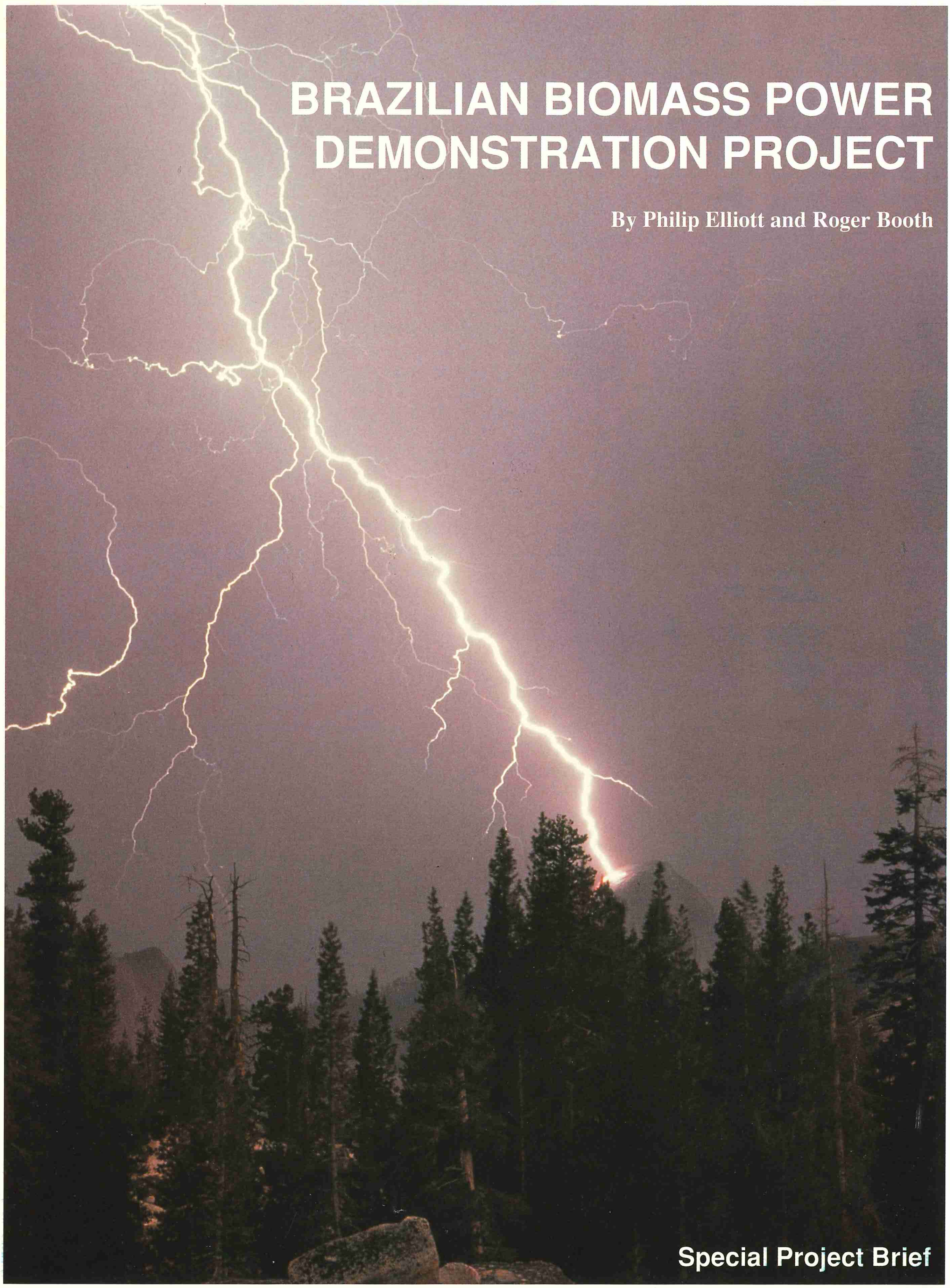
BRAZILIAN BIOMASS POWER DEMONSTRATION PROJECT

By Philip Elliott and Roger Booth



Special Project Brief

Biomass Integrated Gasification-Gas Turbine (BIG-GT) Technology Project - Phase II
A renewable energy technology development funded by the Global Environment Facility

SEPTEMBER 1993

Based upon papers presented to the "Seminar on Power Production from Biomass", VTT, Helsinki, Finland in December 1992; and the "Strategic Benefits of Biomass and Waste Fuels Conference" EPRI, Washington, USA in March 1993.

Brazilian Biomass Power Demonstration Project

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Philip Elliott has a mechanical engineering degree from Bristol University and an MPhil in economics from Oxford. He worked in engineering and marketing in a range of environments from gas turbines to electronics before joining the Natural Gas Division of Shell International Petroleum Company (SIPC) in 1980. He moved to the Non-Traditional Business Division of SIPC in 1983 where he was involved in business activities in forestry and renewable energy. Since 1991, he has been closely involved with third parties in setting up the Brazilian Biomass Power Demonstration Project and is continuing in this role following transfer to SIPC's Supply-Marketing Division in March 1993.

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Introduction

Renewable resources account for around a fifth of world energy supply - 14% from biomass and 6% from hydropower. Much of the biomass is non-commercial and goes unreported in national energy statistics. Its worldwide contribution is estimated at around 25 million barrels of oil equivalent per day and on average it represents 35% of the primary energy used in developing countries.

Globally, photosynthesis produces 8 times as much energy as man currently consumes from all sources. Given that almost 90% of the world's population will reside in developing countries by the middle of the 21st century, the role of biomass energy seems set to expand.

Renewables must compete in a price system set by the costs of fossil fuels with all their attendant scale economies in production and distribution. As a consequence, commercial renewables - apart from hydro - have been confined largely to "niches" at the margins of the mainstream energy sector where local factors enable them to compete.

Advanced biomass power technologies could change this pattern. Close to source, the cost of useful energy in the form of lignocellulose is often competitive with fossil fuels - and this applies not only to residues from agriculture and the forest industry, but also to large-scale forestry plantations in many parts of the world. What has been lacking is a conversion technology capable of delivering this energy to the market competitively, on a modest scale appropriate to biomass. Electricity is by far the highest-value energy carrier and represents the best short/medium term option for introducing biomass into commercial energy channels.

Many small-scale, steam cycle power plants are fuelled by agricultural and forest industry residues around the world. However, such plants are costly and inefficient and are therefore confined to situations combining low feedstock costs with high electricity prices. Broader commercialisation of biomass power requires a more favourable combination of power plant efficiency and specific investment cost.

The Biomass Integrated Gasification-Gas Turbine (BIG-GT) cycles appear promising in this respect and a number of commercial gasifiers exist which could be developed for gas turbine applications. However the concept is only now approaching the stage of demonstration in an integrated system.

Amongst the emerging renewable energy options, biomass power appears particularly well positioned to contribute to commercial energy supply early in the 21st century, both in terms of cost and scale. With careful management, it could also offer considerable social and environmental benefits. Whilst Shell companies are not active in the power sector, they have supported the development of the world's first commercial BIG-GT demonstration project in Brazil. This involvement has arisen from a desire to establish the nature and extent of these potential social and environmental benefits, to assist technology transfer and to promote sustainable development.

BIG-GT Development Targets and Philosophy

The simple numerical examples shown in figure 1 illustrate two key points about BIG-GT economics:

i. Diminishing Returns from Efficiency Improvement :

The fuel component of the ex-plant electricity cost depends on the into-plant cost of feedstock and the net thermal efficiency of the cycle. For a fuel cost of US$ 2 per gigajoule (GJ), an efficiency increase from 20% to 45% reduces the fuel component of the electricity cost from 3.6 US cents per kilowatt hour (kWh) to 1.6 cents/kWh. However, a further doubling of the net plant efficiency or a halving of the feedstock cost to US$ 1/GJ would only shave an additional 0.8 cents/kWh from the overall cost of production.

ii. Capital Costs Dominate Economics

Assuming that most configurations of BIG-GT technology are capable of achieving net thermal efficiencies in excess of 40%, the capital recovery element will be the major determinant of economic viability. Given the assumptions underlying figure 1, capital related costs would represent around 60% of the ex-plant cost of electricity.

A full-scale demonstration plant would be the "first-of-a-kind" and for a net plant output of 25-30 megawatts (MW),would be expected to have a specific investment cost in the range US$2,500-3,000 per kilowatt (kW). This is clearly too high for economic viability in the absence of significant incentives such as capital grants or preferential pricing.

A number of companies have active R&D programmes aimed at commercialising BIG-GT cycles but at this stage, the capital cost and performance parameters which might ultimately be achieved cannot be estimated with much precision. However, the indications are that specific investment costs might fall into the range US$1,300-1,500/kW after five or ten replications of a standard design. This learning curve is illustrated in figure 2 and rests on a number of assumptions:

Value Engineering is pushed to the limit. Value engineering is loosely defined as the process of choosing solutions to specific technical problems in order to achieve some "optimal" mix of capital cost, reliability, operating cost, maintenance cost, energy consumption and so forth.

Whilst precise definition is difficult, the objective - minimising the cost of power production - is straightforward.

Replication of Standard Designs runs counter to conventional wisdom which calls for large scale units (500-1,000 MW) designed and built on a "one-off" basis. Whilst this philosophy opens up economies of scale, it conceals major diseconomies associated with the uniqueness of the design of large plants, the scale of component items, project complexity, long lead times and construction periods, and the inability of companies or consortia to learn by repetition of the implementation process. Furthermore, in many developing countries, it may be difficult for power markets to absorb large, step increases in capacity. Biomass-based power generation will involve a change of "mind-set" - that new capacity brought on-stream in step with incremental demand, and comprising a number of small-scale BIG-GT units (25-50MW) might prove more effective than a single, conventional power plant of 500MW.

Factory Building of BIG-GT power plants to a standardised design is considered feasible with a substantial degree of pre-assembly at the manufacturers' facilities. Little on-site fabrication is envisaged and the construction phase would involve minimal site preparation and foundation requirements; integration of standard, factory-built modules; and a very short time lapse between breaking ground and start-up.

Accelerated Development of BIG-GT by the Global Environment Facility

The learning curve illustrated in figure 2 might be achieved at say 25MW for low pressure BIG-GT plants; and perhaps at a somewhat larger scale for high pressure units. However, in common with all new technology developments, substantial risks and uncertainties will influence the decisions of potential investors:

Technological and **commercial risks** concerning the reliability or efficiency of BIG-GT plants; or doubts about ultimate achievable specific investment costs; or

Political and **environmental issues** such as support for agriculture in the US and EC; or "enhanced global warming" and so forth.

Given the high expected costs of prototype plants, and risks such as those outlined above, a considerable lapse of time might be expected before BIG-GT technology could achieve full commercial viability through the normal processes of product and market development. As an illustration, consider a pioneering project proposal for which the prototype BIG-GT plant is expected to cost US$2,500/kW, whereas an investor's target rate of return calls for a specific investment cost below US$1,500/kW given all the circumstances of the proposal.

At a scale of 25MW, the prototype plant would cost over US$60 million, some US$25 million more than the potential investor would wish to pay.

The Global Environment Facility (GEF) administered by the World Bank (see box overleaf) has therefore stepped in with grants to bring about the implementation of a prototype demonstration project and to accelerate the progress of BIG-GT technology down the learning curve.

Background Leading to Demonstration Proposal for Brazil

Over the past two years, several factors have converged to create a framework for a commercial demonstration of BIG-GT technology in Brazil, and both Shell Brasil and the Renewable Energy Section of Shell International Petroleum Company (SIPC) have been active in the process.

The principal factor was the creation of the GEF with a mandate to promote investment in key areas of environmental maintenance: the ozone layer; biological diversity; international water bodies; and the accumulation of atmospheric carbon dioxide. Concerning this last item of its mandate, the GEF has identified an important role in bringing forward the development of renewable energy technologies which appear close to commercialisation and which are suited to widespread replication. BIG-GT technology could have a positive impact on the carbon cycle, whilst at the same time being potentially competitive with conventional, fossil-based electricity. The GEF has therefore placed a high priority

Economics Overview

Electricity is a high value energy market, with wholesale prices typically ranging around five cents/kWh at the power plant. This is equivalent to $14/GJ, $85 per barrel of oil equivalent (boe), or around three times the wholesale price of automotive fuels in mid 1993.

Agricultural and forest industry residues are used to generate power in steam turbines generally below 25 megawatts electrical output (MW). In the USA, around 8 gigawatts (GW) of capacity operates in situations usually combining low feedstock costs with high electricity prices. Under the terms of the US Public Utilities Regulatory Policies Act (PURPA) of 1978, power utilities are obliged to buy electricity offered by independent generators at prices that reflect "avoided costs" - the costs that would be incurred if the utility itself provided the additional power.

In the early 1980s, such costs often ran as high as nine cents per kWh and, at these guaranteed prices, there was a rush of developers to sign contracts.

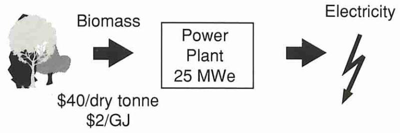
However, as avoided cost levels dropped towards five cents per kWh, the flow of new biomass power projects has declined markedly because conventional steam cycle plants are handicapped by a combination of low efficiency and high specific investment cost at a scale suited to biomass applications.

Recent assessments of emerging technologies suggest that power plants of a modest scale (20-50MW) could achieve thermal efficiencies in excess of 40 percent within a few years (eventually reaching 50 percent or more), combined with capital costs well below those of comparable conventional biomass plants utilising boiler/steam turbine technology.

A number of technological concepts are promising but the BIG-GT cycles are well-placed to make an early impact. This technology involves a gas turbine, closely coupled with an air-blown gasifier. Early plants are likely to incorporate a steam bottoming cycle (combined cycle), but other variants are possible such as an air bottoming cycle; steam-injected gas turbine (STIG); and intercooled, steam-injected gas turbine (ISTIG).

Figure 1

Biomass Power Costs



Conventional Technology

Steam Cycle

Efficiency = 20%
$/kw = 1800
Load factor = 85%
RTEP = 8%

	Ex-plant cost US cents/kWh
O&M	0.5
Fuel	3.6
Capital Recovery	4.2
Total	**8.3**

Emerging Technologies

BIG-GT Cycles

Efficiency = 45%
$/kw = 1300-1500
Load factor = 85%
RTEP = 8%

	Ex-plant cost US cents/kWh
O&M	0.5
Fuel	1.6
Capital Recovery	3.0-3.5
Total	**5.1-5.6**

(RTEP = ungeared real terms earning power)

BIG-GT Technology Learning Curve

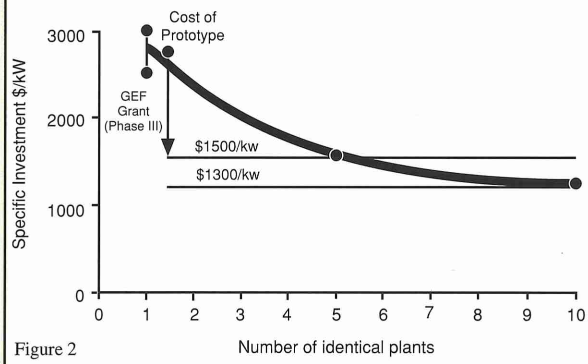


Figure 2

on accelerating the development of BIG-GT technology and substantial funding has been made available.

A second important strand of the process involves Companhia Hidro Eletrica do Sao Francisco (CHESF), the federally-owned utility responsible for bulk electricity supply in the Northeast region of Brazil. The low cost hydro resources of this region will be fully utilised by the turn of the century and the marginal costs of new capacity are expected to rise sharply. CHESF is therefore interested in promoting BIG-GT technology as a leading, low-cost alternative to hydroelectricity. ELETROBRAS, the parent company of CHESF, supports a demonstration project and has formally cleared the way to permit the sale of electricity on appropriate terms.

Brazil is a leading producer of renewable energy - more than 90% of its electricity is based on hydro resources and biomass accounts for almost a third of total primary energy. A successful demonstration of BIG-GT technology would expand the potential of biomass, most notably in the sugar/alcohol industry where considerable quantities of bagasse are incinerated in inefficient energy recovery systems. Indeed, the integration of BIG-GT power technology with high efficiency distilleries could substantially improve the economic performance of the fuel alcohol sector. In addition, sustainably managed fuelwood plantations - established, for example, on degraded grasslands - have the potential to become a major source of primary energy if the economics of BIG-GT plants live up to expectations. The Brazilian government has therefore shown a keen interest in promoting a commercial demonstration.

In June 1991, the Brazilian Secretary of State for Science and Technology invited 18 local Brazilian and multinational organisations to a meeting aimed at creating a project development group. From this meeting, five organisations - CHESF, ELETROBRAS, Companhia Vale do Rio Doce (CVRD), Fundacao de Ciencia e Tecnologia (CIENTEC) and Shell Brasil - registered interest in participating in further studies. A project development outline was envisaged involving:

Phase I preliminary investigation, Q3, 1991 - Q1, 1992;

Phase II process and equipment development, Q2, 1992 - Q4, 1994;

The Global Environment Facility

Purpose of the GEF

The Global Environment Facility (GEF) is a three-year experiment providing grants for investment projects, technical assistance and research. Its aim is to protect the global environment and to transfer environmentally benign technologies to the developing world.

The Brundtland Commission concluded in 1987 that there was a "serious lack of funding for conservation projects and strategies that improve the resource base for development". The idea of an international environment facility emerged from a follow-up study commissioned by the United Nations Development Programme (UNDP) and carried out by the World Resources Institute. The GEF was formally established in November 1990, and the first meeting of participating countries was held in Washington D.C., in May 1991. The GEF mandate covers four areas:

Global warming, particularly the effects of greenhouse gas emissions from fossil fuels and the destruction of forests; reduction of **biological diversity** through the degradation of natural habitats; **pollution** of international waters by oil spills and the accumulation of wastes in oceans and international river systems; and the depletion of **stratospheric ozone** by chlorofluorocarbons (CFCs), halons, and other gases.

Resources Available to GEF

The Facility has US$ 1.3 billion to commit over the three-year pilot phase that began in 1991. In fact, the GEF is an umbrella made up of funds from three distinct sources. The main part is the so-called "core fund", the Global Environment Trust Fund (GET). With some US$ 800 million in commitments, the GET accounts for the bulk of the GEF's resources. In addition, the GEF includes several associated cofinancing arrangements. These funds (some US$ 300 million) are available on grant or highly concessional terms. The GEF also includes some US$ 200 million provided under the Montreal Protocol to help developing countries comply with its provisions to phase out ozone destroying substances. These funds are administered - totally separately from the core fund and the cofinancing arrangements - by the United Nations under the auspices of a 14-country Executive Committee.

Eligibility for GEF Funds

All countries with a per capita income of less than US$ 4,000 a year (as of October 1989) and a UNDP programme in place are eligible for GEF funds.

Resource Allocation

There is no set formula but around 40-50% of GEF resources are allocated to projects concerning global warming, 30-40% to biological diversity, and 10-20% to international waters. Most ozone projects are funded by the Montreal Protocol's Interim Multilateral Funds.

Source of GEF Funds

Twenty-four countries (nine of them in the developing world) had pledged some US$ 800 million to the core fund by December 1991: Austria, Belgium, Brazil, Canada, China, Denmark, Egypt, Finland, France, Germany, India, Indonesia, Italy, Japan, Mexico, Morocco, the Netherlands, Norway, Pakistan, Spain, Sweden, Switzerland, Turkey and the United Kingdom. In addition to their contributions to the core fund, Belgium, Canada, Japan and Switzerland have separate cofinancing arrangements. Australia and the United States have not contributed to the core fund, but Australia has established cofinancing arrangements and the United States has supported parallel financing of GEF-type projects.

Organisation of the GEF

Responsibility for implementing the GEF is shared between the UNDP, the United Nations Environment Programme (UNEP) and the World Bank. No new bureaucracy was created and only modest organisational modifications were made to the three implementing agencies.

The **UNDP** is responsible for technical assistance activities and, through its worldwide network of offices, helps to identify projects through pre-investment studies. It also runs the small grants programme for non-governmental organisations (NGOs); The **UNEP** provides the secretariat for the Scientific and Technical Advisory Panel as well as environmental expertise for the GEF process; The **World Bank** administers the Facility, acts as the repository of the Trust Fund, and is responsible for investment projects.

Projects Qualifying for GEF Funds

Projects that are deemed to benefit the global environment, as distinct from the local environment, qualify for funding under the GEF. To this end, projects must fall into one of the four GEF priority areas and must also be innovative and demonstrate the effectiveness of a particular technology or approach. Given its pilot nature, other criteria include the contribution a project makes to human development (through education, training, and so on), and the provision for evaluation and dissemination of results.

After the Pilot Phase ?

The pilot phase of the GEF comes to an end in mid-1994 by which time all funds will be committed, although actual disbursement is likely to continue until 1997 or 1998. Meanwhile, the international community is assessing the effectiveness of the GEF with a view to replenishing the Facility's financial resources. In parallel, the GEF is undergoing a restructuring process to make its membership more universal and to enable the GEF to serve as the financing mechanism for the global conventions on climate change and biodiversity (signed at the 1992 UNCED conference in Rio de Janeiro).

Phase III implementation, Q1, 1995 - Q2, 1997

Phase IV debugging and pre-commercial operation;

Phase V commercial operation.

Phase I

Phase I was funded by the Rockefeller Foundation, Winrock International, the US Environmental Protection Agency and the US Agency for International Aid. It was completed in March 1992 and achieved a number of objectives:

A **Memorandum of Understanding** was agreed as a basis for cooperation in Phase II;

BIG-GT technology options were explored and process developers and equipment manufacturers were identified and shortlisted;

The **economic potential** of BIG-GT power generation was estimated both for the prototype plant and the "n_{th}" commercial plant;

A **work programme** was outlined for process and equipment development and **budgetary requirements** were assessed.

On the basis of the intermediate and final reports submitted in Phase I, the GEF confirmed the availability of **grant funding** in two tranches:

Phase II a two year process development grant **US$7.7 million;**

Phase III implementation grant **US$23.0 million.**

Phase II

Technology Development Involves Competition - The "Two Leg" Strategy

At this stage there is insufficient information to define the ultimate configuration for BIG-GT technology including gasifier pressure, gas clean-up technology and gas turbine cycle. Competitive tendering for the BIG-GT development process was therefore considered inappropriate given this "softness" of the available technical and economic data. The scheme adopted will keep two distinct technology options open pending the generation of firmer data.

This scheme also injects a strong competitive element into Phase II. Two independent project teams are working in parallel to develop distinct technology packages. Each team is led by a gasifier system developer responsible for the performance of the gasifier/gas clean-up train; integration of the gas turbine and steam bottoming cycle; the overall system control; and the provision of process guarantees. Only in the later stages of Phase II will the choice be made between the two technology packages. The competitive process starts with the selection of the project team leaders, continues through the process development and engineering stage and culminates with the final selection between the two project teams.

Two factors underlie the choice of project team leaders. Firstly, it is not yet clear whether high pressure gasification will dominate BIG-GT power generation in all circumstances, or whether low pressure systems could retain the economic edge over the lower part of the scale range. Secondly, the difficulties of achieving acceptable levels of reliability, efficiency and specific investment cost with a high pressure system of 30 MW capacity, will be compounded by the time and funding constraints of Phase II.

The decision was therefore taken to progress both high pressure and low pressure systems through the Phase II technical development stage (figure 3). Bioflow - a joint venture involving Ahlstrom and Sydkraft - will be responsible for the high pressure system development and TPS Termiska Processer will develop the low pressure technology. Both project teams will work with General Electric who will adapt the LM2500 gas turbine for use in BIG-GT cycles.

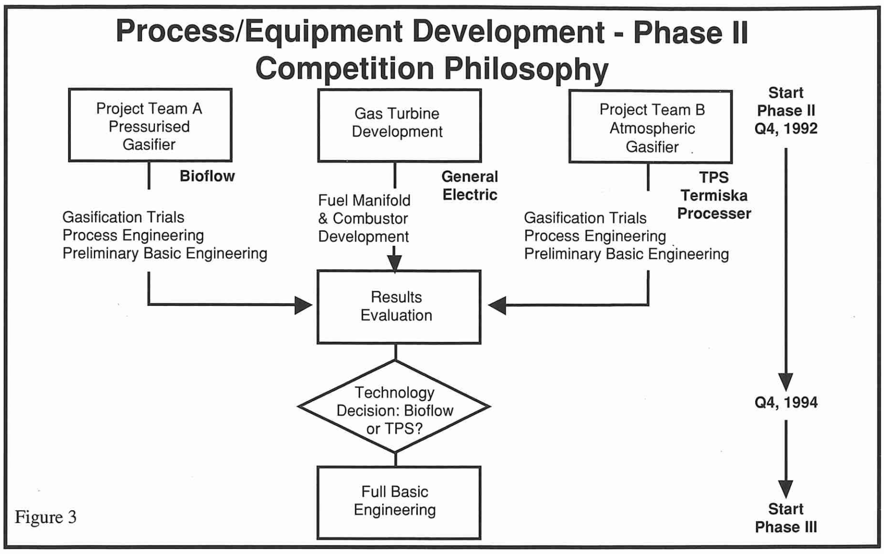


Figure 3

These companies were shortlisted following extensive screening of the available technologies and responded to a formal Request For Proposals (RFP) in mid 1992. The final selection was based on an evaluation of the proposals; the company's commitment to biomass fuels development; the status of its technology; the adequacy of the available funds for work defined in the RFP; compatibility of the developer's timeframe with GEF schedule constraints; and the developer's research facilities, past experience and technical development history.

Project Organisation

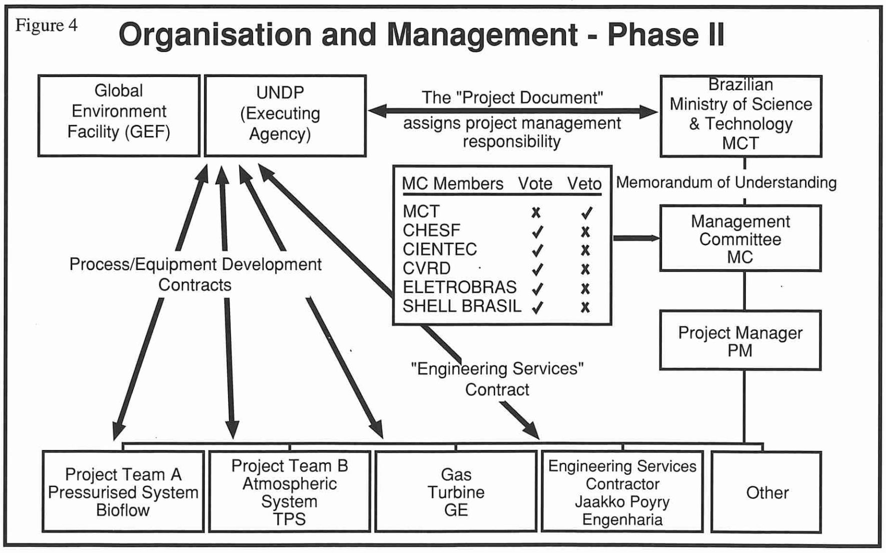
A company will be incorporated in 1995 to build the power plant in Phase III. However, for the purposes of Phase II, it has been necessary to put in place a less formal organisational arrangement (figure 4).

The United Nations Development Programme (UNDP) is the executing agency formally appointed by the GEF to manage the Phase II grant of US$7.7 million.

The Process/Equipment Development Contracts involve on the one hand the UNDP, and on the other hand Bioflow, TPS Termiska Processer and General Electric. These contracts specify an active administrative and supervisory role for the UNDP. However, this role is assigned to the Brazilian Ministry of Science and Technology (MCT) in a separate agreement - "The Project Document" - under which the MCT assumes the ultimate responsibility for the execution of Phase II of the project.

Actual control of the Phase II project development process is in the hands of the Management Committee (MC). The composition, structure, modus operandi

Figure 4



and responsibilities of this committee and its constituent organisations, are defined in a Memorandum of Understanding (MOU), a loose but legally-binding document signed by representatives of CIENTEC, CHESF, CVRD, ELETROBRAS, MCT and Shell Brasil. In executing its responsibilities, the Management Committee draws upon the services of a Project Manager appointed from CHESF, specialists from the organisations represented on the MC and an engineering services company. All aspects of managing the Process/Equipment Development Contracts; site selection; specification of civil engineering and grid connection; negotiation of feedstock supply and electricity sales agreements and so forth, come under the remit of the Management Committee which takes decisions by simple majority vote. The MC is chaired by a representative of the MCT who has no vote but has limited right of veto over decisions which could compromise the agreement between the MCT and the UNDP as laid down in the "Project Document".

Process/Equipment Development Contracts

Early in Phase I, a number of gas turbine manufacturers and gasification process developers were invited to submit preliminary proposals for work programmes to bring their individual products to commercial readiness for a BIG-GT demonstration. A gross funding requirement in the range US$10-15 million appeared necessary to assure success in the Phase II development programme.

During the course of 1992, Bioflow, TPS Termiska Processer and General Electric developed detailed versions of these preliminary proposals with more detailed costings and schedules - taking into account the budgetary constraints imposed by the size of the Phase II grant allocated by the GEF; alternative sources of external funding; and internal funds made available by each company. The Phase II programme adopted gives the project a high probability of technical and commercial success with the following budget:

Developer	Phase II Budget	% BIG-GT Programme
Bioflow	US$1.9m	Small
TPS	US$1.9m	Small
GE	US$1.6m	100%

In the case of Bioflow and TPS Termiska Processer, the Phase II funds provided by the GEF represent a relatively small proportion of their overall BIG-GT (and related) programmes. The companies themselves and the Swedish government have invested substantial sums in developing the technology to its current status. Gas turbine development is being carried out by General Electric on a full cost basis.

Each proposal includes a series of development "milestones" which form the basis for phased payments under the Phase II contracts. This contractual structure allows close monitoring and control over the quality of the process and equipment development work.

The process/equipment development contracts were finalised in December 1992.

Technology Assessment and Gasifier Selection

During the course of Phase II, the process/equipment developers will submit monthly and quarterly progress reviews as well as a series of reports containing test results, engineering studies, cost analyses and so forth.

Selection between the high pressure and the low pressure gasifier systems will be based on a wide range of factors including both hard data and technical judgement. Amongst the aspects to be taken into consideration are: Gasification test results; process engineering; preliminary basic engineering; net thermal efficiency; simplicity of design concept; ease of operation and maintenance; investment, operation and maintenance costs; the potential for further improvements in cost and efficiency; and proposals for Phase III support.

Following the technology selection around Q4, 1994, full basic engineering will be carried out by the successful Project Team in preparation for detailed engineering commencing in Phase III.

Intellectual Property Rights and Confidentiality Arrangements

Grants provided by the GEF to Bioflow and TPS Termiska Processer form only a small component of the BIG-GT programmes being carried out by each of these companies. In the case of GE, the development work pertains directly to a specific gas turbine - the LM2500. Ownership of all intellectual property rights therefore remains with the relevant developer. However, much of the information made available to the Management Committee during the course of Phase II will be of considerable commercial value to the developers. Formal confidentiality agreements have therefore been put in place to protect their interests whilst at the same time allowing the Management Committee to develop a thorough understanding of the technologies and to issue adequate public information on the progress of the project.

The Engineering Services Company

The engineering services contractor - Jaakko Poyry Engenharia - was selected from amongst six companies which submitted proposals, in an open, competitive tender. This company is the executive arm of the Management Committee working under the Project Manager, with responsibility for a wide range of tasks including: Monitoring technical progress and expenditures versus budget; technology absorption and maintenance of documentation; identification of local suppliers; site selection and definition of infrastructure; provision of feedstock for gasification trials; participation in basic engineering, environmental and grid connection studies; natural pre-drying tests for fuel; economic analysis; preparation of Phase III planning; and final reports for Phase II.

Bioflow

Bioflow is a bio-energy technology and marketing joint venture between A. Ahlstrom Corporation of Finland and Sydkraft AB of Sweden.

A. Ahlstrom Corporation:

A. Ahlstrom Corporation is a diversified, multinational, privately-owned Finnish company with group net sales of approximately US$ 2 billion. The company operates in four sectors: **Ahlstrom Machinery; Ahlstrom Paper; Ahlstrom General Products;** and **Ahlstrom Pyropower.**

Ahlstrom Pyropower is responsible for energy-related products and processes. Headquartered in San Diego, USA, the global operations of the sector comprise Ahlstrom Boilers in Varkaus, Finland; Pyropower and Ahlstrom Development Corporation in San Diego; and Pyropower Japan Ltd in Kobe, Japan. In total, Ahlstrom has supplied more than 300 industrial and utility boilers over the last 50 years, with a combined capacity of 20,000 megawatts thermal (MW_{th}).

Close collaboration with the Finnish pulp and paper industry has formed the base for Ahlstrom's expertise in the use of biomass and wood waste material for energy production. The first "Pyroflow" circulating fluidised bed (CFB) unit was built to burn biomass and of more than 110 units sold to date (12,000 MW_{th}), more than 30 operate on biomass.

Based on Pyroflow CFB combustor technology, a gasifier was developed in the early 1980s. Four atmospheric gasifiers are now in operation, fuelling lime kilns in kraft pulp mills. The first unit of capacity 35 MW_{th} was started up in 1983 and continues to operate with high availability.

In 1989, Ahlstrom built a Pressurised Circulating Fluid Bed (PCFB) combustion test facility of capacity 10 MW_{th} at the Hans Ahlstrom Laboratory located in Karhula, Finland. Building on this R&D experience, the world's first commercial demonstration of PCFB technology is in the design phase. This plant, of 78 MW_{th} capacity, will be built in Des Moines, Iowa, and forms part of the US Department of Energy "Clean Coal Technology III Programme".

The combination of experience with atmospheric biomass gasification and pressurised (PCFB) coal combustion forms a strong base from which to develop pressurised CFB gasification technology. In 1990, Sydkraft AB of Sweden joined Ahlstrom to develop pressurised CFB gasification for biomass applications. At the Karhula laboratory, a 7 MW_{th} pilot plant is under construction to further develop pressurised CFB gasification technology for both biomass and coal.

Sydkraft AB:

The Sydkraft Group consists of some 50 wholly or partially owned companies, most of which operate in the electricity sector. It is the largest private energy group in Sweden and is the second largest power company after the state-owned utility Vattenfall. It owns and operates nuclear, fossil and hydroelectric power plants with a combined capacity of around 5GW. Sydkraft is also active in other energy-related areas such as natural gas, LPG, solid fuels and uranium. The group operating revenues in 1991 were around US$ 1.4 billion. Sydkraft has a tradition of technological innovation and invests around 3% of turnover in R&D. These investments include **the world's first biomass power plant incorporating pressurised BIG-GT technology at Varnamo.**

The Varnamo plant:

Construction of Sydkraft's BIG-GT demonstration plant began in September 1991 at the town of Varnamo in central Sweden and the unit is being commissioned in stages during the course of 1993. Full commissioning will be followed by a research programme spanning a period of several years although contracts are in place to supply electricity to the grid and heat to the local district heating system from the outset. The Varnamo plant is a component of a bioenergy programme pursued by Sydkraft with the aim of commercialising heat and power production from fuels based on agriculture and forestry. The Varnamo plant will deliver 6 MW of electricity together with 9 MW_{th} to the district heating system. Sydkraft selected Ahlstrom Pyropower to supply the gasifier/gas cleanup system following a world-wide screening of the available technology.

Bioflow intend to use the Varnamo plant for gasification tests on eucalyptus chips shipped from Brazil; and as a basis for optimising the design of their high pressure BIG-GT system. It is anticipated that by the end of Phase II, the technical and commercial uncertainties of Bioflow's high pressure, BIG-GT technology will be largely resolved.

Sydkraft's BIG-GT Demonstration Plant at Varnamo, Sweden

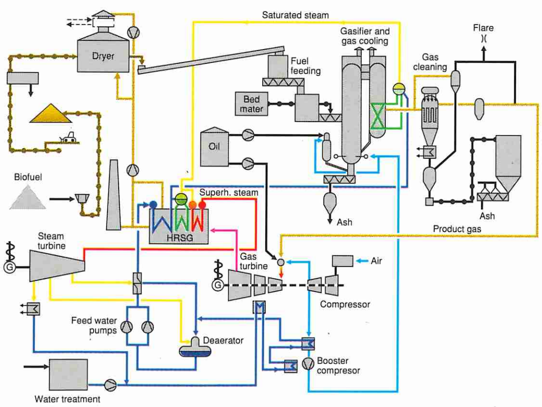


Figure 5

Bioflow BIG-GT Process Schematic

TPS Termiska Processer

TPS Termiska Processer AB is a small independent Swedish company working in the specialised field of energy and environmental process research. Formerly an operating unit of Studsvik AB, TPS has been owned since mid 1992 by a consortium comprising Nykoping Energi, Sigtuna Energi AB, Vaxjo Energi AB, Boras Energi, Graningeverkens AB, Sodra Skogsenergi AB, LRF (The Federation of Swedish Farmers) and TPS personnel.

Studsvik AB developed as an offshoot of the Swedish nuclear energy research establishment when the thermal engineering laboratory switched from nuclear research to the combustion and gasification of solid fuels. The company was originally owned 100% by the Swedish Department of Industry and, following a brief period under Vattenfall (the Swedish State Power Authority), passed into private ownership.

TPS has more than ten years experience of process development, publishing extensively and developing a worldwide reputation in the fields of combustion technology and biomass gasification, both atmospheric and pressurised. The "modus operandi" of the company is to start with small scale and basic research in support of process engineering and design studies. These studies in turn focus larger scale pilot tests towards the requirements of the end user. Commercial exploitation of technologies developed by the company normally progresses through large-scale demonstration plants to commercial operating plants. This pattern of exploitation has been achieved through technology licencing or joint venture activities. For example, TPS Termiska Processer's proprietary CFB combustion technology has been licenced to several major boiler manufacturers including Babcock & Wilcox, USA; Babcock Hitachi, Japan; SGP-VA, Austria; and Generator Industri, Sweden. Twelve units totalling around 750 MW_{th} are now in commercial operation around the world, burning a range of fuels including wood waste and chips, dehydrated sewage sludge, waste coal and heavy oil.

Gasification development activities

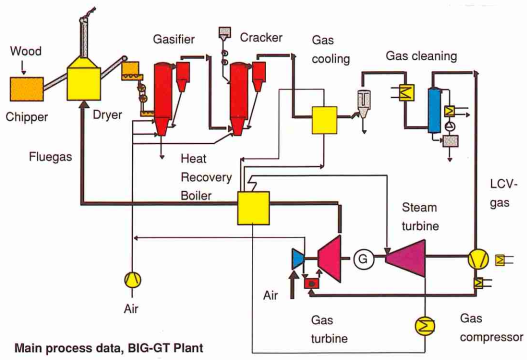
1980/83: Supporting projects for the application of the High Temperature Winckler (HTW) process to wood and peat fuels.

1980/86: Development of the MINO process for the production of synthesis gas from wood and peat. This process featured a high temperature filter as well as catalytic gas cleaning, and was developed in a 2.5 MW_{th} pilot plant with pressures up to 28 bar.

1983/86: Integration of the MINO process with high temperature filtration and catalytic gas cleaning for combined cycle application.

1985/93: Gas cleaning studies at laboratory and bench scale utilising dolomite to eliminate condensable tars and other compounds.

1985/89: Development of the air-blown, atmospheric circulating fluidised bed gasifier (ACFBG) to produce hot fuel gas on a 2MW_{th} pilot scale.



Main process data, BIG-GT Plant

Fuel (LHV AR)	65 MW
Fuel moisture	35%
Electric output	28 MW
El.efficiency (LHV AR)	43%

Figure 6

TPS Termiska Processer BIG-GT Process Schematic

The initial focus was on bark fuel but subsequently, refuse derived fuel (RDF) was targeted. In 1988, Ansaldo Aerimpianti SpA signed a licence agreement for two RDF gasifiers, each of capacity 15 MW_{th}.

1987/93: The ongoing development of a dolomite-based clean-up process for the hot, raw gas from the ACFBG process.

1987/89: Pilot scale demonstration of the ACFBG clean gas concept for wood fuel and its integration with diesel cogeneration.

1990/91: Pilot scale tests on RDF aimed at developing the gas clean-up capability for this fuel. A design study was undertaken for gas boiler application, and diesel and gas turbine cogeneration.

1991: Process design and basic engineering for a 15 MW_{th} test plant and a 140 MW_{th} demonstration plant for pressurised gasification for combined cycle application. This study formed the basis for a budget proposal from Kvaerner Generator AB to Vattenfall for the VEGA project. Design study for Gullspang Kraft AB for an ACFBG-gas turbine plant. Start-up of two 15 MW_{th} gasifiers in Italy.

1992: Submission of proposal and completion of contract to participate in Phase II of the Brazilian biomass power demonstration project.

Low Pressure BIG-GT

The TPS process scheme involves gasification at around 1.8 bar followed by a series of gas conditioning steps prior to the gas turbine: cracking of tars to non-condensable gases; cooling; baghouse filtration; scrubbing; compression; and reheating. The TPS proprietary tar cracking technology is fundamental to the scheme which must generate cool, clean fuel gas for the compressor whilst avoiding the production of significant quantities of noxious wastes. All components of the TPS technology have been demonstrated at pilot or small commercial scale. The task of TPS in Phase II of the Brazilian BIG-GT project is to optimise the system performance for a full commercial demonstration.

Credit: Tommaso Guicciardini/Science Photo Library
TPS Termiska Processer's Commercial Gasification Plant Operating on RDF at Greve-in-Chianti, Italy

General Electric - USA (GE)

GE is a large diversified business with revenues exceeding US$ 62 billion. Commercial activities range from power systems, through domestic appliances to financial services. Aircraft Engines account for around one eighth of corporate revenues; and the Marine & Industrial Engines Division generates an eighth of the revenues of Aircraft Engines.

Aeroderivative gas turbines appear to have a number of potential advantages over their industrial counterparts in BIG-GT applications: Higher open cycle and combined cycle efficiency; the longer term development potential of advanced cycles based on multiple spool aero-engines; and the ease of maintenance afforded by easily-transportable, lightweight engines together with the established, worldwide network of aero-engine maintenance centres.

GE has a substantial capability in the combustion of low-Btu fuels and has long term development plans for advanced cycles such as the Intercooled, Steam-Injected Gas Turbine (ISTIG). The company has also carried out externally-funded trials on biomass gasification using a Lurgi fixed-bed gasifier installation at the corporate R&D establishment in Schenectady, New York. From this work, gas quality issues associated with BIG-GT cycles appear to be manageable and GE is committed to participating in the Brazilian biomass power demonstration project.

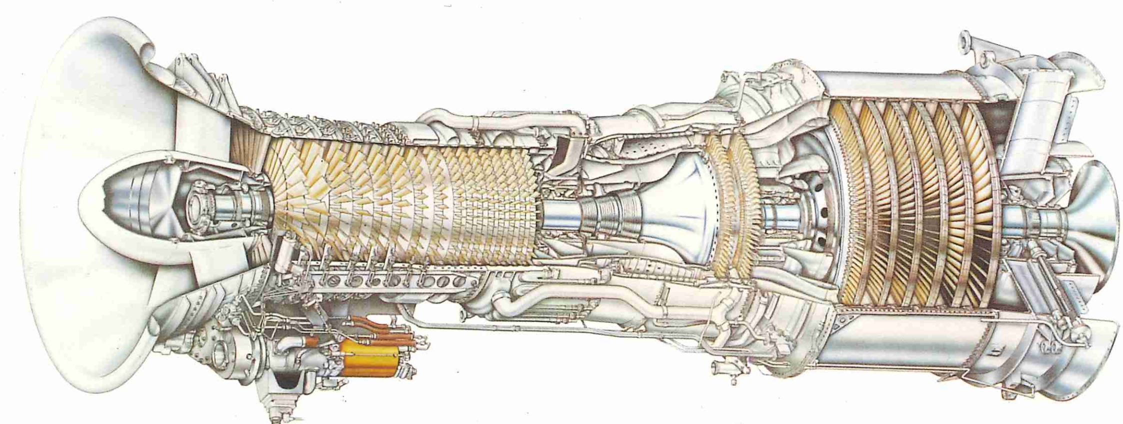
During Phase II of the Brazilian project, GE will perform tests and make modifications to the LM2500 enabling it to burn biomass-based fuel gas produced in the CFB gasifier systems under development by Bioflow and TPS Termiska Processer.

This type of fuel gas has a heating value around one seventh that of natural gas and may be supplied at temperatures as high as 450°C. GE's task is therefore not straightforward and is made somewhat more difficult by volume constraints in the combustion annulus of aeroderivative engines.

The LM2500 is designed for liquid, gaseous or dual fuel operation and already has a substantial capability for low-Btu gas operation. The LM2500 has also been adapted for steam injection (STIG). These were major factors in the gas turbine selection process as other aeroderivative engines require costly modification to accommodate large volumes of hot, lean fuel gas. The LM2500 requires only limited modification which can be accomplished within the time and budgetary constraints of Phase II of the Brazilian biomass power demonstration project. It has a pressure ratio of 18:1 and provides 22 MW of power in simple cycle applications with a thermal efficiency of 37%.

In the future, other engines from GE's aeroderivative range (the LM1600 - 14MW; the LM6000 - 42MW; and the LM5000 - 34MW) which are well suited to BIG-GT applications will also have the capability to burn hot, lean fuel gas. This feature will follow on from the development of low NOx burner programmes already well underway in the company.

GE is working closely with Bioflow to develop an integrated, high pressure BIG-GT design; and separately, with TPS Termiska Processer to develop an integrated, low pressure system. In both cases, the net output of the combined cycle plant will be around 30 MWe for a fully-fired LM2500.



General Electric LM2500 Gas Turbine

Phase III

Organisation and Timing

The Memorandum of Understanding signed by the Phase II participants does not define the nature of the organisation which will build and operate the power plant. However a private sector company is envisaged (figure 7), with the status of an Independent Power Producer and a sub-committee is already addressing Phase III arrangements:

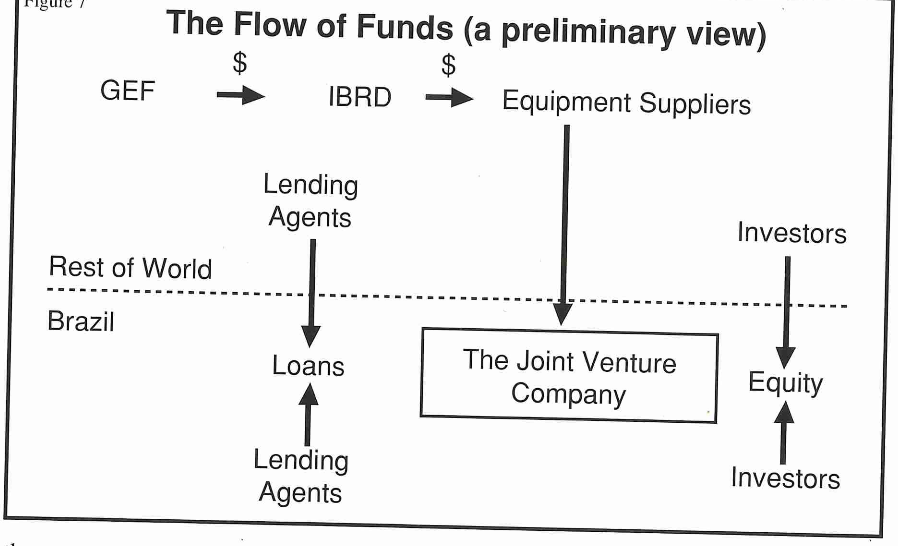
Q4, 1993	Organisation definition and proposed funding schedule;
Q1/2, 1994	Search for investors (equity subscribers);
	Discussions with potential lenders;
Q3/4, 1994	Joint venture negotiations and formation;
Q1/2, 1995	Registration of company finalised;
	Equity commitments formalised;
	Loan contracts signed;
Mid 1995	Formal start of Phase III business.

Financial Structure

Preliminary cost estimates developed during Phase I suggested total capital requirements in the range US$ 60-70 million. The debt equity ratio will depend on a number of factors including the manner in which the GEF's Phase III grant is treated on the company's balance sheet. Assuming a value in the range 1:1 to 2:1, a financial structure along the following lines would apply:

	US$ million
Disposition:	
Total Investment	70
Sources:	
GEF (grant)	23
Equity	25-15
Loans	22-32

Figure 7



Equity Participants

Under the terms of the Memorandum of Understanding, CIENTEC, CHESF, CVRD, ELETROBRAS and Shell Brasil have options for Phase III equity roles which are as yet unspecified. Costs incurred by each of these participants in Phase II are being accounted for possible future capitalisation. No restrictions have been placed on third party equity participation, for example by:

Utilities. The Brazilian power industry (CHESF and ELETROBRAS) is already committed to the project. Independent power producers internationally and in Brazil may also be attracted by privileged access to the experience generated by the world's first commercial BIG-GT demonstration.

Portfolio Investors. Leveraged by the GEF's Phase III grant, the project has good commercial prospects and it is an archetype for sustainable development in the power sector. Some investors are committed to place a proportion of their funds in environment-oriented ventures.

Biomass Producers. The project is of interest to a number of companies in the forestry and sugar cane sectors. COPERSUCAR, an association of Sao Paulo state sugar-cane growers, is planning a complementary project involving bagasse gasification trials at the facilities of both TPS and Bioflow. BIG-GT technology could unlock the potential for 6,000 MW of generating capacity based on cane residues in the State of Sao Paulo where special incentives are already in place to promote independent power production.

Equipment Manufacturers. The gasifier process developers have already expressed informal interest in equity participation.

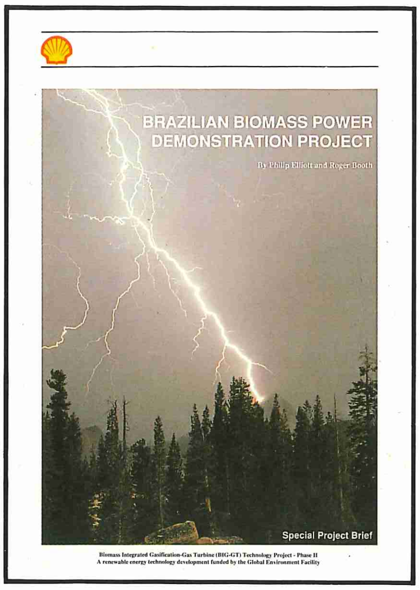
CO_2 Producers. Applied Energy Services (AES), a major US Independent Power Producer has committed "to substantially offset CO_2 emissions from any new AES fossil fuel power facilities by supporting appropriate greenhouse gas mitigation or offset projects". Assisted by the World Resources Institute, AES has donated substantial funds to carbon sequestration projects, most notably in Guatemala. Afforestation for power generation could have an impact on the carbon cycle substantially larger than afforestation solely for carbon sequestration.

Conclusions

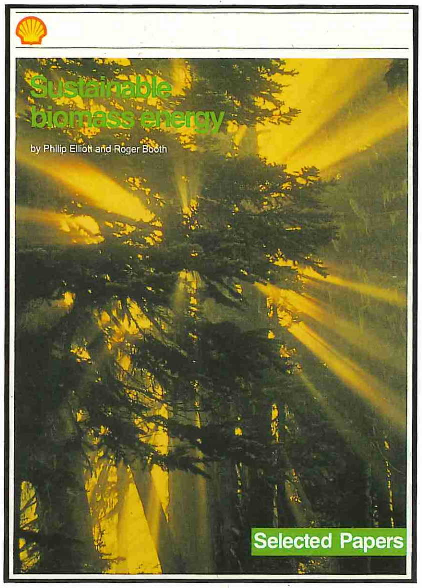
The Brazilian BIG-GT Demonstration Project is sponsored by the MCT and based on resources from the GEF and a number of public and private sector organisations in Brazil and internationally. An organisational framework has been put in place to resolve the remaining technical uncertainties associated with BIG-GT technology and to build the world's first commercial-scale demonstration plant. Shell Brasil and SIPC have been active in supporting this project which embodies many of the principles of sustainable development.

If the technology meets expectations, the global implications could be significant, with biomass possibly contributing to power supplies on a scale similar to nuclear and hydro by the mid 21st century. It could provide a basis for rural development and employment in developing countries, and utilisation of excess croplands in the industrial world.

From the environmental standpoint, the technology has much to recommend it: Sustainably-grown biomass used for power generation is essentially "carbon neutral" to the atmosphere; energy plantations can be designed for biodiversity with multiple tree species; and extensive afforestation offers the opportunity to rehabilitate deforested and otherwise degraded lands. However, environmental and social aspects will need careful management and adverse environmental impacts could arise, for example, if primary or old-growth forest were targeted for energy use. However, BIG-GT power plants require access to the power grid and this places governments in a strong postion to manage the development of a sustainable biomass power industry.



Brazilian Biomass Power Demonstration Project is a Special Project Brief describing work funded by the Global Environment Facility to commercialise BIG-GT power generation



Related Publication

Sustainable Biomass Energy examines the potential, under the economics of sustainable development, of using widespread afforestation to provide an indefinite flow of commercial energy.

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