
1.34 million units cumulative electricity exported (Dec. 2012)	Cost of production higher than industry benchmarks
Benchmarking excercise carried out through continous 1000-hour operation	2 plants yet to be commissioned
Specific fuel consumption: 1.4 kg/kWh	Load shifting arrangement to cater to local loads

REDUCTION IN CO_2 EMISSIONS



Achievements	Challenges
Net reduction of 161,860 tonnes of CO_2	At 27,000 tCO_2 per annum, emissions reduction was below the target of 47,000 tCO_2 set by the project
Agro-forestry activities in 3000 hectares of land	

COMMUNITY MOBILIZATION



Achievements	Challenges
127 farmers organized into Water Users Associations	Community involvement in project dimmed due to change in project design from decentralized distribution of power to grid evacuation
81 Self-help groups for women	
51 Biogas user groups	
28 Village forest committees	

CAPACITY DEVELOPMENT

Achievements	Challenges
Over 124 technical training programmes involving 3742 participants	Inadequate technical capacity to run the biomass power plants
159 management training programmes involving 2556 participants	Enterpreneurial capacity under-developed
109 field trips involving 2843 participants	

Working towards a redressal of this imbalance, UNDP has been using the findings of the BERI experience to work closely with the Ministry of New and Renewable Energy (MNRE) , Government of India, to set differential tariff for small-scale power projects. This would give a big leg-up to the bioenergy sector by making it investment-friendly and help its wider adoption. The data and information generated from the BERI project is also aiding governmental efforts to formulate projects around small-scale biomass power generation in the 12th Five Year Plan.

In addition to drawing policy attention towards a more progressive tariff structure for bioelectricity, BERI circulated a number of policy notes and information documents, all geared towards creating policy consensus on the future of bioelectricity in the country. Documentation created by the project serves as a ready knowledge base for institutions and governments looking to replicate the technology to provide access to modern energy in rural regions. Project details and technical performance data have also been uploaded on the project website <www.bioenergyindia.in>, which acts as a valuable resource for policy makers, technicians, researchers, and academics.

To conclude, a review of the project's impact and the insights gained from areas that did not achieve traction provides a valuable blueprint for similar projects. The project has succeeded in answering many questions regarding the viability of decentralized sub-megawatt-scale power generation using biomass gasification technology, while identifying a number of barriers that need urgent attention if biomass is to achieve its potential as an effective solution to rural energy demand.

CHAPTER V

THE WAY FORWARD

The BERI project has presented several important insights into bioenergy potential and possibilities. It has also revealed a number of technical and practical issues that emerged while implementing this project. The defining achievement of the project has been a demonstration of a viable sub-megawatt power project through biomass gasification, and a replicable model of provision of tail-end support to base loads has emerged from the experience. Further, the 1000-hour benchmarking operation has yielded technical and performance standards for similar projects. The project also confirmed that transmission through a 11-kV line is the optimum solution to connect such power plants to the grid.

Beyond its technical achievements, the BERI project has brought with it a series of tangible and intangible benefits to enable communities to grow and prosper. The participation from traditionally excluded groups such as women (through SHGs) and landless households (through WUAs) was a particularly heartening development. BERI has also presented a model that empowers rural community organizations to generate and distribute power, as demonstrated through the PPA between BESCOM and the Tovinakere *Gram Panchayat*.

However, one of the key lessons from the BERI experience has been the unsustainability of operations under the current tariff structure for bioenergy. BERI has so far supported the gap between production cost and revenue through sales with donor funds, but this option is not available with the closure of the project. An upward revision of tariffs for biomass power generation at kilowatt or small megawatt scales is thus an urgent need to enable the sustainability of BERI's power plants.

The BERI project has had an enriching and occasionally turbulent journey, and as it drew nearer to the December 2012

THE BERI PROJECT

KEY TAKEAWAYS

TECHNOLOGY

First ever demonstration of sub-megawatt power generation through biomass gasification

Successful benchmarking test to evolve standards for replicable models

Power evacuation enabled through a 11-kV transmission line

Load shifting mechanism as a solution for tail-end supply of electricity to villages

SUSTAINABLE BIOMASS SUPPLY

BERI model showcased possibility of energy plantation intertwined with biomass power plant

COMMUNITY

First instance of a power purchase agreement between a utility and a Gram Panchayat

First example of an inclusive arrangement in integrated irrigation management where even landless households receive tradable water rights

POLICY

The BERI model is not sustainable at current tariff and a higher tariff regime for kilowatt-scale bioenergy projects is a requisite for wider replication

project closure date, the question stakeholders were confronted with is – what now? In the near term, this concerned the operation and maintenance of the power plants, and in the long term, the sustainability of the processes and systems put in place by the project, and in a manner that stays true to the original BERI vision of decentralized, adequate, and clean energy supply to rural areas. Overarching the concerns about the project's sustainability is the issue of replicating BERI in other rural settings. It was recognized that gains from the project must be consolidated, sustained, and expanded by replicating the BERI model.

Such issues increasingly preoccupied the project team as stakeholders prepared for exit, and a number of papers were published suggesting options for economic and technical sustainability of the project, as well as suggestions for replication. In 2008, an Exit Plan was prepared, which offered several possible options for short-term support and long-term sustainability. In 2012, a cost-benefit analysis commissioned by the project also identified areas requiring immediate attention and ways to ensure sustainability and replication. These and

Staff of the Kabbigere plant with BERI officials in 2012

other documents published by the project also recommended several approaches that can be taken to encourage the extension of the BERI model in other rural areas. What follows is a summary of the ideas, suggestions, and recommendations that have emerged to secure the sustainability of the BERI project and facilitate the replication of the BERI experience.

ENSURING NEAR-TERM ECONOMIC AND TECHNICAL SUSTAINABILITY

The cost-benefit analysis commissioned by the project underlined the delicate financial situation facing the power plants:

> *The average cost of power exported per unit for the 12 month period (May 2011 to April 2012) works out to ₹ 10.64 (Best performance in March 2008, ₹ 8.28 per unit exported). On the revenue side, it earns ₹ 2.85 per unit from BESCOM. Hence, in terms of financial feasibility, selling to BESCOM at the current rates, the operation will not be viable.*[1]

[1] Ranganathan V and Haque S. October 2012. Cost Benefit Analysis of Biomass Gasifier Based Electrification. Bengaluru: BERI

Inside the Kabbigere plant

The significant gap in cost and revenue had so far been bridged by partner funds, but with their exit, alternative sources of funds are critical to ensure economic sustainability. Initial attempts to transfer the project to a private operator have met with little success, as there are few entrepreneurs capable of running the plants. In this scenario, the options available are continued gap funding and a simultaneous effort to seek tariff revision. The Ministry of New and Renewable Energy (MNRE), Government of India, is a possible source for co-financing to maintain the economic *status quo*. As regards tariff revision, the Government of Karnataka now offers ₹ 3.66 per kWh to new gasifier projects. BERI could discuss possibilities with the KERC (Karnataka Electricity Regulatory Commission) of a revision based on this new tariff.

The KERC could also be approached to consider differential tariff for BERI's power. Current bioenergy tariffs in the state are based on benchmarks from <5 MW capacity biomass plants, placing sub-megawatt projects at a cost disadvantage. Considering BERI is the first such project using technology that can sustainably resolve rural energy shortage and/or unavailability, a strong case can be made for a differential tariff regime for the power exported by BERI's green power plants.

The case for sub-megawatt power generation through biomass gasification becomes even stronger when one considers the societal benefits of the technology. The BERI experience has indicated that 45% of the generation cost of biomass power production remains within the community. Further, the potential for large bioenergy projects to disturb biomass flows through excessive consumption is also mitigated by BERI-type sub-megawatt plants, and therefore they represent a more sustainable option to meet rural energy demand. These factors need consideration by policy makers to enable a differential tariff regime for sub-megawatt biomass power projects.

However, accessing co-financing or making a case for differential tariff are both incumbent on continued operation of the plants. Data generated during operations at Kabbigere has already given insight into the economics of sub-megawatt scale bio-power generation, and more data will strengthen the case for a differential tariff for micro bioenergy projects. Additionally, the Borigunte and Sebbanapalya plants need to be commissioned, as commissioning reports are a prerequisite to co-financing by the MNRE.

Continued operation and commissioning of the new plants are in turn dependent on getting a grip on the technical issues that have dogged the project. An increase in uptimes of engines and gasifiers, improving the power export ratio, and increasing the PLF need to be tackled on an urgent basis, and so too attaining industry benchmarks in efficiency. Attention is also due on ways and means of achieving reductions in operating costs.

For instance, small investments in handling systems can reduce biomass cutting and handling costs.

Another immediate objective in the post-BERI scenario is to implement a 'load shift' mechanism where power from the plants would be directly supplied to villages during grid failures. This would in effect create a local area power backup solution, and reinvigorate community interest and stake in the BERI project. A study assessing such a solution was conducted by independent consultants, who have also presented a plan to implement load shifting. The study has also revealed willingness-to-pay, with villagers displaying readiness to pay ₹ 5–6 per kWh for reliable uninterrupted power. The BERI Project Steering Committee has given its approval to the planned reconfiguration.

STRATEGIES FOR LONG-TERM SUSTAINABILITY

Apart from efficiency enhancements and improvement in operational health of existing installations, developing a medium-/long-term approach for further growth is assessed to be of key importance for the sustainability of the project. In this regard, BERI was registered as a society in 2007, and BERI Society (BERIS) is today mandated to sustain and expand both the project's local operations as well as its global vision.

BERIS is defined as an institution providing biomass development packages, technical guidance, and financial support to different agencies in an attempt to expand and replicate sub-megawatt biomass energy projects in rural areas. One of its priorities has been underlined as completing all remaining activities of the project. The standardization of the technology package and the commissioning of the Borigunte and Seebananapalya plants figure prominently in this regard. BERIS is also envisaged as taking a lead in creating entrepreneurial enthusiasm for sub-megawatt biomass power projects, and developing a management strategy and business plan to market bioenergy.

In the context of distribution and marketing of power, the options before BERIS are many. It may choose to continue with the current operating model, i.e., wheel power through state-owned transmission utilities and sell to a state-owned distribution utility. To operate on this model successfully, apart from operating at industry benchmark efficiency, the tariff must be revised upwards. It has been suggested that apart from making a case for differential tariff, BERIS could persuade a linking of bioenergy tariff with the market price of biomass, mirroring the model prevalent in the high volume freight business where transports are offered contracts linked to the market price of diesel.

Another option for BERIS is an outright outsourcing (on a lease-and-use basis) of the entire operation to a third party, giving it the right to sell electricity to whoever it wants. In such a model, BERIS will be freed from devoting resources for the daily operation of the plants, enabling it to pursue its larger goals.

Yet another way forward for the project is to revert to the off-grid model, selling power directly to end users in rural areas. Forming a rural electric cooperative, which directly distributes power and collects revenue, may be considered. Such a cooperative may also be eligible for subsidies from the state Department of Rural Development and Panchayati Raj. This model resembles the original project design, and is fraught with the same risks. A more prudent option could be the sale of BERI power on a wholesale basis to rural entrepreneurs, who, in turn, would manage retail subscribers.

REPLICATION

Beyond ensuring project sustainability, BERIS is also expected to play a leading role in developing a rural energy scenario. The organization has at its disposal data and insight gained from the first-ever demonstration of biomass gasification technology at sub-megawatt scales. While the thermal route to produce bioenergy is well established in <1 MW-scale projects, gasification at sub-megawatt scales also has its niche and requires servicing. Gasification plants may be 30% more expensive than thermal plants, but with a gestation period of only six months (as against 36 months for thermal plants),[2] they qualify as a viable investment proposition. It is envisaged that BERIS will, over time, play the role of a facilitator/catalyst in the development of biomass gasification technology projects. It is expected to do so by developing trained manpower, building entrepreneurial capacity, and conducting research on gasification. Funds for research and capacity building can be sourced from the Government of India's Department of Science and Technology, and funding programmes in other relevant ministries.

Technical support aside, BERIS is mandated to continue policy advocacy to achieve a favourable tariff regime for sub-megawatt biomass power generation. A higher purchase price for bioenergy will aid replication by enthusing private entrepreneurship in the sector. It has been suggested that BERIS approach the energy regulatory commission for higher purchase prices on the basis of it being produced through eco-friendly technology. In a 'win-win' situation for all, the purchasing utility can subsequently distribute the power to industry and commercial consumers at higher tariffs, enabling

2 BERI PMU and UNDP. *Post BERI: BERI Society - Business Strategy.* Note on BERI Exit Strategy.

them to achieve substantial carbon credits. One could even consider motivating private consumers to buy green energy at a marginally escalated cost. In this context, legislation could also be advocated, where a 'green cess' would be added to electricity bills, enabling users to invest in green energy. The German example, where legislation has mandated a significantly higher purchase price for renewable energy, can be explored in this regard; as also the Austrian model where low capacity biomass power projects receive higher tariffs.

The replication of the BERI experience has shown encouraging signs of movement forward, with the Karnataka Department of Rural Development and Panchayati Raj planning to see replication possibilities in each of the state's 27 districts. The Government of Karnataka is also keen to enhance biomass-based power to 1500 MW in the state, a goal that lends itself eminently to the BERI model of decentralized sub-megawatt bioenergy production. Such initiatives are currently being discussed and debated at the policy level, and BERI PMU has been a participant in these deliberations.[3]

The tremendous replication possibilities of the BERI model can be appreciated if one takes into account that India has over 230,000 *panchayats*, each requiring 0.1 to 0.5 MW of electricity. Sub-megawatt projects are tailor-made for such low demand, and the fact that a vast majority of *panchayats* also have significant biomass potential and can raise plantations to fuel small power plants makes the proposition more attractive. The BERI experience indicates that sub-megawatt biomass gasification power projects can generate an annual revenue of ₹ 15–20 million per year for a *Gram Panchayat* by selling power, with about 100 people employed in the management of the

[3] UNDP. 2009. BERI Project Implementation Report. New Delhi: United Nations Development Programme.

power plants. In addition, employment can be generated in plantations management and nursery arrangements.

However, sub-megawatt power generation through biomass gasification is still an enigma in terms of proven sustainable supply of biomass and sustainable operation of power plants in non-industrial settings. BERI was launched to help overcome some of these barriers, and BERIS has to now continue to chip away at them to enable wider replication.

ANNEXES

ANNEXE 1

PROJECT INFORMATION

Project Information

Area: Environment and Energy

Budget: US$ 8,623,000
US$ 4,017,000 (Global Environment Facility)
US$ 2,495,000 (India Canada Environment Facility)
US$ 1,481,000 (Government of Karnataka)
US$ 391,000 (Ministry of New and Renewable Energy, Government of India)
US$ 239,000 (Others)

Duration: 2002-2012

Government Counterpart:
Rural Development and Panchayati Raj Department, Government of Karnataka

Implementing Partner(s):
Rural Development and Panchayati Raj, Government of Karnataka

Location(s):
Tumkur district, Karnataka

ANNEXE 2

JOURNEY OF BERI PROJECT THROUGH VISUALS

Unprocessed biomass lined up outside the Kabbigere plant

Plant staff cutting biomass in the Kabbigere plant

Members of Biomass Users Group pose with a biogas unit

Visiting dignitaries from UNDP briefed about operations in the Kabbigere plant

The Kabbigere plant was handed over to the community in a public function in 2007

BESCOM officials present the first cheque to the VBEMC at Kabbigere in 2008, making it the first panchayat *selling power to a utility*

A borewell constructed by the project adjacent to cultivated fields

Members of a women's self-help group engaged in tree plantation

Women participate in a Mahila Samavesh *function*

NOTE ON REFERENCES

The publication draws all its data, figures, and statistics from documents made available by BERI PMU. These documents are publicly available at <www.bioenergyindia.com> and the UNDP BERI project website <http://www.in.undp.org/content/india/en/home/operations/projects/environment_and_energy/biomass_energy_forruralindia.html>. The documents referred to in this book are given below. Any reference external to these sources are marked with a footnote.

1. Project Document, Biomass Energy for Rural India
   2001; Government of Karnataka, Government of India, UNDP, GEF

2. Cost Benefit Analysis of Biomass Gasifier Based Electrification
   Ranganathan V and Haque S, 2012, BERI PMU

3. BERI Project Implementation Report, 2012
   UNDP

4. BERI Policy Paper
   Chessin E, Gilmartin P, Shaffer B, IkinkJelmer D, 2012; Fletcher School of Law & Diplomacy

5. Compendium of Data
   2013; BERI PMU

6. BERI: Carbon Mitigation Report
   Ravindranath, Darshini; 2012; BERI PMU

7. BERI: Mid Term Evaluation
   Jayakumar P, 2005; Eco Ltd and BERI PMU

8. BERI: Final Evaluation Report
   Wong R and Mande S, 2012; UNDP-GEF

9. Grid-Interactive Biomass Gasification Based Power Generation in Rural India
Freund K, 2008; UNDP

10. Post-BERI: Business Strategy
2012; BERI PMU

This book, titled *Bioenergy for Rural India*, narrates the implementation and impact of a unique energy project that focused on decentralized, bottom-up power generation using biomass gasification technology. BERI or Biomass Energy for Rural India project was implemented in Tumkur district of Karnataka between 2001 and 2012. The Global Environment Facility, the United Nations Development Programme, the India Canada Environment Facility, and the governments of Karnataka and India came together to support the agendas of environmental sustainability, poverty reduction, and inclusive growth that the BERI project stood for.

Overall, the project was unique in three respects. First is that the project ensured supply of biomass resources through a dedicated plantation to run a 1 MW cumulative biomass gasifier plants on a continuous basis. Second, it strengthened grid interaction at the tail end with continuous power supply to the 11-kV transmission line, which, in turn, ensured sustained operation of the grid-connected sub-megawatt plants located in the villages. And third, the project established operational benchmarks for sub-megawatt biomass-based gasifier plants on the field. These achievements and benchmarks are significant in that they can be effectively used for similar projects not only in the country but also in countries where biomass resources are available in plenty.

The project is also a model of sustainable rural development through biomass energy, introducing to project villages group biogas programmes, women's self-help groups, and a landmark community irrigation programme, which included landless households in water users associations, the first such instance in any integrated watershed management programme.

This book offers valuable insight and lessons for development professionals, policy makers, researchers, and students on the implementation and management of renewable energy-based sub-megawatt power projects in rural areas.

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United Nations Development Programme
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