Towards Cleaner Technologies

A process story in the Firozabad glass industry cluster

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GLASS PROJECT TEAM

Project facilitation/management

Amitabh Behar (2003/04)	SDC
Somnath Bhattacharjee (till 2003)	TERI
Jean-Bernard Dubois	SDC
Urs Heierli (till 1999)	SDC
Pierre Jaboyedoff	Sorane SA
Veena Joshi	SDC
Siglinde Kalin (till 1996)	SDC
Girish Sethi	TERI

Project implementation

Somnath Bhattacharjee (till 2003)	TERI
Mohit Dua (1997–2001)	TERI
Ananda Mohan Ghosh (from 2002)	TERI
B N Ghosh (from 2005)	Consultant, TERI
W Andrew Hartley (till 2000)	British glass
Pierre Jaboyedoff	Sorane SA
Puneet Katyal (2001–2005)	TERI
Sachin Kumar (from 2004)	TERI
Jayanta Mitra (1999–2006)	TERI
Girish Sethi	TERI
B C Sharma	Consultant, TERI
N Vasudevan	TERI

Demonstration pot furnace unit

Express Glass Works

Demonstration muffle furnace unit

Saraswati Glass Works

Collaborating industry associations

Firozabad Glass Chamber of Commerce and Industry
Glass Industries Syndicate, Firozabad

Collaborating NGO for techno-social programme at Firozabad

Vikas Sansthan, Shikohabad

The glass team acknowledges the invaluable contributions made by a number of workers (firemen, masons, operators, and others) and entrepreneurs of the Firozabad glass industry cluster.

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Editors
Girish Sethi
Ananda Mohan Ghosh

Narrator
R P Subramanian

Series Editors
Girish Sethi
Pierre Jaboyedoff
Veena Joshi

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Fax 2468 2144 or 2468 2145
India +91 • Delhi (0) 11
E-mail teripress@teri.res.in
Web www.teriin.org

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FOREWORD

The history of glass-making in India goes back thousands of years when beads, bangles and other small glass items were made in kingdoms in North and South India and traded with other ancient civilizations such as Persia, Greece, and Rome. Indeed, the origin of glass bangles is perhaps as old as the Indus Valley Civilization; the famous bronze figurine of a dancing girl unearthed by archaeologists at Mohenjo-Daro (c. 2500 BCE) has her left arm and wrist completely encased in bangles. Interestingly, the very word 'bangle' is derived from the Hindi word *bangri*, meaning 'glass bracelet'! Over the ages, the bangle has come to be closely associated with the institution of marriage or *suhag* throughout India. Today, the nation buys an estimated 50 million bangles each day, and all these bangles are made by units in the small-scale glass industry cluster at Firozabad (or 'suhag nagri' as it is popularly called), located about 40 km from Agra, the city of the Taj Mahal.

Traditionally, Firozabad units use open pot furnaces to produce glass for processing into bangles. Besides the open pot furnace units, Firozabad also has hundreds of muffle furnaces or *pakai bhattis* to anneal the finished bangles. Till the mid-1990s these furnaces operated on coal and/or wood. TERI undertook energy audit studies at that time, which revealed that the energy consumed by the furnaces was very high and that there was ample scope to reduce their existing levels of energy consumption. The Firozabad glass-making industry came into the limelight in December 1996, when the Supreme Court of India ordered 292 coal-based factories in the area known as the Taj Trapezium Zone, including the Firozabad pot furnace units, to switch from coal to cleaner alternative fuels such as natural gas, or else to relocate or shut down. Although the Court directed the government to supply natural gas as an alternative fuel to the affected industries, the pot furnace units – which constitute the apex of the multi-level bangle-making industry – had neither the technology nor the know-how to operate their pot furnaces on gas at that time. Hence, they faced the prospect of closure; and this threatened the future of tens of thousands of families in Firozabad who depended on the bangle-making industry for their livelihood.

It was against this backdrop that TERI (The Energy and Resources Institute) with the support of SDC (Swiss Agency for Development and Cooperation), set out to develop clean, energy-efficient technologies based on natural gas for pot furnaces and *pakai bhattis* in Firozabad. By carrying out intensive action research in a participatory manner, and by pooling the competencies of international experts, TERI successfully designed, developed, and demonstrated two such technologies: the gas-fired recuperative pot furnace, and the gas-fired *pakai bhatti*. The TERI-designed pot furnace reduced energy consumption by nearly 30% compared to the other 'retrofitted' gas-fired pot furnaces that came up in the cluster. The gas-fired *pakai bhatti* design helped in reducing particulate emissions and thereby greatly improved the environment in the workplace.

Close involvement with the cluster over the years has made TERI aware of the health hazards faced by workers in the household-level units that processed bangles and other decorative items. TERI therefore also partnered with an NGO (non-governmental organization) to initiate a few pilot social action initiatives in select areas of Firozabad, aimed at bringing about improvements in the lives of household unit workers.

SDC has contributed greatly to the success of the intervention: by allowing TERI to remain engaged with the Firozabad cluster for an extended period of time, as well as by giving TERI the room to alter its strategies and activities on an ongoing basis to meet the challenges of the changing external environment. Today, over half of the 80-odd open pot furnace units in Firozabad have adopted the recuperative furnace design developed by TERI, and most of the remaining units are expected to follow suit in the next few years. This is a very significant achievement, considering that there were just two TERI-designed pot furnaces operating three years ago. TERI's dissemination strategy in Firozabad was based on three pillars: (1) optimizing furnace design parameters to suit the needs and demands of the local entrepreneurs; (2) ensuring the success of the first few replications through close monitoring, both during construction and operation; and (3) capacity building of operators and entrepreneurs.

However, the story is not as encouraging with regard to the gas-fired *pakai bhatt*i, despite its proven benefits. The number of gas-fired *pakai bhattis*, which once reached a figure of 100 units, has now dropped to just around ten. The primary reason is that *pakai bhatti* units have been unable to obtain gas connections at their existing locations. At the same time, gas prices have sharply escalated in recent years even as coal continues to be available in Firozabad at comparatively cheap prices.

TERI's experience in Firozabad, as indeed in other SSI (small-scale industrial) clusters over the past decade, brings to focus the fact that in order to achieve significant gains in terms of increased energy efficiency and reduced carbon dioxide emissions in this highly dispersed sector, it is extremely important to develop cluster-specific technology intervention programmes with clearly defined objectives. The Firozabad experience also highlights the fact that small-capacity users of energy, such as *pakai bhatti* operators and household-level processing units, find it very hard if not impossible to access cleaner fuels at affordable prices.

It is important to start looking at the SSI (small-scale industry) clusters from a social perspective, as they provide employment opportunities for millions to workers, and also act as nerve centres for the overall growth of the rural and peri-urban areas in the country. Greater attention must be paid to the technological and R&D (research and development) needs of SSI clusters, so as to ensure that higher energy and environmental standards become an integral part of the nation's overall economic growth process. TERI will provide impetus to the sustainable development of this sector through its ongoing initiative titled CoSMiLE (Competence Network for Small and Micro Learning Enterprises), by continuing to work with various stakeholders both at the national and international levels. TERI will build upon the lessons and knowledge gathered during the intervention in Firozabad, for the benefit of the SSI sector as a whole. The focus will be on knowledge-sharing through technology interventions and innovative practices, programmes, and projects.

R K Pachauri
Director-General, TERI

PREFACE

SDC (Swiss Agency for Development and Cooperation) has been working in India since 1961. Although a relatively small donor organization, SDC enhances the effectiveness of its programmes and activities by giving them sharp focus, yet enough flexibility to meet changing ground realities, and by carrying them out over long intervals of time in order to ensure their sustainability in the long term. Particular emphasis is given to address both local and global concerns, and to build and nurture long-term partnerships with local organizations.

SDC has been particularly concerned about the effects of globalization on the MSME (micro, small and medium enterprises) sector in developing countries such as India. Traditional technologies used in the MSME sector invariably suffer from low energy efficiency, which translates into excessive fuel consumption and expenditure, low profitability of operations, and high levels of emissions. SDC strives to find ways by which the MSME sector can meet the challenges of the new era by means of improved technology, increased productivity and competitiveness, and measures aimed at improving the socio-economic conditions of the workforce.

In 1991, SDC established a Global Environment Programme to support developing countries in implementing measures aimed at protecting the global environment. In pursuance of this goal, SDC India, in collaboration with Indian institutions such as TERI (The Energy and Resources Institute), conducted a study of the small-scale industry sector in India to identify areas in which to introduce technologies that would yield greater energy savings and reduce greenhouse gas emissions. Four energy-intensive small-scale industry sectors were selected for intervention: one of them was the small-scale glass industry cluster located in Firozabad, near Agra.

The Firozabad glass units provide a source of livelihood to over 150 000 people and produce an estimated 2000 tonnes of glass products daily, including around 50 million bangles. These glass products are mainly low-value items. The bangle-making industry comprises tier upon tier of units whose activities are closely interlinked. At the apex are open pot furnace units that produce molten glass and 'raw' bangles; below them are thousands of household-level units in which these 'raw' bangles are processed; finally there are hundreds of muffle furnace (*pakai bhatti*) units in which the processed bangles are annealed to yield the finished products. Traditionally, the pot furnaces and muffle furnaces operated on coal, and were marked by low energy efficiency and high levels of emissions.

SDC and TERI in partnership intervened in the Firozabad cluster with their focus on introducing clean, energy-efficient technologies for the pot and muffle furnaces. This goal assumed particular significance in 1996, with the Supreme Court of India ordering 292 industrial units in the area known as the Taj Trapezium Zone – including the Firozabad pot furnace units – to stop burning coal and instead use natural gas as fuel. By 2001, TERI succeeded in developing and demonstrating two clean, energy-efficient technologies based on natural gas for the glass industry: the energy-efficient recuperative pot furnace, and the gas-fired muffle furnace. Since then, efforts have focused on disseminating the improved technologies, and also in undertaking a few pilot social action initiatives to improve the lives of workers in the household-level units that process bangles and other decorative items.

Working in the Firozabad cluster was far from easy. There were technological challenges as well as socio-economic barriers to face and overcome at the cluster level. Interactions with entrepreneurs were often inhibited by the walls of wariness so commonly encountered in the MSME sector. Little information was available on the construction practices followed in glass units, or on the nature of their operations—and gathering such information was difficult in the closed, fiercely competitive environment of the cluster. When the pot furnace units were ordered to stop using coal following the Supreme Court verdict, there were no readily available gas-fired technologies for them to adopt; nor did units know exactly how much natural gas they would need. The muffle furnace units were, and still are, unable to obtain gas connections at their existing locations. Traditional and cultural barriers make it extremely difficult to access the workers in household-level units, especially because a sizeable proportion of the workforce comprises women and children. At the policy level, these difficulties have been further compounded by shortages in availability of natural gas; an uneven pricing formula for gas; and the continued availability of coal in the Firozabad cluster at relatively affordable prices.

Despite these barriers, the project has been extremely successful in replicating the recuperative pot furnace model in Firozabad. Today, more than 40 pot furnaces based on the TERI design are operating in the cluster, which represents a penetration level of close to 50%. As a result, a reduction in carbon dioxide emissions equivalent to 70 000 tonnes per year has been achieved. The project has also initiated dialogue among various stakeholders – at both cluster and policy levels – on a number of issues related to energy efficiency, fuel supply, and the socio-economic conditions of the workforce. The challenge in coming years will be to work with policy-makers and other stakeholders to address these various issues.

This book is a process document: a brief, non-technical account of the process by which SDC and TERI have worked in partnership to successfully develop and demonstrate energy-efficient and environment-friendly technologies for the small-scale glass industry, and the measures taken by them to aid replication of these technologies and to improve the socio-economic conditions of the workforce.

The process is still continuing. It has taken place in phases, and each phase has involved several players—among them experts and consultants from India, Switzerland, the UK, and elsewhere; academic institutions; individual glass units and glass industry workers; consultants; NGOs; and others. Each player has brought unique skills and capabilities to the process; each has had a special role to play; each has worked according to an individual agenda. Yet, their combined efforts have helped move the process forward towards achieving the partners' goals.

The book highlights technological problems encountered by the project staff and their resolution, as well as socio-economic issues that had to be confronted and tackled. It describes the experiences of project teams and other stakeholders in the field, and discusses both their achievements and their setbacks—for lessons may be drawn from these by future researchers and others interested in the field.

This book is primarily intended as a guide/reference document for researchers, NGOs, academic institutions, donor organizations, policy-makers and others who might be interested in setting up projects and programmes aimed at development and dissemination of cleaner technologies in other small-scale industrial sectors in India and in other developing countries.

Veena Joshi
Team Leader
SDC, New Delhi

Jean-Bernard Dubois
Deputy Head
Natural Resources and Environment
SDC, Berne

Introduction

Small and micro enterprises in India

In India, small and micro enterprises, or SMiEs, comprise a wide variety of units, ranging from tiny artisan-based cottage industries and household enterprises to small-scale manufacturing firms. There is great diversity among them—in their patterns of ownership, organizational structures, technologies, financial status, and other characteristics. However, SMiEs do have a few common features as well. In general, an SMiE is managed by its owner(s) in a personalized way; it has a relatively small share of the market in financial terms; and its small and independent nature makes it relatively free from outside control in decision-making. SMiE operators and workers usually acquire their skills by tradition; these skills are transmitted through generations with minimal change or upgradation.

SMiEs form the backbone of the Indian economy

The SMiE sector plays a vital role in the Indian economy. It manufactures a vast range of products, mobilizes local capital and skills, and thereby provides the impetus for growth and development, particularly in rural areas and small towns. The SMiE sector is next only to agriculture in providing employment; in 2004/05, small-scale industries alone employed around 28 million people.[1]

SMiEs are found in clusters all over India. There are many historical reasons for the clustering of units—availability of fuels and raw materials, access to pools of semi-skilled labour, proximity to markets, and so on. There

[1] MoSSI (Ministry of Small-scale Industries). 2006. ***Annual Report 2005/06***. New Delhi: MoSSI, Government of India

are about 6500 SMiE clusters in all, of which around 400 are industrial clusters and the remaining are low-technology micro-enterprise clusters.[2] According to some studies, there are an estimated 140 clusters within or in the periphery of urban areas in India, with at least 100 registered units in each. These urban SMiE clusters vary significantly in size; some clusters are so large that they account for 70%–80% of the entire country's production of a particular item. For example, Ludhiana produces 95% of India's woollen hosiery, 85% of sewing machine components, 60% of bicycles and bicycle parts, and accounts for over half of Punjab's total exports. Similarly, Tirupur in Tamil Nadu has thousands of small-scale units engaged in spinning, weaving, and dyeing of cotton garments; this city alone accounts for around 60% of India's total cotton knitwear exports.[3]

In general, cost factors weigh much more for an SMiE owner than issues such as energy efficiency and pollution. Hence, an SMiE uses the cheapest fuels that are available in its locality. Because of the easy availability of biomass such as fuelwood, husks, and assorted agricultural wastes, almost all rural SMiEs burn fuelwood and other biomass for energy. For instance, each year an estimated 438 000 tonnes of fuelwood are used up for curing tobacco leaf; 250 000 tonnes for tea drying; and 100 000 tonnes for silk reeling. Urban SMiEs too burn fuelwood; around 1.72 million tonnes of fuelwood is used up each year by fabric printing units.[4] Coal and petroleum-based fuels such as kerosene and diesel are used mainly by urban SMiEs, because these fuels are much easier to obtain in urban areas than in rural areas. SMiEs also burn highly polluting low-grade fuels such as 'spent' machine oils, lubricants, and used tyres.

Costs weigh much more for SMiEs than issues such as pollution and energy efficiency

The protected years

Recognizing the vital role played by SMiEs in production of goods and in employment generation, the Indian government took various measures from

[2] Foundation for MSME Clusters. 2007. **Policy and status paper on cluster development in India**. Draft paper presented at the study workshop on 10 July 2007, India Habitat Centre, New Delhi

[3] Albu M. 1997. ***Technological learning and innovation in industrial clusters in the South***, Paper No. 7. Brighton: Science Policy Research Unit, University of Sussex

[4] Kishore V V N, *et al*. 2004. **Biomass energy technologies for rural infrastructure and village power—opportunities and challenges in the context of global climate change concerns**. *Energy Policy* **32:** 801–810

the time of independence onwards to provide fiscal, credit, marketing, and infrastructure support to the SMiE sector—even as the nation followed a path of industrialization that emphasized the building of heavy industries, primarily in the public sector. From 1967 onwards, the government reserved certain items for exclusive manufacture by small-scale industries. Forty-seven items were reserved to start with: that number grew over the years to around 800 items at the turn of the century. In recent years, the government has been progressively dereserving the items set apart for small-scale industries, and as of March 2007, 326 items were reserved for the small-scale industrial sector. Thanks to the government's support policies, the small-scale industrial sector today forms the backbone of India's manufacturing capacity. It contributes nearly 4200 billion rupees to India's industrial production, of which close to 1000 billion rupees are from exports.[5]

However, the government's policies have proved to be a mixed blessing for SMiEs. The policies were primarily intended to ensure the survival of SMiEs, to protect the jobs of those employed in them, and to increase the overall production of the sector (rather than the productivity of individual units) to cater to the demands of a growing indigenous market. Scant attention was paid by the state to improve the operating practices of units, or to help them modernize their technologies through exchange of ideas or by indigenous R&D (research and development) efforts. In the technical institutes and engineering colleges, there is a lack of interest in studying small-scale industrial processes such as drying of agro-products and food processing—even though these activities are of great socio-economic importance (in terms of revenue and employment generation), use up huge amounts of energy, and generate vast amounts of pollutants.

Protective state policies have proved to be a mixed blessing for SMiEs

On the one hand, SMiEs were insulated against healthy competition from medium and large-scale enterprises, within and outside India; on the other, they were unable to access information on technological advances made elsewhere, and had neither the incentives nor the resources to conduct their own R&D. Outdated and inefficient technologies, compounded by poor management practices and declining labour productivity, steadily ate away their profits and slowed down industrial growth. By the early 1990s, the

[5] MoSSI (Ministry of Small-scale Industries). 2006. ***Annual Report, 2005/06***. New Delhi: MoSSI, Government of India

SMiE sector suffered from widespread technological obsolescence, low productivity, and an inability to access or adopt better technologies.

Liberalization challenges

In 1991, a new industrial policy paved the way for liberalization of the Indian economy. Since then, the market has been opened up in stages to private entrepreneurs—Indian and foreign. The government is progressively withdrawing from the commercial and manufacturing sectors, even as the private sector is moving in to fill the spaces vacated. Where there was state control and state monopoly, there are now new opportunities for private players; where there were fixed prices and protected markets, there is now competition and the free play of market forces. Thus, liberalization has created new opportunities in trade, investment, and manufacturing for Indian and overseas investors.

The liberalized market favours the strong and punishes the weak

However, liberalization has considerably increased the problems of the SMiE sector. The reason is simple: the new market paradigm favours the strong and punishes the weak. For decades, the sector survived primarily because it had been shielded from the competitive currents of both indigenous and global markets. Since 1991, that protective framework has steadily been dismantled, and now SMiEs have to face competition not only from medium and large enterprises in India, but also from imports. In today's liberalized economy, the survival and growth of SMiEs depend on their ability to become competitive: that is, to improve productivity and quality of products, and to develop new products to keep up with changing demands. This in turn means that they must use better technologies and methods of operation. But these are precisely the tasks that they are incapable of doing on their own. Having functioned for five decades within an overly protective economic and industrial framework, they lack the flexibility, technical capacity, and resources to change the ways in which they function.

The environmental imperative

The SMiE sector also has to contend with a new challenge: environmental regulation. SMiEs largely use low-grade fossil fuels or biomass such as fuelwood for energy. These fuels are burned using inefficient equipment and technology, releasing gases that are harmful to health as well as to the atmosphere. The last two decades have brought a new and growing awareness across the world about global warming and its adverse effects—particularly after the UNFCCC (United Nations Framework Convention on Climate Change) held at Rio de Janeiro in 1992. India is also enacting laws to curb local pollution. However, SMiEs do not have the technical ability or the resources to modify/change their inefficient technologies, or to install pollution control equipment to meet the standards set by the new laws. Thus, the threat of closure constantly looms large over them.

SMiEs do not have the technical ability or resources to modify their inefficient technologies

Clearly, SMiEs need help to survive in today's liberalized economy. Closure of these units would threaten the very existence of millions of people who depend on them for their livelihood, particularly in rural areas. It is against this backdrop that two organizations—SDC (Swiss Agency for Development and Cooperation) and TERI (The Energy and Resources Institute)[6]—decided to intervene in partnership in the SMiE sector.

A partnership is forged

SDC—human and institutional development

SDC is part of the Swiss Federal Department of Foreign Affairs. SDC focuses on poverty alleviation. Towards this mission, it supports programmes that promote good governance, helps improve working conditions, aims at solving environmental problems, and provides better health care and educational opportunities for the most disadvantaged sections of society.

SDC has worked in India since 1963. Initially, it focused on the areas of livestock and animal husbandry; later, its interventions expanded to cover vocational training and SMiEs. In 1987, it began to work in the field of sericulture. From the outset, SDC's interventions paid great attention to training and teamwork, and in ensuring the participation of local people in projects to make them sustainable. In the course of its work in India, SDC has clearly outlined four areas: poverty, civil society, human rights, and sustainable use of natural resources. It recognizes that these areas are closely linked to one another; that developments in one have an impact on the other areas; and that all the areas together have a fundamental role to play in addressing the issue of sustainable development.

SDC has been particularly concerned with the effects of liberalization on the poor

[6] Formerly, the Tata Energy Research Institute

From 1991 onwards, SDC became particularly concerned with the effects of liberalization on India's poor. It recognized that in an increasingly market-driven scenario, even as the government withdraws from key sectors of the economy, NGOs (non-governmental organizations) and private institutions play an important role in the development process. Interventions to alleviate poverty successfully, therefore, require partnerships with NGOs and other private bodies. Hence, SDC has introduced the principles of HID (human and institutional development) into all its interventions. In essence, HID aims at building strong partnerships with individuals, organizations and institutions, and in developing and enhancing partners' skills through motivation, training, access to information, and exchange of ideas.

Global Environment Programme

In 1991 the Swiss Parliament sanctioned a special grant to SDC on the occasion of Switzerland's 700th anniversary. One of the aims of the grant was to address global environmental problems. SDC accordingly set up a Global Environment Programme, or GEP, to support developing countries in furthering the goals of the UNFCCC. Under the grant, SDC initiated a study and cooperation programme in India for the phasing out of CFCs (chlorofluorocarbons) in the refrigeration sector. It also co-financed a market development programme for photovoltaics along with the World Bank.

SDC recognized that there existed enormous potential for energy conservation and environmental protection in the Indian small-scale industrial sector. It thereupon sought and identified two institutional partners to implement its energy–environment programmes in the country: TERI and DA (Development Alternatives). Both TERI and DA are NGOs based in Delhi.

TERI—global vision, local focus

TERI was established in 1974 through a corpus of a few Tata Group companies. Initially, TERI funded and supported research in the fields of energy efficiency and renewable energy in academic institutions. Thereafter, its activities expanded to hardware research in renewable and rural energy (first at its Field Research Unit in Puducherry, and later at its research facility in Gual Pahari, near Delhi), and to documentation and

TERI focuses on energy efficiency and sustainable development....TERI recognizes the link between poverty and depletion of natural resources dissemination of energy-related information. TERI works at both micro- and macro-levels. For instance, it provides environment-friendly solutions to rural energy problems; helps forest conservation efforts by local communities; promotes energy efficiency in Indian industry; shapes the development of the Indian oil and gas sector; finds ways to combat urban air pollution; and tackles issues related to global climate change.

Among other achievements, TERI has acquired considerable expertise in conducting energy audits in various industrial sectors. The institute has highly skilled human resources equipped with state-of-the-art instrumentation and software for gathering and analysing energy-related data.

Like SDC, TERI strives to make its programmes participatory, that is, they are undertaken with the full involvement of local communities, and they tap local skills and traditional wisdom in order to ensure their adoption and success. TERI, too, lays great emphasis on training, capacity building, and education. It clearly recognizes the links between degradation and depletion of natural resources on the one hand, and increase in poverty on the other. Its activities are guided by the principle that the development process can succeed, and be made sustainable, only through the efficient utilization of energy, sustainable use of natural resources, large-scale adoption of renewable energy technologies, and reduction of all forms of waste.

By 1992, TERI had worked for nearly two decades in the field of energy, environment, and natural resources conservation. It was the largest developing-country institution working to move human society towards a sustainable future. It had unique skills in conducting energy audits. Above all, the model of development pursued by TERI corresponded well with the one envisaged by SDC. Thus, SDC decided to intervene in the fields of energy and environment in India in partnership with TERI.

The macro-level study

In 1992, SDC initiated a study of energy consumption patterns in the Indian SMiE sector in order to help identify areas for intervention. Pierre Jaboyedoff from Sorane SA, Switzerland, was mandated as an international consultant to assist SDC in coordinating the exercise. SDC collaborated with TERI in conducting energy sector studies in SMiE areas such as foundries, glass making, and silk reeling. SDC had already been working with DA in the building materials sub-sector, which included the brick-making industry.

The macro-level study revealed that the energy efficiency of Indian SMiEs (that is, the efficiency with which they extract and use energy from fuels) is much lower than that of their counterparts in industrialized nations. Besides having low energy efficiencies, many SMiEs are highly energy intensive: that is, the cost of fuel makes up a large portion of production cost. Examples include foundries, food-processing units, forging units, and industries that manufacture glass, ceramics, and bricks. At the same time, SMiEs employ large numbers of workers. If these units are to remain competitive, it is essential to find ways to increase their energy efficiency, and thereby reduce the burden of fuel costs.

Many SMiEs have low energy efficiencies. They are also energy intensive: the cost of fuel makes up a large portion of production cost

Herein lies a challenge. To increase energy efficiency, an SMiE must make changes in its technology and operating practices. But such changes require the investment of time and money—both scarce resources in the small-scale sector! Unlike medium or large-scale units, small-scale units have limited financial and human resources, and they operate with slender profit margins. They might show willingness to adopt change—provided the change offers benefits in terms of increased productivity and profits. But they do not have the capacity or resources to initiate or invest in change.

The scope for intervention

SDC recognized this challenge faced by the SMiE sector, and saw in it an opportunity for intervention. Improving the energy efficiency of small-scale units – particularly those in energy-intensive areas – would be the best way to increase their productivity and profitability. It would also translate into reduced consumption of non-renewable fossil fuels and wood, and bring down the emissions of greenhouse gases and other pollutants by the units.

SDC recognized the challenges faced by the SMiE sector, and the opportunity to intervene with improved technologies

How could energy efficiency be increased? The answers would vary among different SMiE sub-sectors, and indeed among units within a particular sub-sector. Better methods could be found to burn a fuel and to use its energy; alternative fuels might be identified, that were readily available and that yielded the same amount of energy at little or no extra cost and with less pollution; systems could be devised to recover and reuse heat energy generated during the manufacturing process; and so on. Whatever be the mechanism, increased energy efficiency would translate into a higher yield of product for the same amount of fuel consumed, and thereby improve a unit's performance—in terms of resource consumption, environmental impact, and productivity.

However, it was clear that an intervention to improve energy efficiency would be sustainable only if it addressed the following imperatives.

- The SMiEs must be enabled to meet environmental laws and regulations.
- They must be made economically competitive, particularly in energy-intensive categories.
- The quality of their products must be upgraded, and their markets must be preserved/enhanced.

Screening workshop, December 1994

To discuss the results of the macro-level study and finalize its strategy for intervention in the energy sector, SDC organized a Screening Workshop on 8–9 December 1994 in New Delhi in collaboration with TERI. The workshop brought together scientists, policy-makers, government representatives, NGOs, representatives of industrial associations, and experts in diverse fields, ranging from biofuels, foundries, and forestry to renewable energy, glass-making, and silk.

The workshop adopted a unique approach. First, a total of 11 options for intervention in the energy sector were presented to an advisory panel, whose members represented the collective wisdom in India on policy issues related to energy. Each panel member examined and ranked the options in order of preference. The options were foundries (Agra); glass industries (Firozabad); silk-reeling ovens; alternative building materials; brick kilns; building energy efficiency; solar photovoltaics; solar water heaters; oil from *Jatropha curcas* (bio-diesel); diesel pumpsets; and biomass.

Thereafter, sectoral experts used the rankings of the advisory panel to discuss the options in detail, and to suggest to SDC possible areas for action. Certain criteria were applied in order to identify the best areas for interventions. The criteria included energy intensity; potential for energy savings; potential for replication; importance of the SMiE sub-sector concerned, particularly in terms of the number of workers employed and their socio-economic status; non-duplication of efforts; techno-economic viability of measures proposed; compatibility with SDC's India Country Programme; and potential partners, and their ability and willingness to cooperate.

Finally, based on the participants' recommendations, SDC selected the following four areas in which to intervene with technologies designed to improve energy efficiency, environmental performance, and productivity.

1 Foundries
2 Sericulture (with wood gasifiers for improving thermal efficiency of silk-reeling ovens)
3 Glass industries
4 Brick manufacture

While selecting the small-scale glass industries for providing technological (non-financial) support, SDC also had in mind the possibility of complementing the collaborative activities it was exploring with SIDBI (Small Industries Development Bank of India) at that time to provide financial services to this sector. As it turned out, however, the collaboration with SIDBI for the Firozabad cluster did not materialize.

This book describes how SDC and TERI intervened in the Firozabad glass industry cluster to assist glass units in switching over from low-efficiency coal-fired furnaces to energy-efficient gas-fired furnaces.

Getting started

While structuring the interventions and drawing up work plans, the project had to consider a few vital issues.

Cluster-level intervention

At what level should the interventions be undertaken—on a national scale or at unit level? If so, where?

The idea to intervene at cluster-level sprang from the Screening Workshop. Units producing similar goods, and possessing great similarity in levels of technology and operating practices, are found in close proximity within a typical SMiE cluster. Therefore, it was felt that the best way to disseminate an improved technology would be to first demonstrate its benefits to a few representative units in a cluster. Ideally, these units should be chosen by local industrial associations. Where such formal groups did not exist, the units should be identified by other bodies familiar with the cluster profile (such as district industries centres). Once the selected units realized the advantages of the new technology and adopted it, other units in the cluster would tend to follow suit—and dissemination of the technology would be rapid and effective. Therefore, each intervention took place initially at cluster level.

A list of ‘**dos**’ and ‘**don’ts**’ suggested by the Screening Workshop for the glass sub-sector

Finding the right technology

Which technology is best suited for a particular sub-sector? Obviously, it should be a technology that uses less energy and results in less pollution than the existing technology. It should retain the existing quality of the product, and if possible improve upon it. Yet, the answer is not as simple as finding and importing the best technology available in the world that meets these requirements. The selected technology must be acceptable to local people; it must be easy for them to use (perhaps with training); and it must suit local conditions.

The selected technologies must be acceptable to local people, easy to use, and suit local conditions

In India, unemployment is high and capital is scarce. Therefore, the new/improved technology should be affordable; and it should minimize the impact on the existing workforce in terms of loss of jobs. It should not depend on external inputs or non-local resources to function, except at the initial stages. Like existing technologies, it too should work on fuels and raw materials that are locally and readily available at affordable prices. As far as possible, it should resemble the technology being used in the area; for this would help make it acceptable to and easily adaptable by local people.

Therefore, in selecting a technology for intervention, existing technologies had to be evaluated – in India and elsewhere – to identify those that could be adapted/modified to meet the standards set for energy efficiency and environmental performance. Thereafter, from among the available options, the most appropriate one, that is, the one most suited to adaptation to meet local needs and conditions, had to be selected and developed for demonstration and eventual dissemination.

Participatory technology

To succeed in the long-term, a technology should not only be appropriate. As far as possible it must build on, and be built upon, the skills and knowledge of local people; it should be adapted/developed with their full participation. This approach to technology development gives the beneficiaries a sense of 'ownership' over the technology; they become confident in its use. By its very nature, participatory technology is developed on the basis of collective learning, sharing of ideas and traditional wisdom, and R&D based on community needs. Because it works closely with the community and at a deep level of society, participatory technology has the potential to bring about profound social change.

To ensure the participatory development of technologies, the project teams worked closely with unit owners, workers, industry associations, local government institutions, NGOs, and other bodies at the field level.

Capacity building—key to sustainability

The success of any intervention is measured by its sustainability. This in turn depends on the capacity of the recipients to absorb the new/improved technology. The recipients should be able to continue to adapt and innovate the technology long after the intervention project has ended—to cope with and overcome whatever challenges the future might bring. Here, it is important to recognize that technology is not just about equipment and tools. It is a package of knowledge that enables the recipients to use the equipment and tools to produce specific products of specific quality.

In other words, it is not enough merely to develop a new technology and to demonstrate its benefits. Local people should be given the information and skills that they require to use the technology in the long term. They should learn the benefits of exchanging ideas and sharing experiences, and how this would help them manage changes without depending on external sources for help. Capacity building, therefore, formed a vital component of the project's interventions.

Structuring the interventions

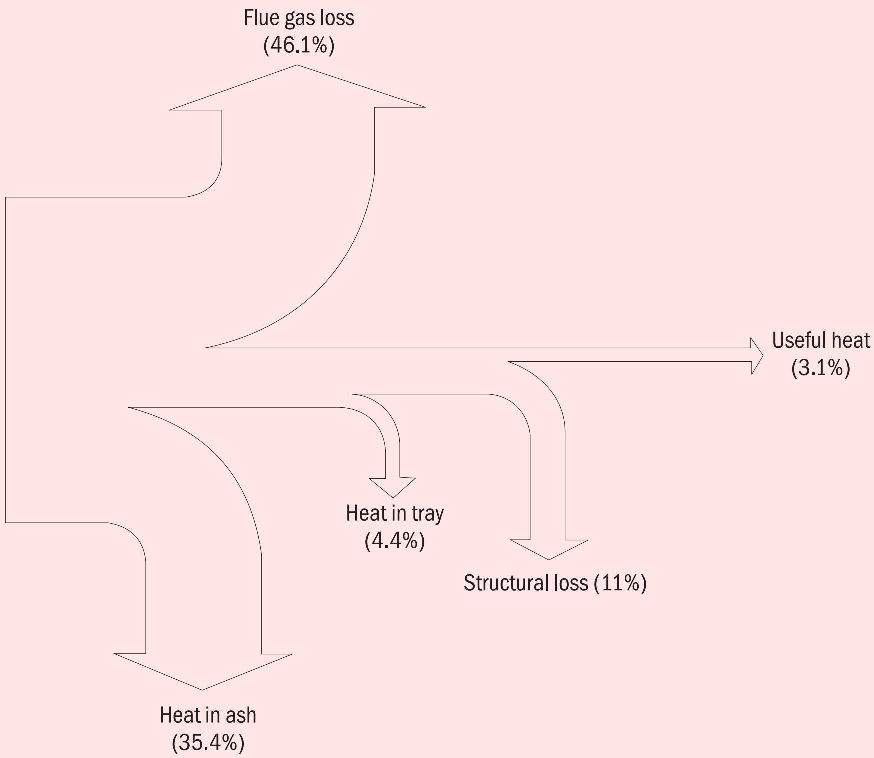
Having considered all the above issues, SDC and TERI structured each intervention as a package of parallel and ongoing measures that are listed below.

- Perform energy audits (Box 1). Learn, during the energy audits, about things beyond energy, such as existing operating practices, quality of fuel, and so on.
- Search for suitable solutions to achieve the benchmarks set for energy efficiency and environmental performance.
- Develop and demonstrate an improved technology, in terms of energy and environmental performance and other parameters. Fine-tune the developed technology for wider dissemination.
- Help other units to upgrade and adapt their existing technologies as required.

BOX 1
Energy audit and Sankey diagram

An energy audit is a kind of baseline study. It examines the pattern of energy use in an existing industrial process, and provides data on certain parameters. These data are then mulled over, and some or all of them are used as yardsticks to evaluate other technological options. The Sankey diagram shows, at a glance, the amounts of input heat used up in different parts of a process (Figure 1). Thus, the Sankey diagram is a simple but powerful tool to identify areas in which energy efficiency might be improved.

Figure 1
Sankey diagram of a coal-fired muffle furnace



- Seed the markets, that is, help make the technologies available via local suppliers; promote measures to reduce their costs and increase their uptake.
- Increase the number of partners and collaborators in the field, and strengthen their capabilities by ongoing HID so as to promote dissemination of the technology.
- Make efforts to establish a regular policy dialogue between various players in each area (industries, institutions, government bodies, etc.).
- Conduct studies on the socio-economic conditions in the clusters concerned. Devise strategies for the improvement of working conditions in the clusters.
- Identify new areas for R&D activities, for future interventions.

Action research

In each area, the project's work followed the dynamic and cyclic pattern of 'action research', with activities taking place in three broad and overlapping phases.

1 Developing a plan of action based on reconnaissance (the 'recce' phase)
2 Taking actions according to that plan (the 'pilot' phase)
3 Assessing results of the actions, to formulate and take further action (the 'assessment' phase)

For the sake of clarity, the various activities have been described sequentially as far as possible in this book. In reality, though, action research does not take place according to a neat timeline. Action research is a dynamic framework: a process of continuous planning, experimentation, assessment, and learning that cuts across timelines, and that involves frequent and extensive interplay between different phases and the players in those phases. Action research does not achieve targets and goals by linear paths, but by a series of iterations and loops.

Competence pooling

The development of an appropriate participatory technology requires many specialized skills—in fields ranging from energy management to pollution control, from engineering and equipment design to training, market research, and market development. Therefore, each intervention took the shape of a technology package that was developed and implemented by a multidisciplinary team, comprising experts and consultants from India and abroad, technology providers, engineers, and others (Box 2). These specialists pooled their competencies and adapted equipment designs and operating practices to local conditions and to suit the requirements of the local operators.

BOX 2
Competence pooling—
putting the pieces together

When the TERI teams started out on their interventions more than a decade ago, they did have a lot of expertise with energy audits. Most of these energy audits were focused on large and medium industries. But when the teams started analysing brick kilns, foundries, glass furnaces, and silk-reeling units, they soon realized that the complexities of these small and micro enterprises were no less than the former; often, they were even greater.

Instead of reinventing the wheel, TERI decided to call in specific experts to fill up the lack of knowledge in the many technology-related domains. This strategy of 'competence pooling' has proven to be very effective. Typically, technology specialists are excellent at analysing and running processes; but they are not very interested in things like energy efficiency. On the other hand, energy specialists like TERI and I perhaps tend to underestimate some of the technology-related hurdles. By interacting closely with one another, and with the industry associations and the pilot plant unit workers, we were able to develop technologies adapted to the needs of SMiEs.

The more the different components of the intervention progressed, the more specific the demands for expertise became. The intervention process is like a puzzle. After so many years of work, it has become evident that for the successful completion of the process, the pieces of the puzzle – made up of knowledge and expertise – have to be put together in the correct way. Competence pooling is like many minds coming together to move a body in a chosen direction. The concept cuts across, indeed holds together, all the interventions by SDC and TERI in the small-scale sector.

Pierre Jaboyedoff
Sorane SA

Charting the course

Overview

Glass has been known to humankind for thousands of years. Archaeologists have determined that Egypt and Mesopotamia made glass articles as early as 2100 BC. In India, glass beads dating back to around 1000 BC have been found among the artifacts of the 'painted grey ware civilizations' of the Ganga valley, and at other sites, including Nasik, Ujjain, Nalanda, Brahmagiri, and Arikamedu. Indian glass industry really began to flourish in the period between the third century BC and the third century AD. Unlike in Greece and Rome, glass vessels were generally not made in India. These were brought to India from Persia and from Venice and other European cities by traders or by invaders. Except for small phials and bottles, glass products in India were limited to ornaments and decorative ware. However, the Indian glass ornaments – particularly bangles and beads – found a ready market in Middle Eastern and European countries.

Each day, glass units in Firozabad produce an estimated 2000 tonnes of glass products, including 50 million bangles, and provide direct employment to an estimated 150 000 people

The Indian glass industry received royal patronage during the Mughal period (16th to 18th century AD). It was during this period that the foundations of the Firozabad bangle industry were laid. Firozabad lies about 250 km away from New Delhi, and 40 km from Agra. According to an estimate by TERI, each day, glass units in Firozabad produce an estimated 2000 tonnes of glass products, including 50 million bangles, and provide direct employment to an estimated 150 000 people (Figure 2, Box 3).

Figure 2
Glass products made in Firozabad

How glass is made

Annexure 1 describes in some detail the process by which glass is produced, and the three main kinds of glass. The principal constituent of glass is silicon dioxide, or SiO_2. Silica sand contains about 96% by weight of SiO_2. However, silica melts at a very high temperature; so in order to reduce the fusion temperature, soda ash and potash are added to the charge as fluxing agents, that is, these chemicals permit the use of lower melting temperatures in the glass furnace.

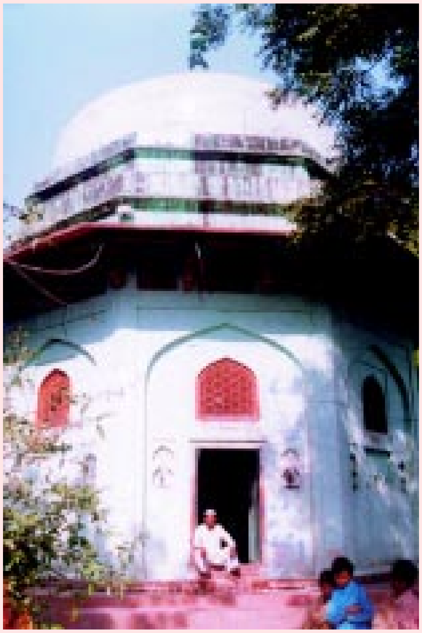
To improve the chemical resistance of the glass, small amounts of lime, alumina, and magnesia are added. Other chemicals are added as needed to

Box 3
History of the Firozabad cluster

During the reign of the great Mughal Emperor Akbar (1556–1605), the region where Firozabad lies today was densely forested and was a den of robbers. In the midst of the forests lay a tiny village named Chandwar. The story goes that Raja Todar Mal – one of the *navaratnas*, or nine most valuable members of Akbar's court – was passing through the region while on a pilgrimage to the holy city of Kashi, when his group was set upon by robbers. The Raja complained to the Emperor, who sent a contingent of soldiers under a commander named Firoz Shah to rid the forests of robbers. Shah vanquished the robbers and established a garrison in Chandwar to guard the area against future incursions. After Firoz Shah's death, Chandwar was renamed Firozabad (Figure 3).

Bangle-making was already known to the people in the Firozabad region; indeed, an ancient kind of glass melting furnace (called *bhainsa bhatti*) is still used in Sasani (near Aligarh) and Purdial Nagar. Among Firoz Shah's retinue were a number of glass workers from Rajasthan who specialized in making beads and bangles. Having settled in Firozabad, in due course they deployed their skills and taught them to local artisans. Clay furnaces were made; silica was obtained from the sandy surface soil of nearby lands; wood, or wood charcoal, was used for fuel. Thus, the foundations of the Firozabad glass industry were laid. Today, Firozabad is nicknamed 'suhag nagri' because it fulfils almost the entire country's demand for bangles and other glass ornaments worn by *suhagins*, or married women.

Figure 3
Firoz Shah's tomb



impart different colours to the glass. For instance, oxides of iron are added for a greenish-blue colour, selenium oxide for red, and cobalt for blue. To remove air bubbles that may form within the molten glass, certain chemicals such as potassium or sodium nitrate, arsenic oxide, and antimony oxide are added in small quantities. The various raw materials are weighed, blended with one another in the required proportions, and then fed (or 'charged') into the glass-melting furnace.

The glass is produced in the molten state. It is drawn from the furnace and blown (or 'formed') into desired shapes (Box 4). These products are then heated and cooled in a controlled manner, in a process known as annealing, to impart hardness to the glass. Depending on their nature, the products are then subjected to various cutting and finishing operations before being packed for despatch to the markets (Figure 4).

The glass industry is highly energy intensive, with fuel cost accounting for over 40% of product cost. In some cases, the melting process alone takes

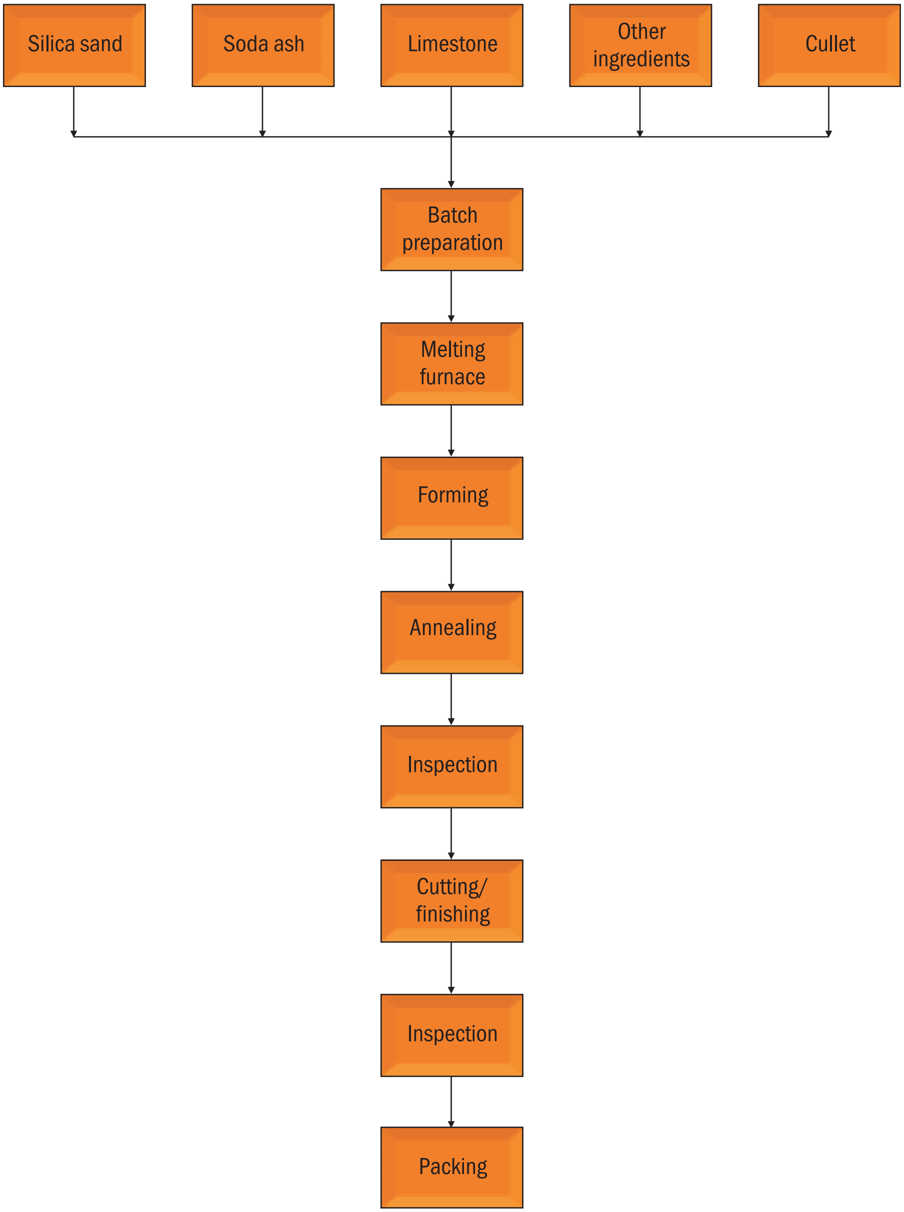
Box 4
The wonder of glass

'Take 180 parts of sand, 180 parts of ash (from marine plants) and five parts of chalk. Melt together. The result is an amazing liquid. Glass is a humble material, not as youthful as plastic nor with as exotic a range as wood; it lies like a servant waiting to be formed into whatever we desire. It is free of the intimidating, complex language of plastic but can boast a similar level of advanced technology...

'Glass is also a material of contradictions—it has moments when it beckons to be adored, and others where it silently and humbly provides a crucial function. It has thousands of decorative applications, as well as acts as an invisible partner to other materials, lending strength and stability. It has been used for thousands of years and continues to be used in some of today's most technologically advanced applications. It can be harder than steel, yet wearable. It supports buildings, yet can be as thin as a piece of paper and as flexible as a blade of grass. It can take months to create a delicate piece which can be smashed in a split second—but it also protects space shuttles re-entering the earth's atmosphere.'

Chris Lefteri, 2002
Excerpt from his book *Glass—materials for inspirational design*
[Rotovision SA: Mies, Switzerland]

Figure 4
Process flow chart:
glass production



up over 80% of the total energy consumed by a glass factory. Hence, the profitability of a glass unit hinges crucially on the efficiency of its melting furnace.

Glass melting furnaces

Glass melting furnaces are continuous furnaces. That is, a melting furnace operates non-stop for 24 hours each day from the moment it is commissioned till its final shutdown. The reason is simple. If a melting furnace is shut down in the middle of operation, charge material and fuel worth several tens of thousands of rupees is irretrievably lost. Furthermore, the costs of cleaning up the furnace and reheating it, along with the costs of the labour and time required to do this, add up to enormous losses for the unit.

There are two basic kinds of melting furnaces used in the Firozabad cluster to make glass: the tank furnace and the pot furnace.

Tank furnaces

Tank furnaces are large: each has a capacity to make around 15–30 tonnes of glass daily. Glass from tank furnaces is used to make a wide range of items such as jars, tumblers, signal lamp covers, lamp shades, headlight covers for automobiles, thermos flasks and their refills, and laboratory ware. Tank furnaces are fitted with heat recovery devices called 'regenerators', which are primarily large brick structures. These devices recover heat from flue gases and use it to preheat combustion air. Prior to 1996, there were two kinds of tank furnaces operating in Firozabad: coal-fired and oil-fired. The former burned around 16 tonnes of coal daily, while the latter burned around 5200 litres of RFO (residual fuel oil) each day.[7]

Pot furnaces

Pot furnaces are used to make relatively small quantities of different colours of glass. A typical pot furnace has 10 to 12 pots, with each pot holding a charge of about 300–500 kg. The pots are filled with charge material, and the glass melted overnight. The melt is drawn the following day. A typical pot

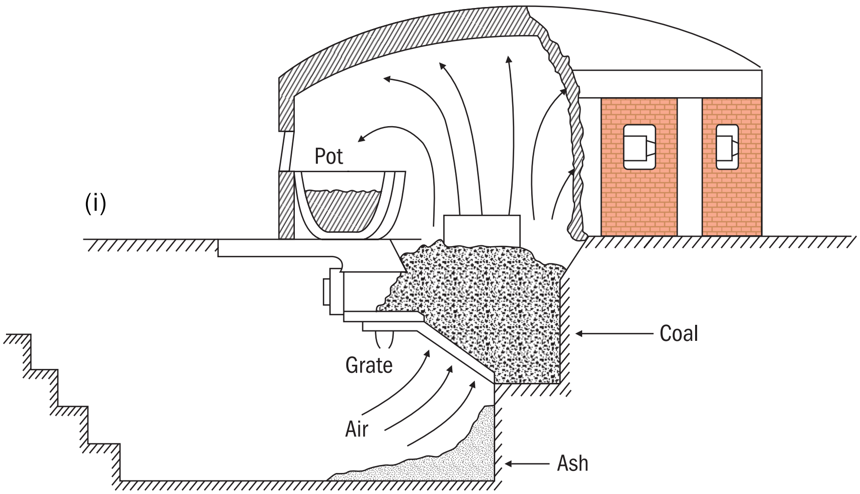
[7] The amounts of different fuels required to obtain 1000 kcal of heat are as follows: coal—0.18 kg; RFO (residual fuel oil)—0.10 litres; natural gas—0.12 Sm^3 (standard cubic metres). For this calculation the gross calorific values of these fuels are assumed to be 5680 kcal/kg for coal; 10450 kcal/litre for RFO; and 8500 kcal/Sm^3 for natural gas.

furnace operates on a ‘downdraft’ principle, that is, the hot gases from the burning fuel flow up to the roof or crown of the furnace, and then sweep downwards on to the pots (heating them in the process) before escaping through the chimney via a flue gas channel laid beneath ground level (Figure 5).

There are two kinds of pot furnaces: open-pot and closed-pot. The closed pots (also called Japanese pots) protect the glass within the pots from

Figure 5
Traditional coal-fired pot furnace: (i) schematic (ii) view

(i)



(ii)

Figure 6
Emissions from a coal-fired pot furnace

contamination by the dust and particulate matter in the furnace. Closed pots are used to melt relatively small batches of glass of special quality and composition. This glass is used to make a wide range of products such as tubes, rods, and decorative items. Open pots are used to make glass entirely for bangles, where the quality of glass is comparatively less important.

Prior to 1996, all pot furnaces were fired by coal. Typically, a closed pot furnace burned around 5 tonnes of coal daily to produce 3 tonnes of glass, while an open pot furnace burned 4 tonnes of coal daily to make 5 tonnes of glass (Figure 6).

Bangle-making/auxiliary furnaces

Bangles are made from glass melted in open-pot furnaces (and sometimes, tank furnaces) in a series of steps that involve special kinds of furnaces and workers with special skills. The basic steps are briefly described below (Figure 7).

- First, a worker (known as the *gulliwalla*) uses a long iron pole to scoop out a glob of molten glass from the pot furnace at a temperature of around 1300 °C.
- He races with the glob to a worker who gives it an appropriate shape (somewhat resembling an ice-cream bar!). If necessary, he coats the glass

Figure 7
Making raw bangles

(i) Batch preparation

(ii) Raw material feeding

(iii) Glass melting in pot furnace

(iv) Drawing out melt glass

(v) Shaping of glass ball

(vi) Applying different shades

Figure 7 (*Continued*)
Making raw bangles


(vii) Re-dipping of glass ball


(viii) Re-shaping ball


(ix) Re-heating glass ball


(x) Making spiral


(xi) Cutting and bundling

with a small quantity of coloured block glass that is melted separately in a small refractory container called *tali*.

- The shaped glob is then taken to the *sekai bhatti*—a furnace fired directly by coal. Here, a worker known as the *sekaiwalla* gives the semi-fused glob of glass a roughly cylindrical shape by rotating the rod.
- The still-soft cylindrical mass of glass, now cooled down to a temperature of around 500 °C, is then taken to a third coal-fired furnace, the *belan bhatti*. Here, three workers operate in concert to draw the glass into a spiral shape (Figure 8). The *belanwalla* rotates a '*belan*' machine – essentially a long iron rod – inside the furnace at a constant speed. The *tarkash* draws a thin filament of glass from the melt and places it steadily on the rotating rod, so that the constant turning motion gives the filament a spiral shape. The *muthia* uses an abrasive tool to cut off lengths of the spiral at periodic intervals.

Figure 8
Traditional *belan bhatti*

- The spiral lengths of glass (still hot but now hardened) are collected and sent for cutting.
- The cut bangles are tied with strings into bunches. Each bunch contains approximately 320 bangles, and is called a *tora*.
- The bangle bunches are then sent to household units for further processing into 'raw' bangles (Box 5).

BOX 5
Tangled bangle chain

Bangle-making is a complex chain of interdependent processes, carried out by skilled workers at the household level with all the smoothness and precision of an assembly line in some giant factory (Figure 9). The bangles coming out of the glass-melting unit are plain, without any decorative work on them. *Sedhai* and *judai* are the crucial first stages in converting raw bangles from tank/pot furnace units into finished products. Both operations are carried out by workers in their homes.

Sedhai means 'straighten'. As the name suggests, in this stage the raw bangle is levelled or straightened by heating it over a small flame – usually from an LPG (liquefied petroleum gas) cylinder – and then pressing the heated bangle against an iron plate. Women and teenaged girls usually do *sedhai*.

After straightening, the two open ends of the bangle (now in alignment) are joined together once more by heating over a traditional kerosene lamp. This process is called *judai* (literally, 'joining'). *Judai* is usually done by women—and in some cases also by teenaged children.

After *sedhai* and *judai*, the bangles are decorated according to requirements. The decorative work is carried out in a series of steps or processes, with each step/process being dependent on completion of the earlier step. The bangles are painted in different colours; intricate patterns and designs may be engraved or etched on them; silver and gold polish (*hil*)[8] applied on their surfaces; and finally they are sent to the *pakai bhattis* for baking. Thereafter, the bangles are intertwined and strung together again, wrapped in brown paper, and packed into cardboard boxes, which are transported to godowns all over Firozabad by hand-drawn carts.

A popular saying in Firozabad: '*A bangle passes through 50 hands before it finally adorns a lady's wrist!*'[9] Interestingly, in Firozabad the word 'dozen' means 24 and not 12...because each one of us has two hands, and the bangle-maker counts 12 bangles per wrist!

Broken bangles are not wasted. The shards are sorted out into separate piles according to colour (a process called *chatai*), and then the piles of shards are pounded manually into a fine powder for return to the glass melting factory.

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[8] Presently, synthetic chemicals are used in place of gold and silver polish.

[9] In 1997, Balkrishna Gupta, head of the Advance Group of Glass Industries, estimated that a bangle passes through 139 hands before it reaches a woman's wrist. ('India's Glass Town', *Business India*, 19 May–1 June 1997).

Figure 9
Processing raw bangles

(i) Sedhai

(ii) Judai

(iii) Applying decorative colour

(iv) Cutting patterns

(v) Packaging in godown

- Finally, the raw bangles are annealed in a furnace known as the *pakai bhatti* to yield the finished product.

Muffle furnaces or pakai bhattis

Pakai bhattis are traditional coal-fired muffle furnaces[10] that are specifically used to bake or anneal raw bangles. A typical *pakai bhatti* has three horizontal tiers or 'muffles' made of fireclay (Figure 10). Coal is burnt at the bottom of the furnace, and hot flue gases flow upwards and around the muffles, heating them up in the process before leaving the furnace at around 700 ºC. The

Figure 10
Coal-fired *pakai bhatti* unit

(i) Stocks of wood and coal

(ii) Front view of furnace

(iii) Rear view of furnace

(iv) Emissions

[10] To avoid confusion with the gas-fired muffle furnace later developed by the project, the term '*pakai bhatti*' is always used in this book to refer to the traditional coal-fired muffle furnace.

lowest muffle is the hottest, followed by the middle and top muffles. The raw bangles to be baked are arranged in trays. Each tray is then placed in turn on the top, middle, and bottom muffles for about two to three minutes at a time to bake the bangles (Box 6).

Pakai bhattis operate throughout the year. An estimated 100 000 tonnes of coal are consumed each year by *pakai bhatti*s in Firozabad, generating very high levels of pollution in the form of CO_2, smoke, and particulates. The effects of this pollution are all the more serious because *pakai bhattis* are located in the midst of densely populated residential areas of Firozabad.

An estimated 100 000 tonnes of coal are consumed each year by pakai bhattis in Firozabad, generating very high levels of pollution

Box 6
Pakai bhattis—
bringing glitter to bangles

Raw bangles are baked for two main reasons.

1 While going through the various stages in their making – particularly grinding – raw bangles lose the natural shine of glass. Baking the bangles in *pakai bhattis* restores their shine, and at the same time helps in removing the internal stresses in the glass, thus providing a degree of strength to the bangles.

2 While decorating raw bangles, gold polish (known as *hil*) is applied to their surfaces to make the end-products more attractive. The polish is invisible when applied; but its lustre appears when the raw bangles are baked.

Pakai bhattis usually operate in three daily shifts of eight hours each. A unit typically has five workers: three at the furnace, and two to transport raw bangles and finished bangles. There are three basic stages in the operation (Figure 11).

1 The raw bangles are arranged on trays by the *chinnaya*.

2 The trays are picked up and transferred from muffle to muffle in the furnace by the *pakaiya*—the most skilled worker in the unit, and therefore the most highly paid.

3 After baking, the trays are removed from the furnace, and the bangles are placed on the ground and allowed to cool. The *ginnaiya* then counts them and bunches them in *toras*. A typical coal-based *pakai bhatti* burns 0.5 tonnes of coal daily to bake around 400 *toras* of bangles.

Figure 11
Muffle furnace—
stages in baking bangles

(i) Tray preparation

(ii) Baking in progress

(iii) Baked bangles

Cluster dynamics: high competition, low technology

As mentioned earlier, the Firozabad glass industry has a near monopoly in production of bangles in India. Besides bangles, the Firozabad cluster also produces popular low-value glass products in the country (bowls, tumblers, lamp shades, and so on). Considering the steady demand in the country for such products, logic suggests that the Firozabad glass industry could dictate prices to the market if individual units joined to form a cartel. However, such unity of purpose was not discernible among the Firozabad glass units. Indications were that the very nature of the small-scale glass manufacturing industry – in particular, the fiercely competitive nature of the industry, the lack of control over market forces on both raw materials and product sides, and the narrow profit margins within which unit owners had to operate – made it difficult for unit owners to work together in common interest.

In general, the Firozabad glass units did not sell their products directly to retailers or customers. Instead, it had become an established practice for units to sell their products to dealers or their agents. Usually, there was little to distinguish the glass products made by one unit from another, and hence unit owners routinely resorted to under-pricing their products in order to dispose of accumulated stocks. Indeed, products were sometimes sold by the kilogram! The dealers and middlemen took full advantage of this situation – in effect, it was a buyers' market – and dictated prices for glass products that were totally unrelated to the products' prices in the retail market. (Consumers did not benefit from this situation, because the middlemen did not pass on the benefits of low procurement prices to them.) As a result, most units in the Firozabad glass cluster were trapped in a never-ending cycle of vicious competition, in which the only beneficiaries were the middlemen (Box 7).

With hardly any room to cut down on capital expenditure or production costs, and no control over either their raw material costs or selling prices, the Firozabad glass entrepreneurs were extremely wary about considering any changes in their technology or operating practices

In such an environment, the unit owner was constantly worried about the viability of his operations. His profit margin was thin and unpredictable. Because his melting furnace had to be operated non-stop, he was constantly under pressure to offload accumulated finished products. The only way he

Box 7
Fractured glass

'Cooperation is so lacking among us, that when somebody's furnace breaks down, others make offerings at the temple in thanksgiving... *jab kissi ka bhatta baith jata hai to hum jakar Hanumanji ko prashad chadhate hain!* We just don't care what the effect is on others of our selling below cost; we are only concerned with keeping our furnaces running continuously, even if it means a small loss!'

A Firozabad glassmaker
[Quoted by Krishna Rao and Kanan Shah in *Kanch*, September 1992]

could increase his returns was by cutting down on production costs; but here too he had very few options. His glass factory worked day and night, and required a certain minimum number of workers at any point of time. Therefore, he could neither cut down his workforce strength nor reduce the wages of workers. To cut down on fuel (coal) costs he would have to reduce coal consumption: that is, increase the efficiency of his melting furnaces. However, he did not have the contemporary technical knowledge or technical skills to do so, nor did the *mistrys* (masons) who built the furnaces. Besides, coal availability was itself a constant source of concern, and the price and quality of the coal too were often beyond his control (Box 8).

This, then, was the situation in the Firozabad glass industry till the mid-1990s. The market for Firozabad's low-value glass products was undiminished; but the benefits were not being fully reaped by the manufacturers. The market demand for high-value products such as crystal cut-ware, opal glass, borosilicate glass, and ovenware had steadily grown over the decades; but the special quality glass required to make such products had to be melted at temperatures of 1600 °C or more—well beyond the capabilities of Firozabad's traditional coal-fired tank and pot furnaces.[11] With hardly any room to cut down on capital

Box 8
Coal worries

The principal supplier of coal for the Firozabad cluster was the government-owned CIL (Coal India Limited), with whom many units had registered their names for coal supply. The coal was sent to Firozabad by rail from CIL's collieries in different parts of India. Usually, the coal supplied by CIL was of good quality. However, coal shipments were often delayed because CIL and/or the railways did not keep to delivery schedules. Also, a substantial amount of the good-quality coal that came by rail was cornered by middlemen. Glass factory owners were then forced to purchase coal for their melting furnaces in the open market, irrespective of its quality and usually at exorbitant rates. They had no option but to do this—their melting furnaces had to be kept going at any cost!

[11] The oil-fired tank furnaces were capable of achieving temperatures up to 1450 ° C and producing special quality glass; but such furnaces were expensive and beyond the resources of units that produced less than 12 tonnes per day of glass.

expenditure or production costs, and no control over either their raw material costs or selling prices, the Firozabad glass entrepreneurs were in general extremely wary about considering any changes in their technology or operating practices. Their fear was that any such changes might increase their costs of production. This fear manifested itself in a marked reluctance on the part of the entrepreneurs to invest their resources in any innovative technology—even though they had the resources to invest, and they clearly needed energy-efficient technology that would help them reduce fuel costs.

Energy audits

To assess the potential for improving energy efficiency in the Firozabad glass industry, SDC commissioned energy audits by TERI in the Firozabad cluster in 1994. Accordingly, TERI conducted detailed audits in five representative units in the cluster that used: (i) oil-fired tank furnace; (ii) coal-fired tank furnace; (iii) closed pot furnace; (iv) open pot furnace; and (v) muffle furnace. The results of the audits clearly showed that all the furnaces – in particular, the coal-fired pot and muffle furnaces – were very low in energy efficiency, primarily due to two reasons.

1 Poor furnace design
2 Little or no heat recovery

Firozabad's glass melting furnaces were built by *mistrys* who derived their knowledge and skills from tradition. The dimensions and shapes of the furnaces were based on designs that had changed very little over the decades. Also, in the absence of knowledge on better alternative materials, the *mistrys* used refractory materials with very poor heat insulation properties in fabricating the furnaces (Box 9). As a result, huge quantity of heat was lost from the furnaces in the form of structural losses (Figure 12). Poor quality structural material also greatly reduced the furnaces' lifespans; typically, a traditional pot furnace lasted barely a year.

Large quantities of input heat were carried away from the furnaces in the form of hot flue gases. While tank furnaces had heat regenerators – devices that recovered heat from the flue gases and used it to heat up combustion air – pot furnaces did not have any such mechanisms at all for heat recovery. Heat losses were hence much higher in the pot furnaces, with the flue gases escaping the furnace at temperatures of around 950 ºC. However, overall energy efficiency was the lowest in case of the *pakai bhatti*. Not only did this furnace lack a heat recovery system; the 'bottom ash' that settled at the

Box 9
Refractory facts

A material that has the ability to withstand the effect of high temperature is known as refractory material (or collectively, 'refractories'). However, according to ASTM International (formerly, the American Society for Testing and Materials), the term 'high temperature' has been qualified as minimum of 1500 °C. A refractory not only has to withstand the effect of high temperature exposure, but it also has to be resistant to corrosive and abrasive action of solids, liquids, or gases with which it comes into contact.

A refractory material may be made up of one single compound, or it may consist of a number of compounds—usually, oxides of elements such as aluminium, silicon, and magnesium. These oxides react with each other at high temperatures to form various compounds with different crystal structures and with formation of liquids. These liquids, known as glass, spread around the grains and help in binding them together.

Oxides of aluminium (Al_2O_3) and silicon (SiO_2) occur in nature and are accompanied by some undesirable elements in the form of impurities or combustibles. These materials are processed for obtaining the desired characteristics like stability at high temperature, adequate strength, corrosion resistance, and so on. The nature of the crystal structure and the liquid/glass developed during the processing, along with the 'voids' or pores generated, determines the various properties of the refractories.

Refractory materials are tailor-made to suit particular applications. For a refractory to be cost-effective, its performance must be reliable, predictable, and consistent. The constituents in a refractory, and their relative proportions, are determined by process parameters such as temperature profile, the nature of chemical environment, conditions and duration of operation, and so on.

Listed below are a few compounds used in making refractories, along with their melting points (in pure state).

Substance	*Melting point* (°C)
Silica (SiO_2)	1723
Titania (TiO_2)	1850
Alumina (Al_2O_3)	2050
Lime (CaO)	2570
Magnesia (MgO)	2800

Refractories with alumina and silica as predominant constituents can be placed in four categories

1 Fireclay refractories
2 Silica refractories
3 High-alumina refractories
4 Mullite refractories

Besides differing in their chemical composition and physical

(*Continued*)

Box 9 (*Continued*)
Refractory facts

characteristics, refractory materials are used in two different forms: unshaped and shaped. Unshaped refractory material is manufactured in the form of a granulated powder. When mixed with water, the powder assumes a fluid-like consistency. It can then be spread on to surfaces as a coat (for instance, to line a furnace).

Shaped refractories comprise pieces that have particular shapes and sizes. The most familiar and traditionally used shape is the rectangular 'brick'. However, today refractories are manufactured in a variety of shapes for convenience in construction. Besides the standard brick shape, refractories are also made in shapes such as arch, wedge, circle, skewback, and key brick (Figure 13). Properly shaped pieces of refractory material will fit together precisely, reducing the gaps between pieces and thereby giving the assembled structure greater strength and longer campaign life.

B N Ghosh
Refractory Expert

Figure 12
Sankey diagram of a coal-fired pot furnace

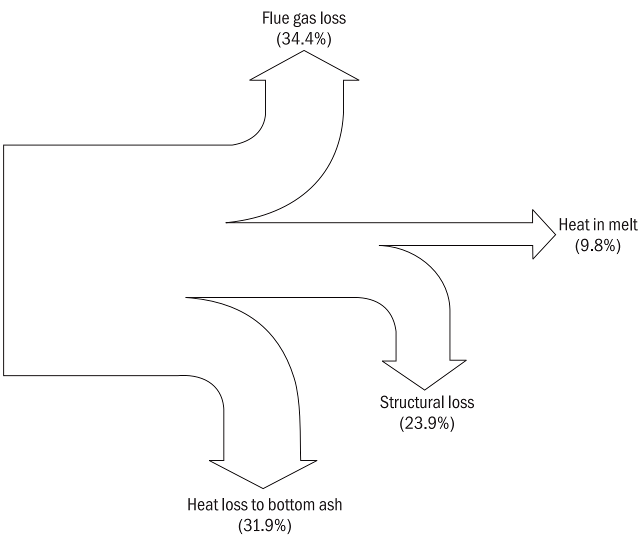
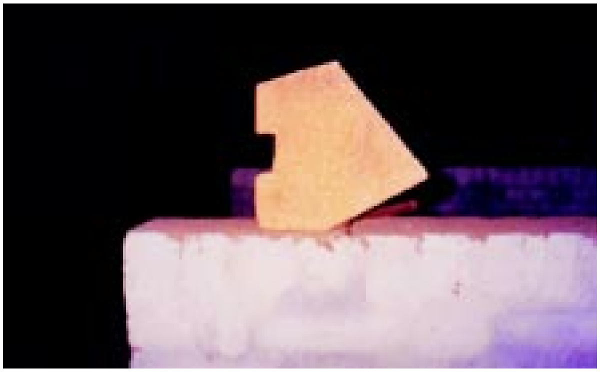


Figure 13
Skewback



bottom of the *pakai bhatti* contained a high proportion of unburned carbon, representing potential heat energy gone to waste. Barely 3.1% of input heat was actually being utilized by the *pakai bhatti* to bake bangles.

In case of pot furnaces there was another factor that indirectly led to considerable wastage of heat: poor quality of pots (Box 10). On an average, a pot lasted barely 15 days before it cracked or 'failed'. Not only did each pot failure represent a loss of hundreds of kilograms of charge material; it also meant loss of all the heat supplied to that pot, and hence, wastage of fuel. Pots were shortlived primarily because of inferior quality materials used in their moulding, and faulty methods used to fire the 'green' pots. The problem was made much worse by the fact that neither potters nor pot furnace

Box 10
The price of uncertainty...

'Even if I knew that a pot could be expected to last only one month, it would be of great help...because then I could make it a rule to discard every pot before its month was up to minimize breakage (and consequent losses) during a melting campaign. But in the absence of a pot-testing laboratory, neither the pot-maker nor I can make any improvements in our way of working. We are helpless to change...'

A pot furnace owner
Quoted in 'Glassmakers' town',
Kanch, June 1992

owners had the latest technical knowledge or the means to determine beforehand how long a pot would last. It might last a few weeks—or just a few hours.

Discussions, recommendations, and decisions

The results of the energy audits were examined and discussed at the Screening Workshop in December 1994. Participants made the following salient observations.

- The glass melting process consumed the maximum amount of energy. Hence, the project should focus on the glass-melting furnace while considering steps to increase energy efficiency.
- All the furnaces studied during the energy audits showed considerable 'structural' heat losses—the result of low-quality refractory bricks having been used in their fabrication. Use of better refractory materials would enable the furnaces to achieve and maintain higher temperatures. These higher temperatures would enable better heat recovery through suitable devices and, therefore, increase energy efficiency and productivity.
- None of the units studied had instruments to monitor the air–fuel ratio in furnaces to ensure optimal combustion. As a result, energy available in the fuel was being lost in the form of unburned carbon, which was deposited in the bottom ash.
- Several tank furnace operators had already switched from coal-based operations to oil-based operations. The remaining coal-fired tank furnaces too were expected to switch to oil-based operations without much difficulty. However, pot furnaces continued to operate on coal because no technologies were readily available to run pot furnaces on oil or gas; nor did the economics of such operation appear favourable at that point in time.
- The pot furnace was inherently inefficient in design and, therefore, burned very large quantities of coal to melt down a given quantity of glass. In countries such as Britain, Germany, and (former) Czechoslovakia, this did not matter so much—for, the few pot furnaces there burned better-quality coal or coke to make very high-value products such as crystal ware, and the proportion of fuel cost in the product cost (that is, the energy intensity) remained low. In Firozabad, however, the low-efficiency pot furnaces burned excessive amounts of coal to make relatively low-value items, and hence the fuel cost made up a substantial portion of the product cost. The result: low profitability of operations.

- *Pakai bhatti*s operated at temperatures of around 480 ºC.[12] Pot furnaces emitted flue gases at temperatures of around 950 ºC. If *pakai bhatti*s could be conveniently located in the vicinity of pot furnaces, it might be possible to use hot flue gases from the latter to heat up bangles in the former, thus saving considerable amounts of coal.
- Although *pakai bhatti*s were individually small consumers of coal, their large numbers (around 400 operating units, as estimated in 1994) collectively made them a large-scale coal consumer.
- GAIL (Gas Authority of India Ltd)[13] had laid a pipeline from Gujarat to Rajasthan and Uttar Pradesh to supply natural gas to large-scale industries in northern India (Box 11). In future, it might be possible for the Firozabad glass units to burn natural gas in their furnaces as a cleaner, more efficient fuel option. However, in 1994 the indications were that gas from GAIL's pipeline would not be available for the Firozabad cluster in the near term. Under the circumstances, the project should continue to view coal as the primary source of energy for the cluster.

Box 11
GAIL: pipeline of hope

GAIL was established by the Indian government in August 1984 following the discovery of large gas reserves off India's western coast from 1977 onwards. GAIL's primary responsibility was to set up nationwide transmission, distribution, and marketing networks to enable utilization of these gas resources. In 1986, GAIL began construction of a 2700-km onshore pipeline (called the HBJ pipeline because it runs from Hazira via Bijaipur to Jagdishpur) to supply natural gas to power plants, fertilizer factories, and other industries in Gujarat, Rajasthan, Madhya Pradesh and Uttar Pradesh.

The HBJ pipeline was commissioned in 1988. In 1997, GAIL completed a 505 km-long 'loop line' on the HBJ pipeline to take gas up to Dadri, near New Delhi. Following the Supreme Court's order in the Taj Trapezium case (Box 12), GAIL laid a 'spur line' to tap gas from this loop line and take it first to Agra (through a 52-km, 10-inch pipeline) and then onwards to Firozabad (through a 37-km, 8-inch pipeline).

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[12] Later, it was found that higher temperatures are required in the *pakai bhattis*.
[13] Now renamed GAIL (India) Limited.

Taking into account all the above observations and points, the Screening Workshop felt that the project should focus on improving the design and operation of existing coal-fired glass furnaces to enable better utilization of energy from coal. The workshop made a number of recommendations to achieve this goal.

General recommendations

- Develop low-cost systems for pot furnaces to recover and reuse heat from flue gases.
- Set up demonstration plants to highlight the benefits of the new technology.
- Identify and demonstrate BOP (best operating practices) in areas such as combustion control, reducing cullet, and so on.
- Devise awareness/training programmes for operators.

Specific recommendations

Tank furnaces

Many tank furnace units had already converted from coal-fired operation to the more efficient oil-fired operation; others were in the process of doing so. The Screening Workshop, therefore, concluded that tank furnace units did not immediately need any interventions aimed at improving energy efficiency.

Pot furnaces

Interventions were urgently needed to improve energy efficiency in open- and closed-pot furnaces. All these furnaces operated on coal. The Screening Workshop suggested that the project focus on the following areas.

- Explore the possibility of using coal gasification systems.
- Improve the quality of pots.
- Introduce proper instrumentation (such as thermocouples to control/monitor furnace heat).
- Explore the use of better-quality refractories and insulation material in fabrication of furnaces.
- Identify measures to control cullet levels.

Muffle furnaces (pakai bhattis)

The Screening Workshop recommended that activities be initiated in the following areas to improve the energy performance of muffle furnaces.

- Modify the traditional *pakai bhatti* design.
- Find simple ways (such as increasing the number of trays) to improve operating efficiency.
- Use better refractories and insulation material in furnace construction to reduce structural heat losses.
- Explore the possibility of using alternative fuels.

Taking a stand on child labour

Around the time of the Screening Workshop, SDC also came to grips, during an internal meeting, with an issue very specifically related to the Firozabad glass industry, namely, the use of child labour among glass units in the cluster, which had become a matter of widespread concern both at the national and international level. SDC too was deeply concerned about the issue. At the same time, glass entrepreneurs were quite sensitive about the subject. It was a tough choice for the project. On the one hand, in order to have access to the Firozabad cluster and conduct successful demonstrations of improved technologies, it was essential not to alienate the entrepreneurs. On the other hand, the project certainly would not in any way countenance the practice of child labour. Finally, after an intensive internal debate, SDC decided that the project would work in Firozabad as planned—but only with demonstration units that did not employ child labour.

First contact

Initially, the project team was unsure as to how to approach and initiate activities in the Firozabad cluster. As a first and vital step, the project wanted to conduct a diagnostic study of the cluster to identify and prioritize sectors within the glass industry, where technological intervention would have the maximum impact in terms of reducing coal consumption and increasing energy efficiency. However, it was difficult for the project team to allay the nervousness and suspicion with which most glass unit owners regarded 'outsiders', that is, those who did not belong to the cluster or those not directly associated with the glass industry. This wariness on part of unit owners was partly due to campaigns by social activists and NGOs against the widespread practice of child labour among Firozabad's glass units, and the harsh conditions under which women and children worked in the bangle-making chain (as described later). Also, the period 1995/96 was a particularly tense and uncertain time for the Firozabad glass industry because of the issue of environmental pollution. A PIL (public interest litigation) case had been filed before the Supreme Court of India, seeking steps to curb air pollution from coal-burning industries in the area known as the Taj Trapezium Zone (Box 12).

The period 1995/96 was a particularly tense and uncertain time for the Firozabad glass industry... a PIL case had been filed before the Supreme Court of India, seeking steps to curb air pollution from coal-burning industries in the area known as the Taj Trapezium Zone

Box 12
Pollution—
monumental damage!

The 'Taj Trapezium Zone' is an area of about 10 400 km^2, covering parts of Uttar Pradesh and Rajasthan states in India. At its centre lies Agra, city of the Taj Mahal. Besides the Taj, the Trapezium is home to over 40 protected monuments, including other World Heritage Sites such as Agra Fort and Fatehpur Sikri.

The Trapezium also has a few SMiE clusters: notably, the glass industry cluster at Firozabad and the Agra foundry cluster. From the 1970s onwards, public concern grew across the world at the damage being caused to the Taj Mahal and other monuments by air pollution from industries in the area, and from the Mathura oil refinery. Norms were established for control of industrial emissions in the years that followed, but enforcement was lax.

In 1984, a prominent lawyer, Mahesh Chandra Mehta, filed a writ petition before the Supreme Court of India, pointing out that emissions from industrial units in the Trapezium were causing extensive damage to the Taj Mahal and other monuments, and pleading for orders to industries to stop the pollution (M C Mehta vs Union of India, WP 13381/1984). The Supreme Court delivered its judgment on this case on 30 December 1996. The Court banned the use of coke or coal by industries within the Trapezium, and ordered 292 coal-based industries in the Trapezium to switch to alternative fuels or else relocate outside the Trapezium. At the same time, the Court ordered GAIL to supply natural gas to industrial units in the Taj Trapezium that could adapt their technologies to use this far more environmentally benign fuel.

Under the circumstances it was understandable that pot furnace owners were in no mood to listen to any innovative ideas put forward by 'outsiders' to improve the energy efficiency of their existing furnaces.

It was a local glass entrepreneur, Viswadeep Singh, who finally came to the team's rescue (Box 13). Singh used his considerable influence and persuasive powers to overcome the reluctance of his co-industrialists to deal with 'outsiders'; he arranged for project members to meet with other glass unit owners, individually and in groups. It was Singh's patient efforts that eventually enabled the project to conduct a diagnostic study of the cluster.

As described later in this book, Viswadeep Singh continued to be of immense support to the project throughout the intervention in a variety of ways—familiarizing the project team with the ground realities of the cluster, helping to break the ice with other glass entrepreneurs, identifying persons who would support the project in its efforts at developing and propagating

Box 13
Viswadeep Singh—
facilitator, prime mover

Viswadeep Singh is a glass industrialist from Firozabad; he owns a tank furnace unit named Electronic Glass Industries. Singh comes from an illustrious and highly regarded family in Firozabad; his father was a Member of Parliament and Leader of the Opposition from 1957 to 1962, when Jawaharlal Nehru was India's Prime Minister.

Singh's first contact with TERI was in 1994, when he met Somnath Bhattacharjee (then working with TERI) at a meeting organized by the Uttar Pradesh State Financial Corporation. Singh was then the President of the Firozabad Glass Chamber of Commerce and Industry (an association of tank and pot furnace owners in the cluster). When the Screening Workshop of 1994 was organized by SDC and TERI, Singh was invited to present the Firozabad glass industry's points of view.

'Indeed, there was a great deal of apathy and cynicism among the glass factory owners in Firozabad at that time,' recalls Singh. 'Technology had stagnated; little efforts were being made to improve operating practices; unit owners didn't expect anything much to emerge from my attending the workshop. Frankly, neither did I. Yet somehow I managed to present our views, our needs, in an effective way—for research and development to improve our equipment and operating practices, for better technology! I was most happy when the Firozabad glass industry was selected by SDC for intervention.'

the new technologies, liaison with government officials, and so on. Indeed, had it not been for Viswadeep's constant support and encouragement, the project team would have found it very difficult to work in the cluster.

Diagnostic study

The project conducted the diagnostic study of the Firozabad cluster in late 1995. From the data gathered, it was estimated that about 730 tonnes of coal and 25 000 litres of RFO (residual fuel oil) were being consumed each day in the cluster. Of the coal consumed, pot furnaces (open and closed) accounted for about 48% of the coal (350 tonnes); muffle furnaces around 27% (197 tonnes); and tank furnaces the remaining 25% (183 tonnes) (Figure 14). Table 1 shows a summary of the study's findings.

Figure 14
Daily consumption of coal
(1 wagon = 60 tonnes of coal)

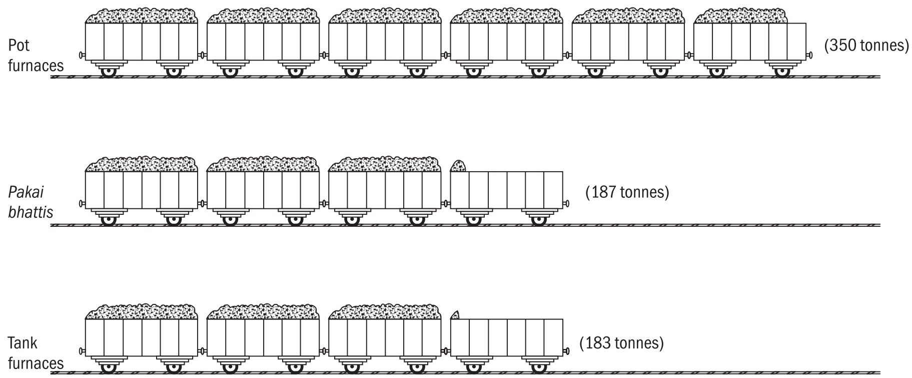


Table 1 Firozabad glass cluster—summary of the diagnostic study (1995)

Type of furnace	*Operating units* (~)	*Capacity* (tonnes/day)	*Specific energy consumption* (Gcal/tonne of melt)	*Fuel to melt ratio* (kg fuel/kg melt)	*Thermal efficiency* (%)
Tank (coal)	15	15–25	3.6	0.6	12.7
Tank (oil)	6	15–25	2.1	0.2	21.3
Open pot	50	4.8–6.7	5.5	1.0	9.8
Closed pot	30	2–4	9.5	1.7	4.7
Muffle	400	–	–	–	3.1

Gcal – gigacalories

The findings of the diagnostic study were in tune with the results of the earlier energy audits, and reinforced the observations made by the Screening Workshop. Oil-fired tank furnaces showed the highest energy efficiency, averaging over 21%, followed by coal-fired tank furnaces (12.7%). The coal-fired pot and muffle furnaces showed the lowest energy efficiencies, and hence were in greatest need for better technologies to improve energy performance. Hence, as suggested by the Screening Workshop, the project decided to upgrade the coal-firing technology of pot furnaces (both open and closed pot types), and develop a more energy-efficient design for the *pakai bhatti*s.

Drawing up plans

Pot furnace

The project decided to design, fabricate, and demonstrate an improved coal-fired pot furnace with a recuperator (heat recovery system) that would reuse heat from flue gases. The idea was to design the improved furnace in such a way that it resembled the traditional pot furnaces to the maximum extent possible. The project proposed to achieve its objectives stage by stage, as listed below.

- Inform pot furnace entrepreneurs in the Firozabad cluster of the project's plan of action, and ask the entrepreneurs themselves to identify a unit in which the project could set up a demonstration plant.
- Perform a pre-demonstration energy audit of the identified unit, to obtain detailed data on the design and operation of its existing coal-fired pot furnace.
- Conduct a literature review to examine various options that were available for improving the pot furnace design. Also, study design details of gasifier-based pot furnaces that were in operation in the UK in the first half of the twentieth century.
- With the assistance of Pierre Jaboyedoff of Sorane SA, prepare a checklist of parameters that were needed to design an improved coal-fired pot furnace, and send it to British Glass, UK, for critical review.
- Develop conceptual and detailed designs of the improved pot furnace. Thereafter, send these designs too to British Glass, UK, for evaluation and approval.
- Identify a local consultant to supervise construction of the demonstration plant and help in training operators. This consultant should be a glass expert with credibility among the local industry.

- Fabricate and commission the demonstration plant.
- Conduct test-runs, and fine-tune the plant.
- Train operators.
- Perform a follow-up energy audit.
- Develop a strategy for dissemination of the new technology.
- Design a commercial model of the improved pot furnace.

Muffle furnace

TERI's preliminary energy audits as well as the diagnostic study revealed that Firozabad's traditional muffle furnaces or *pakai bhattis* operated with extremely low energy efficiencies, primarily due to inherent drawbacks in their design. However, in seeking to develop an improved muffle furnace two vital points had to be borne in mind.

1 The *pakai bhatti* operators had very meagre resources, and therefore, the improved muffle furnace should be affordable to them.

2 The *pakai bhatti* itself was unique to the Firozabad cluster—there were no other furnaces like it anywhere in the world. Hence, the improved muffle furnace too had to be developed locally, and in a participatory manner to ensure its acceptability to operators.

The project, therefore, decided to conduct an all-India competition to help arrive at a more energy-efficient design for the *pakai bhatti*. The plan was to have the competition entries judged by a panel comprising technical experts, as well as representatives of the glass industry; suitable awards would then be given to the best designs. Thereafter, pilot muffle furnaces based on the winning designs would be fabricated and tested in the Firozabad cluster, and their designs further modified based upon feedback from *pakai bhatti* operators.

To achieve these objectives the project decided to take a series of measures as listed below.

- Make the Firozabad *pakai bhatti* operators aware of the project's goal and plan of action.
- Identify suitable locations in the cluster for the proposed testing and demonstration of improved muffle furnaces.
- Identify a core team to set up and coordinate the design competition.
- Prepare a mailing list of contestants—design consultants, engineering and technical institutes, manufacturers, and fabricators—and invite them to participate in the competition.

- Conduct the design competition, review the entries, and select the three most promising options among them.
- Develop detailed engineering drawings based on the three chosen design options, and construct pilot muffle furnaces based on them.
- Conduct test-runs, fine-tune the new muffle furnaces, and select the best option among them.
- Train operators in the use and maintenance of the new muffle furnace.
- Perform a follow-up energy audit of the new muffle furnace.
- Develop a dissemination strategy for the new muffle furnace.

Supreme Court verdict—and its impact

Till this point, the project was focused on finding ways to develop improved versions of coal-firing pot furnaces and muffle furnaces. And then, on 30 December 1996, the Supreme Court pronounced its long-awaited verdict in the PIL case related to the Taj Trapezium. The Court identified coal-burning industries in the Trapezium – including the glass units in Firozabad – as active contributors to air pollution, and ordered GAIL to supply natural gas to industries within the Trapezium as an alternative, less polluting fuel. The Court also laid down a time schedule for coal-burning industries to switch to natural gas or other fuels. Units were warned that if they failed to switch from coal to alternative fuels before December 1997, they would either have to relocate or shut down.

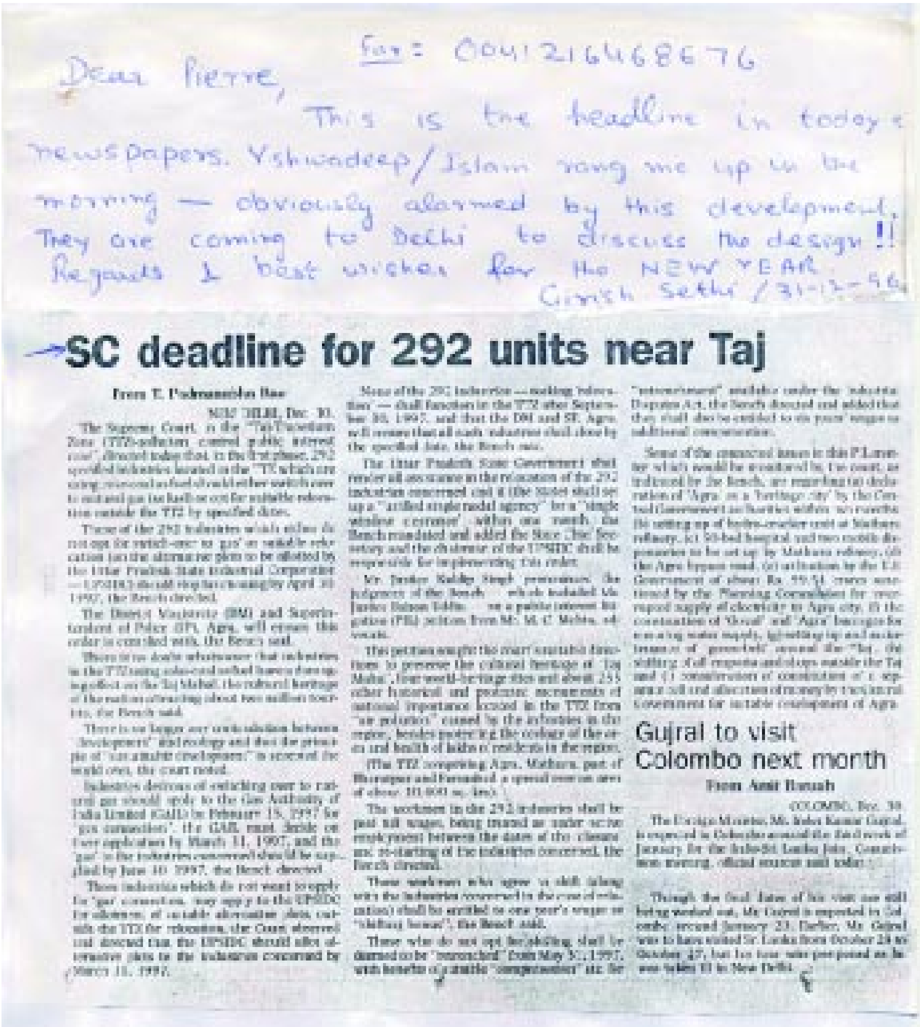
Although the 'spirit' of the Supreme Court's ruling clearly required all units located within the Trapezium to stop using coal, it remained freely available in the local markets and pakai bhattis continued to use it as fuel

The Supreme Court verdict had far-reaching implications for all the coal-burning glass units in the Firozabad cluster. On the one hand, these units – and, therefore, TERI – came under immediate and intense pressure to switch to gas-based operation (Figure 15). On the other hand, the units did not know how or where to find gas-firing technological options. Even when options were made available, the units faced problems in obtaining natural gas supply from GAIL (Box 14).

Tank furnace operators did not face much of a problem in the wake of the Supreme Court verdict. As mentioned earlier, most had already switched from coal to oil-firing, and the change from oil to gas-firing was even easier for them as it required little additional investment or changes in technology.

The pressure on pot furnace operators was far more acute. Unlike in the

Figure 15
News report on
Supreme Court verdict



Fax: 0041216468676

Dear Pierre,

This is the headline in today's newspapers. Yashwadeep/Islam rang me up in the morning — obviously alarmed by this development. They are coming to Delhi to discuss the design!!

Regards & best wishes for the NEW YEAR

Girish Sethi / 31-12-96

SC deadline for 292 units near Taj

From T. Padmanabha Rao

NEW DELHI, Dec. 30.

Gujral to visit Colombo next month

From Amit Baruah

COLOMBO, Dec. 30.

case of tank furnaces, no off-the-shelf solutions were available in Firozabad for running pot furnaces on oil or natural gas. The situation was further complicated by the fact that many pot furnace units were located in areas that had been declared 'no-gas zones' by GAIL, that is, the areas to which

Box 14
Short on gas!

The Supreme Court, in its verdict of 30 December 1996, ordered GAIL to make natural gas available to 292 identified industries in Agra and in the Firozabad glass cluster. Based on initial assessments, GAIL fixed its total natural gas allocation for Firozabad at 0.3 MMSCMD (million metric standard cubic metres per day). However, a survey conducted later by GAIL and UPSIDC (Uttar Pradesh State Industrial Development Corporation) estimated the total demand as 0.9 MMSCMD, based on the requirements of 204 units that had registered with GAIL for gas connections. There was thus a considerable shortfall in gas availability for units in Firozabad.

The situation was further compounded by the fact that, based on a study by the consultant group Energy Management International, UK, GAIL identified seven pockets in the Firozabad cluster as 'no-gas' zones. That is, GAIL decided that it would not be able to supply natural gas to these 'no-gas' zones because of safety considerations.

As Table 2 shows, the combined effect of shortfall in gas supply and 'no-gas' zones was two-fold: (1) many units wanted gas but were denied it because they were located in 'no-gas' zones; and (2) many other units, although located in the 'gas zone', were denied gas because GAIL simply did not have enough gas to supply.

Table 2 Allocation of natural gas by GAIL to Firozabad—status of glass units as of February 1998

Furnace type	*Location and status*		
	No-gas zone	*Gas zone, getting gas*	*Gas zone, not getting gas*
Tank (oil-fired)	5	7	10
Tank (coal-fired)	10	10	–
Closed pot	10	11	15
Open pot	82	36	105

Source TERI report number 95 IE 59 (1998)

GAIL could not supply natural gas because of lack of basic safety criteria. With the Court deadlines looming, a couple of entrepreneurs from Gujarat – a gas-rich state – saw a business opportunity in devising low-cost ways by which Firozabad's pot furnaces could be operated on natural gas. In the absence of any better alternatives, many pot furnace operators in 'gas zones' adopted the gas-firing designs offered by these Gujarati entrepreneurs—primarily, the design offered by P M Patel, as described later. Although these 'retrofitted' gas-fired pot furnaces met the immediate imperative – to switch from coal to gas-firing mode – they were basically simple modifications of the existing coal-fired pot furnaces. They did not have safety features or systems for heat recovery, and the energy efficiency of the furnaces remained low.

As for *pakai bhatti*s, the impact of the Supreme Court verdict was unclear. There were hundreds of *pakai bhatti* units in Firozabad, and all of them burned coal and/or wood as fuel. Yet, the *pakai bhattis* did not figure among the 292 units covered by the Supreme Court verdict of 1996! Perhaps for this reason, GAIL too did not envision supplying natural gas to *pakai bhattis* at the outset. Besides, at that point in time GAIL's experience was entirely at the large-scale commercial and industrial levels, whereas the *pakai bhattis* were unregistered units, very small in size, yet numerous and scattered across highly congested residential areas of the town. Although the 'spirit' of the Supreme Court's ruling clearly required all units located within the Trapezium to stop using coal, it remained freely available in the local markets and *pakai bhatti*s continued to use it as fuel. The local authorities – specifically, the UPPCB (Uttar Pradesh Pollution Control Board) – understandably could not initiate action against these units for three simple reasons.

1. Natural gas was not being supplied to *pakai bhatti* units.
2. No technology was then available for running *pakai bhattis* on natural gas.
3. *Pakai bhattis* formed the vital end-link in the bangle-making chain that provided the sole source of livelihood to tens of thousands of families.

No-gas zone units: tough choices

Having been prohibited from burning coal, and in the absence of assured natural gas supply from GAIL, coal-fired pot furnace units in no-gas zones were left with three options.

- Convert their furnaces to run on propane or LPG.
- Relocate their units to sites outside the Taj Trapezium.
- Shut down.

The first option was simply not practical. There were no ready technologies to operate pot furnaces on propane or LPG. Besides, setting up facilities to store propane and/or LPG required huge investments, far beyond the capacities of most pot furnace owners. Also, operating on these fuels entailed much higher fuel costs, and this would place units at a severe disadvantage against competitors using the relatively cheaper natural gas.

The second option – relocation – meant sale of existing factory plots in Firozabad, and reinvestment in land and infrastructure elsewhere. This too was practically impossible. In the changed scenario following the Supreme Court verdict, the value of land in Firozabad sharply fell. Therefore, sale of pot furnace sites no longer promised to fetch adequate money to purchase new sites outside the Trapezium. Even more important, glass-melting furnaces like the pot and tank furnaces were positioned at the very apex of the Firozabad glass industry. They produced the raw glass that was used in intricate chains of processes by hundreds of other small and micro units to manufacture bangles, beads, and other glass products. These smaller units were spread all across Firozabad. Relocation of pot furnace units would break the entire production chain—disrupting the work of all these smaller units and causing huge economic and social problems in the entire cluster. In this uncertain situation, the no-gas zone units continued to operate on coal.[14]

Change in project strategy

In order to address the new challenges following the Supreme Court ruling, the project was forced to revise its earlier strategy and modify its plans based on using natural gas as fuel, on the lines described below.

Pot furnace

The greatest pressure to switch from coal to gas-fired operation was being felt by pot furnace units. Hence, the project decided to develop and demonstrate a more energy-efficient pot furnace with a heat recovery system as earlier planned; but the improved furnace would be designed to operate on natural gas instead of coal.

Muffle furnace

The coal-burning *pakai bhatti*s were completely excluded from GAIL's natural gas network because of safety and infrastructural considerations. At the

[14] Subsequently, the 'gas' and 'no-gas' zone demarcations were changed in response to requests made by the local industry. At present (2007), almost all the tank and pot furnace units in the cluster are provided with gas connections.

same time, the spirit of the Supreme Court verdict was against the use of coke or coal in the Taj Trapezium. It was, therefore, vital to design and develop a gas-fired bangle-baking furnace for *pakai bhatti* units, which they could adopt as and when GAIL made natural gas available to them. The project, therefore, decided to conduct the design competition for an improved muffle furnace as planned earlier. However, participants would be asked to submit designs based on fuels other than coal or coke.

Local institutions

It was important for the project to get to know the institutions active in the Firozabad glass cluster, and if possible, to work with them in the course of its intervention. The institutions are listed below.

- **DIC (District Industries Centre)** The government of India introduced DICs in 1978 with a view to promoting industrial development in India at the district level. The DIC, Firozabad, was established after Firozabad became a district in 1989.
- **UPPCB (Uttar Pradesh Pollution Control Board)** The UPPCB is a statutory organization entrusted with the responsibility of implementing environmental laws and rules that are framed by the CPCB (Central Pollution Control Board). Its functions include monitoring and assessment of air and water quality, and enforcement of pollution control norms set for industry.
- **CDGI (Centre for Development of Glass Industry)** This is an R&D institution set up by UNIDO (United Nations Industrial Development Organization) and the Government of India to benefit and provide support services to the glass industry (Box 15).
- **FGCCI (Firozabad Glass Chamber of Commerce and Industry)** This was an association of owners of tank and pot furnace units in Firozabad.
- ***Pakai bhatti* associations** There were around 16 such associations, with their members drawn from the 800 or so operating *pakai bhatti*s in the Firozabad cluster.

Identifying partners and collaborators

The project worked in close cooperation with a number of partners during the intervention. The idea was to share the partners' diverse knowledge and expertise: that is, to pool individual competencies in pursuit of the project's goals. The interactions between the project and various partners are shown

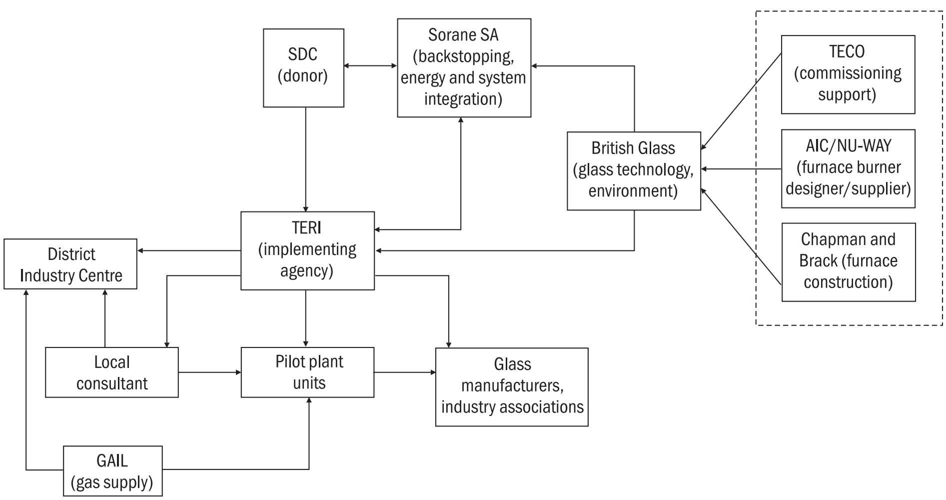
Box 15
CDGI—untapped potential?

The genesis of the CDGI (earlier known as the Centre for Improvement of Glass Industry or CIGI) dates back to 1984, when a committee was set up by the Government of India to investigate the reasons why large quantities of coal were being consumed by the glass industry. The committee recommended the setting up of a glass technology institute. The project was approved by UNIDO and the Government of India in 1991, and CDGI came into being.

As the name suggests, the aim of CDGI is to help the glass industry by providing technical assistance to improve quality, productivity, and efficiency, and by offering testing facilities and specialized training to entrepreneurs.

With its campus and laboratories in Firozabad, the CDGI was ideally located to provide help to the glass industry, particularly in the wake of the Supreme Court verdict of 1996. Unfortunately, however, over the years, the CDGI had not been able to generate credibility in the cluster. Glass industrialists viewed its activities as being too 'remote' from the practical problems faced by units in the cluster.

Figure 16
Competence pooling



in Figure 16. The principal partners are briefly described below.

- Pierre Jaboyedoff of Sorane SA, Switzerland, provided strategic inputs to the planning and implementation of various project activities. He gave advice in energy management and systems integration, helped identify and coordinate activities with international energy and environmental consultants, and provided support by way of backstopping.
- AIC (Abbeville Instrument Control Ltd), UK, helped in developing the concept and design of the new furnace, including its heat recovery unit (recuperator).
- Chapman and Brack, UK, provided guidance in constructing the crown of the demonstration pot furnace.
- TECO (Toledo Engineering Co. Inc.), UK, provided expertise in commissioning the recuperator for the pot furnace.
- British Glass, UK, provided expertise in glass technology. British Glass, along with other partners, finalized the conceptual and detailed designs of the pot furnace.
- NU-WAY, UK, supplied the burners for the demonstration pot furnace.

Local consultant

The project realized that for the intervention to be successful, it was important to find a local consultant to coordinate and supervise activities in Firozabad. The local consultant had to be a person who belonged to Firozabad; who knew glass technology well; and most important, who could undertake local liaison, supervise fabrication of the demonstration plant, and handle other related tasks. It was Viswadeep Singh who helped TERI identify a suitable person for the job—B C Sharma.

Sharma played a vital role in the intervention. As the project's representative in the cluster, Sharma worked alongside entrepreneurs, *mistrys,* and other workers, and helped bridge the gaps in understanding and communication between factory owners and workers on the one hand, and project staff on the other. He supervised the day-to-day construction of the demonstration plant, and helped find on-the-spot solutions to problems that arose. As described later, under the guidance of project staff, Sharma trained local masons to construct the new gas-fired pot furnaces, and with the help of the TERI team taught operators how to use instruments to monitor furnace performance in order to maximize operational efficiency.

Choosing a demonstration site

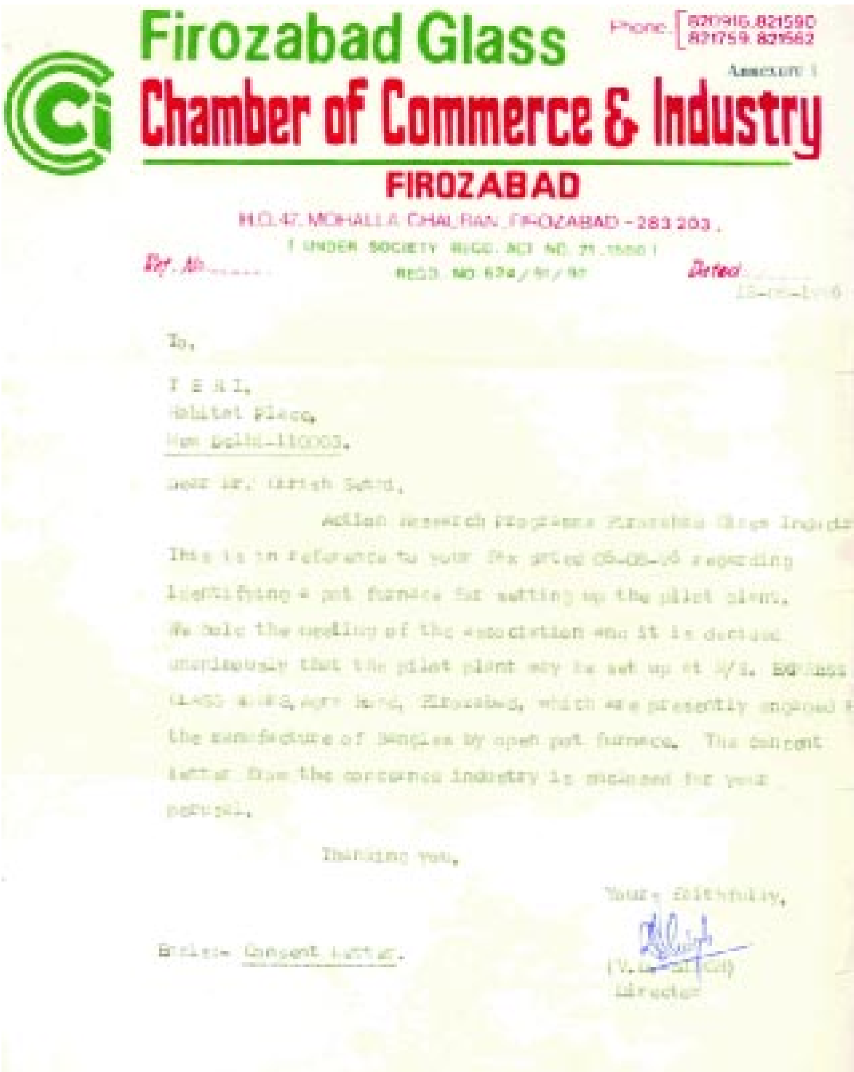
The sheer size of the traditional pot furnace (with its capacity of around five tonnes per day) ruled out the possibility of developing and testing a prototype gas-fired model off-site. The project had to construct and demonstrate the new pot furnace at an existing pot furnace unit in the Firozabad cluster.

To make the venture as participatory as possible, the project asked the FGCCI to identify a pot furnace unit among its members as a demonstration site. But the FGCCI was reluctant to do so, primarily because of the deep-rooted apathy and wariness among unit owners mentioned earlier. Besides, even though the project offered to meet all the costs of demonstration, it still called for commitments on part of the selected unit—in terms of time, labour, power, provision of a shed to work in, and so on. No unit was willing to make such commitments.

Yet, the FGCCI did not want to say 'no' to the proposal either! After all, the project was offering to develop and demonstrate gas-firing technology for pot furnaces that, if successful, promised to yield great benefits in the form of energy savings and improved productivity. FGCCI members, therefore, chose an easy way out—they asked the project itself to select a demonstration site! The impasse continued for several weeks. Finally, after a fruitless day-long meeting with FGCCI members in Firozabad, the project announced an ultimatum: if the FGCCI did not choose a pot furnace unit as a demonstration site within a fortnight, the project would cancel its plans to intervene in the cluster. The strategy worked! With the assistance of some gentle but firm prodding by Pierre Jaboyedoff of Sorane SA, Veena Joshi of SDC, Andrew Hartley (a specialist from British Glass), and Viswadeep Singh himself, the FGCCI chose a unit for demonstration of the new gas-fired pot furnace—Express Glass Works, owned by Mohammed Islam Khan (Figure 17). This factory was renowned in Firozabad for the exquisite red glass it produced for making bangles (Box 16) (Figure 18).

Subsequently, the project entered into a formal agreement with Express Glass Works to cover the demonstration project. As per the agreement, the project agreed to bear the hardware and construction costs of the gas-fired pot furnace and its associated systems, as well as production costs (including costs on account of energy, raw material, pot breakages and labour) during the trial runs and fine-tuning of the new furnace. On its part, Express Glass Works agreed to bear all production costs once the furnace was stabilized, and to buy back the new furnace at a concession after it had been successfully demonstrated. In addition, Express Glass Works assumed the

Figure 17
FGCCI letter identifying demonstration plant



Firozabad Glass
Chamber of Commerce & Industry
FIROZABAD
H.O. 47, MOHALLA CHAUBAN, FIROZABAD - 283 203.
(UNDER SOCIETY REGD. ACT NO. [illegible])
REGD. NO 624/91/92

Phone [illegible]

Annexure 1

Ref. No. .... Dated [illegible]

To,

T E R I,
Habitat Place,
New Delhi-110003.

Dear Mr. [illegible],

Action Research Programme Firozabad Glass Industry

This is in reference to your [illegible] regarding identifying a pot furnace for setting up the pilot plant. We held the meeting of the association and it is decided unanimously that the pilot plant may be set up at M/s. [illegible] GLASS [illegible], Firozabad, which are presently engaged in the manufacture of bangles by open pot furnace. The consent letter from the concerned industry is enclosed for your perusal.

Thanking you,

Yours faithfully,

([illegible])
Director

Encl:- Consent Letter.

responsibility of providing the land, shed, generator, and other infrastructure, and to bear the related costs.

Box 16
Blessing in red

My factory, Express Glass Works, is famous for its special quality of red glass. My grandfather, Bhooray Khan, set up the factory in 1914. My granduncle, Rustam Ustad, was skilled at designing bangles, and so for a while business thrived. One day, a stranger walked in to meet Bhooray Khan. He was haggard and dishevelled, yet articulate: obviously, a respectable man who had fallen on hard times. He asked Khan for a hundred rupees—a princely sum in those days! Always generous, Khan at once gave the stranger the money. In return, the man handed Khan a folded slip of paper. 'This is all I have left to give you in return for your kindness,' he said. 'Don't read it now…wait till I have gone.'

After the stranger had left, Khan opened the little scrap of paper and read its contents. The note carried a set of instructions on how to make red glass—the chemicals to be added, how and in what proportion they were to be mixed in the charge, even where the chemicals should be obtained from! He decided to try out the recipe. In those days, chemicals had to be imported from Britain. Khan placed the orders, and in due course, the chemicals arrived. The charge was prepared in accordance with the note's instructions, and under Khan's personal supervision. The pots were loaded, the furnace fired…and the reward appeared in the form of glass of the most exquisite shade of red. Never had glass of such a colour been made in Firozabad before. It was a unique hue; it still is!

In Indian tradition, red is a sacred colour. It is the colour of grace, of *suhag*, or sanctity of marriage. For the last 92 years, my factory has been the only one to produce this wonderful shade of red glass. The formula for making it remains a family secret; I learned it from my father, and in turn I have taught it to my sons. Indeed, that stranger repaid my grandfather's kindness in full measure. Till today, Firozabad knows my factory not as 'Express Glass Works' but as Bhooray Khan's factory!

Mohammed Islam Khan
Express Glass Works

Figure 18
Blessing in red: bangles of
Express Glass Works




Into the field

Gas-fired pot furnace

As described earlier, Express Glass Works emerged as the site in which to set up and demonstrate a gas-fired pot furnace. The project team had plenty of experience in conducting energy audits, and in designing and developing technological solutions for a number of diverse applications. However, the team lacked experience in glass technology. Indeed, there were no gas-fired pot furnaces anywhere in the world to serve as models for the proposed furnace. The only pot furnace models available were the existing coal-fired ones in Firozabad—but no formal drawings were available even for these furnaces! The methodology for constructing them had been developed over decades without written records; their design data and material specifications existed only in the minds of the master furnace builders—the local masons or *mistrys* (Box 17).

As a first step towards designing the new gas-fired pot furnace, it was necessary for the project team to examine the design, structural features, and performance of the existing traditional coal-fired pot furnace at Express Glass Works in some detail in order to identify measures that could be taken to increase energy efficiency. The team, therefore, performed a detailed energy audit to gather baseline data on the existing (12-pot) open-pot furnace. The audit revealed that the furnace operated at very low efficiency, with flue gases escaping from the furnace at a temperature close to 1000 °C. This indicated considerable scope for recovering heat and using it to preheat combustion air and increase furnace efficiency.

The specific fuel consumption of the furnace was estimated to be 5.6 Gcal/tonne of melt. The audit also revealed scope for making changes in the furnace structure itself to increase its life span and improve the overall

Box 17
How the traditional pot furnace was made

Mistrys usually took 30 to 45 days to make a traditional coal-fired pot furnace. First, material for the bed of the furnace was made with a moistened mixture containing equal proportions of powdered 'IS-8' refractory bricks and fireclay bricks. The wet mixture was allowed to stand for 15 days and then filled into a cavity made in the ground, where it hardened to form the floor of the furnace. Usually, the floor was about 12.5 cm thick, and the hardening process took at least 15 days in summer or 45 days in winter.

Thereafter, the *mistrys* made the base, pillars, and crown of the furnace with refractory bricks. The crown was usually constructed in four stages.

1 Erecting a temporary dome structure
2 Cutting IS-8 bricks into shape
3 Fitting the bricks into place with the help of clay mortar
4 Removing the temporary dome structure

The channel for flue gases was laid beneath the ground, leading up to a chimney about 20 metres away from the furnace. The flue gases were hottest near the furnace; hence, the first few metres of the channel were usually made of IS-8 bricks and the remainder of fireclay bricks. The draft (which determined the rate of flow of gases through the furnace) was controlled by removing or adding bricks in a grid of bricks – called *jaali* – provided in the flue gas path.

energy performance of the furnace. As with other traditional pot furnaces in the cluster, the life of the pot furnace used by Express Glass Work was usually no more than 10 to 12 months. The most common reasons cited for furnace failure/shutdown and low furnace life are listed below.

- The refractory material that made up the crown of the furnace was progressively weakened by the action of hot, corrosive gases within the furnace till eventually the crown collapsed.
- The flue gas channel became blocked over time—by molten glass as well as particulate matter. The blockages increased the pressure of gases inside the furnace – a potentially dangerous situation – and also reduced the temperature inside the furnace, ruining the quality of melt. It was not possible to remove blockages in the flue gas channel without shutting down the furnace.

Figure 19
Failed pots

- Every time a pot failed (Figure 19), molten glass flowed out of the damaged pot on to the floor of the furnace, where it ate away at the refractory lining in the central portion of the furnace floor. Because of this progressive destruction of the floor, the 'firebox' area of the furnace (that is, the area of the floor directly exposed to flames from the burning coal) increased over a period of time till a stage came when the flames directly touched the pots. The furnace then had to be shut down immediately.

From concept to design

The project considered the option of developing a smaller version of a tank furnace – known as a 'day tank furnace' – for use by pot furnace units. (CDGI had actually developed a laboratory version of a day tank furnace; but it had never been commercialized.) However, the idea was dropped because of one major disadvantage: the tank furnace would be able to produce only one colour of glass per batch, whereas pot furnaces are used to make glass of many different colours per batch.

The project team explored the possibility of modifying (or 'retrofitting') the traditional coal-fired pot furnace to make it suitable for gas firing, but was again confronted by a number of hurdles. For instance, the refractory materials used in making the new furnace had to be of much better quality than those used in the traditional furnace, to withstand the higher temperatures achieved with gas-firing. Such high-quality refractory materials were far more expensive and not easily available in Firozabad. Also, using new refractory materials meant that *mistrys* had to be trained in new skills and techniques to construct different parts of the furnace.

However, the greatest challenge to retrofitting arose from the fact that for optimal performance, the gas burner had to be positioned either on the side of the furnace firing tangentially, or in the crown of the furnace firing downwards. In either case, the traditional furnace had to be completely redesigned.

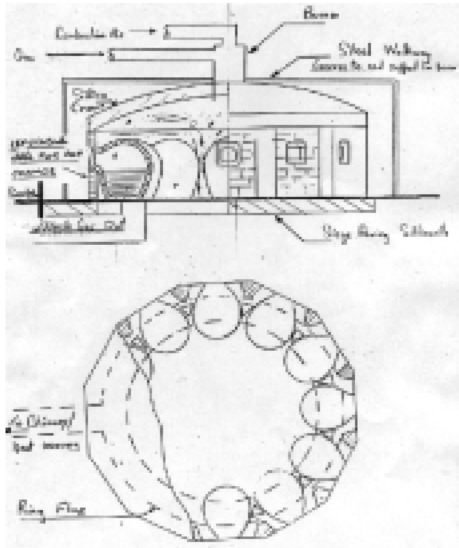
Having weighed all these factors, the project team decided that it was not practical to retrofit the traditional coal-fired pot furnace to operate on natural gas. That left the team with only one option—to design an entirely new kind of furnace from scratch.

Pierre Jaboyedoff, of Sorane SA, Switzerland, was asked to help. He looked all over the world for people who could develop the concept and design of a gas-fired pot furnace. He got in touch with Andrew Hartley of British Glass, UK. They in turn identified Jed Dogget and Mike Dogget, a father–son team who were then working with AIC (Abbeville Instrument Control Ltd), UK.

A group comprising Jed, Mike, Andrew Hartley, and Pierre met several times in Europe and in India, and discussed various possibilities. In the course of their discussions in Firozabad, Mike came up with what appeared to be a workable concept of a top-fired gas-based pot furnace. Team members from TERI joined the discussions, and the idea was further developed. Later, the team visited Firozabad, and Mike drew the first sketches of the new furnace at a meeting held in Islam's office and attended by project staff and several pot furnace entrepreneurs (Figure 20). The new furnace did not differ greatly from the traditional pot furnace in its walls and base. However, it had a hemispherical crown (unlike the traditional furnace, which had a more or less flat crown); and this crown had a heavy gas burner at its centre. The new furnace also had a device – called a 'recuperator' – placed in the flue gas path to recover heat from flue gases and use it to preheat combustion air. Mike provided the basic design of the recuperator as well. The project did a cost–benefit analysis in order to arrive at the right size and specifications for the recuperator (Box 18).

All the while, there was growing pressure on the pot furnace owners to convert to gas-based operation in keeping with the Supreme Court verdict. Besides the project team, other players too were making efforts to develop a gas-fired pot furnace.

Figure 20
Mike's sketches of
demonstration furnace



Box 18
Recuperator: recycling heat

The key to increasing the energy efficiency of the new gas-fired furnace lay in the recuperator. In essence, this device was placed in the flue gas path and hot flue gases from the furnace passed through it on their way to the chimney.

Air meant for combustion was blown at room temperature through a series of tubes set within the recuperator. As it flowed through the tubes, the air picked up heat from the flue gases and reached the furnace's gas burner at a much higher temperature

For the project team, the vital question was: to what temperature should the combustion air be preheated by the recuperator? On the one hand, a larger and more efficient recuperator would increase the temperature of preheated combustion air and hence improve energy efficiency by reducing gas consumption; on the other hand, the recuperator cost would go up as its size and efficiency increased! The team had to find a balance between these two opposing factors in order to determine the optimal size and design characteristics of the recuperator.

CDGI model

At the behest of the CDGI, a Turkish consultant designed and fabricated a pot furnace based on tangential firing of natural gas. However, this model failed during demonstration. Although few details were available about the design of this furnace, reports indicated that flames had emerged from the 'gathering holes' in the furnace walls during trial runs and made it very difficult for workers to draw molten glass through the holes. There were also unconfirmed reports that the crown of the furnace collapsed during trials. After this venture, the CDGI made no further attempts at developing a gas-firing technology for pot furnaces.

'Retrofitted' models: a quick-fix solution

There were entrepreneurs who saw a business opportunity in the crisis facing the pot furnace operators in Firozabad. One such entrepreneur was P M Patel, who came from the gas-rich state of Gujarat, where gas-fired industrial furnaces had been in use for years. He developed a gas-fired pot furnace (henceforth referred to as 'retrofitted' gas-fired furnace) that was a simple modification of the traditional coal-burning furnace (Figure 21). In effect, all Patel did was to replace the coal grate at the bottom of the traditional furnace with a locally made gas burner—an option that had been

Figure 21
Retrofitted pot furnace

considered and rejected earlier as unviable by the project! Combustion air was provided to the burner by means of a small, 5 HP (horsepower) centrifugal blower. The first Patel-designed furnace was set up at The Amrit Glass Works in 1999 (described later).

Another 'retrofitted' gas-fired pot furnace design, known as the 'Wesman' model, was almost identical to the Patel model except that it did not have a blower to provide primary combustion air. Other entrepreneurs developed similar designs for gas-fired pot furnaces. These retrofitted gas-fired furnaces did not have separate devices for heat recovery from flue gases. Nevertheless, they provided a quick solution to the Firozabad pot furnace owners' imperative need to switch to gas-based operations in accordance with the Supreme Court mandate. In the absence of any alternative, by the year 2000 many pot furnace units adopted some version of the retrofitted design.

Project approach: only the best will do!

The project was well aware of these developments. It had hoped to be the first in providing gas-based technology to pot furnace units, and therefore, regarded the spread of retrofitted gas-firing models with chagrin. The temptation to develop and offer a similar 'quick-fix' solution was strong; but the project decided that it must instead remain focused on designing and demonstrating the best possible gas-firing technology; one that would set a benchmark for gas-fired pot furnaces in future in terms of proven energy efficiency, technical viability, and quick payback on investment.

Fabrication/furnace construction

The shape and dimensions of the new furnace were arrived at based on Mike Dogget's initial concept of a top-firing furnace, and on the design that evolved during the group discussions that followed. The furnace was to be fired centrally by a gas burner positioned in the 'eye' of its crown. To support the heavy burner, it was decided to erect a metallic structure that could also serve as a platform to access the burner for maintenance/repair (Figure 22).

Furnace: the basics

Under the supervision of local consultant B C Sharma, in early 1997 Islam's masons began to construct the base and sides of the new furnace (Figure 23). After Islam had constructed a new factory shed to house the TERI-designed

Figure 22
Sketch of demonstration furnace showing crown and burner

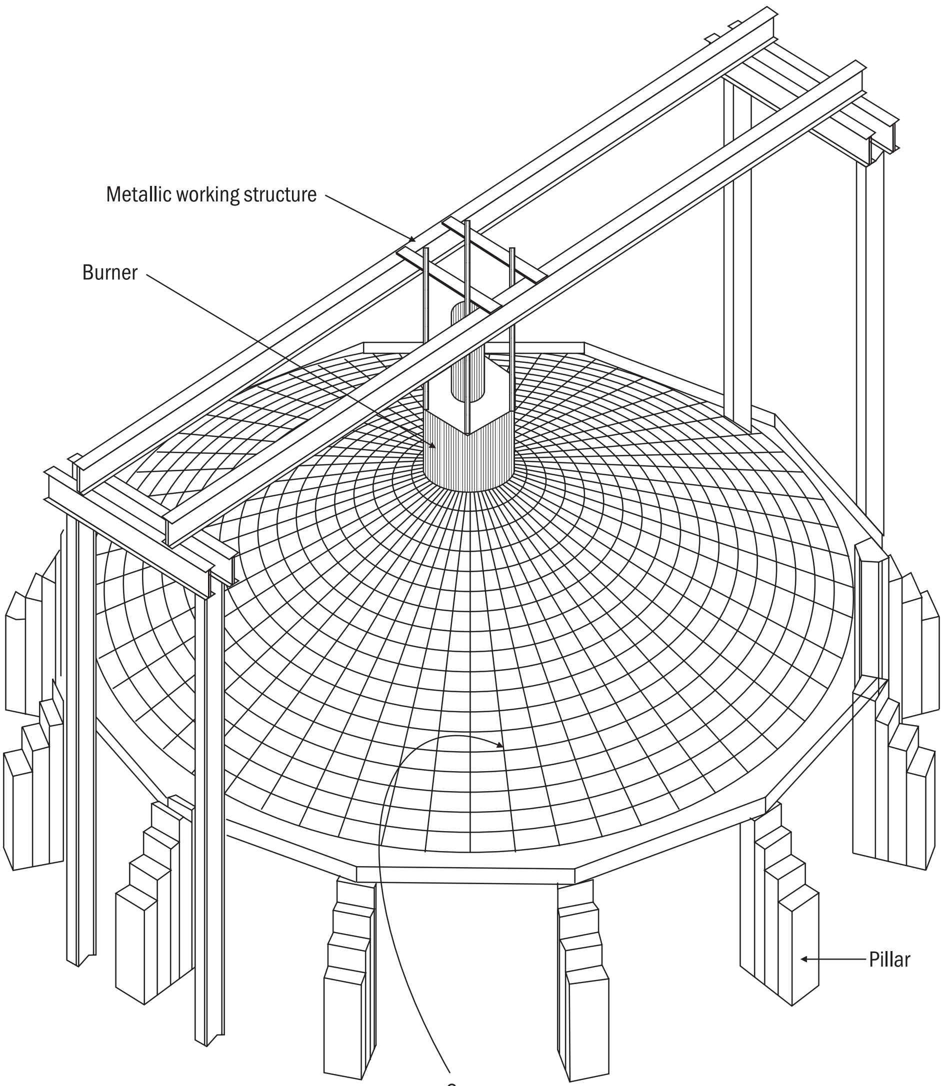


Figure 23
Construction of base and floor

(i) 25/2/1997

(ii) 27/2/1997

(iii) 2/3/1997

(iv) 4/3/1997

(v) 5/3/1997

(vi) 6/3/1997

Figure 23 (*Continued*)
Construction of base and floor

(vii) 9/3/1997

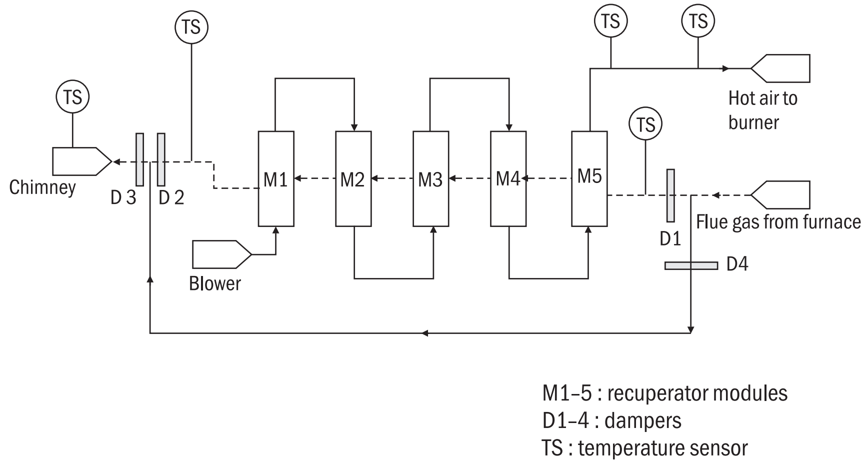
(viii) 26/4/1997

furnace, a two-metre deep pit was dug in the shed to accommodate the new furnace. The bottom of the pit was covered with layers of red bricks and mortar to make the surface level and provide a firm foundation for the furnace. The walls of the pit were lined with mortar. Thereafter, the floor of the furnace was made using layers of IS-8 refractory bricks with the topmost layer comprising blocks of sillimanite—a refractory material especially resistant to molten glass. Also, the floor was constructed so that it sloped towards the centre, where an annular drain was provided to collect any spilled molten glass from 'failed' pots. A hole was provided in this drain to facilitate the removal of the accumulated glass. The idea was that a burner could be placed at the mouth of this hole once each day to melt the accumulated glass in the drain and remove it. It was hoped that this would save the furnace floor from the kind of damage caused by pot failure in traditional furnaces.

Recuperator and gas line

As mentioned earlier, the recuperator held the key to improving the energy efficiency of the gas-fired pot furnace. Hence, great care was taken to get its design details right. The project team designed the recuperator in the form of five modules arranged in series (Figure 24). There were two main reasons for this.

Figure 24
Air and flue gas flows in recuperator



1 The 'hot' end of the recuperator, that is, the section closest to the furnace, would bear the maximum stress from the hot flue gases and hence suffer more damage than the 'cold' end. By making the recuperator in modules, the hot end module and cold end module could be switched after some time to reduce the extent of damage to the former and prolong the repair/maintenance cycle for the recuperator.
2 There were a total of 720 tubes (each one metre long) through which air passed in the recuperator. If all these tubes were stacked together as a single unit, cleaning the spaces between them would be extremely difficult. It was more convenient to undertake cleaning, maintenance, and repair work on separate modules, than if the recuperator was designed as a single large unit. A modular design also made the recuperator easier to handle.

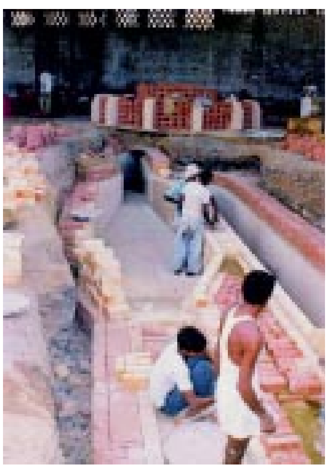
Preheated air from each module was collected in a 'wind box' and passed on to the next module. To ensure that the temperature of preheated air was kept below the maximum temperature allowed for the burner, a 'stack breaker' or 'false air infiltrator' was built into the flue gas channel before the recuperator. The stack breaker was simply a trap door that could be opened to allow cold air into the flue path (and thereby lower the temperature of flue gases) if and when required. The thermal design for the recuperator was examined and confirmed by Kvaerner Powergas, Mumbai. Calculations indicated that if it was fabricated according to Mike Dogget's design, the recuperator was capable of preheating air up to 600 °C.

From its earlier studies the project team was aware that in case of pot failure or furnace breakdown, molten glass often entered the flue gas path. To prevent molten glass from flowing into the recuperator and damaging it, a 'bypass line' was laid at a level slightly lower than the main flue gas path. This bypass line was normally kept closed, but could be opened when necessary to lead away any molten glass that might enter the flue gas path. Also, in case the recuperator had to be dismantled for repairs or maintenance work, the bypass line allowed flue gases to reach the chimney directly, obviating the need to shut down the furnace (Figure 25).

Because of the high temperature and corrosive nature of flue gases, the tubes in the recuperator had to be made of stainless steel—and choosing the right quality of stainless steel was another challenge for the project team (Box 19).

The next step was to find a firm capable of fabricating the recuperator. After exploring a number of options, TERI, along with Jed Dogget and Andrew Hartley, identified a fabricator—Gujarat Perfect Engineering,

Figure 25
(i) Platform for recuperator
(ii) Recuperator platform with bypass line



(i)

(ii)

Box 19
Test of steel

The tubes that made up the recuperator modules had to withstand corrosive flue gases at temperatures of 900–1000 °C. They had to be made of stainless steel, or SS. However, SS came in many grades. The question before the project team was: which grade(s) of SS should be used to make the tubes? On the one hand, high-grade SS would withstand the onslaught of the flue gases; but it was very expensive. On the other hand, low-grade SS was cheap, but might not survive the destructive effects of the flue gases.

It was vital that the demonstration plant performed well. The project team, therefore, decided to make the entire recuperator modules from the best quality stainless steel (SS-310 grade). Pierre also came up with an idea, based on which the team set up an ingenious experiment. A number of experimental tubes, made from MS (mild steel) and different grades of SS, were arranged within each module of the recuperator. The idea was to examine the condition of these different experimental tubes after trial runs had been completed. The team would then be able to assess the abilities of various grades of SS and MS to withstand the fierce onslaught of flue gases. In turn, this might reveal cheaper options to using SS 310 tubes in future replications.

The idea paid off. In July–August 2001, when the demonstration furnace was shut down for repairs and maintenance, the project team examined the experimental tubes in the recuperator. As described later, in all the modules, two categories of SS tubes – tubes made from grades SS-316 and SS-304 – showed no damage at all.

Vadodara. This firm undertook the detailed engineering work on the recuperator. When completed and assembled, the recuperator was three metres long and weighed over 2.5 tonnes (Figures 26, 27)! It was placed within the flue gas channel and covered with two layers of ceramic fibre insulation to reduce heat losses (Box 20).

A blower was required to push combustion air through the recuperator for preheating. The project wanted to use a high-efficiency blower, and hence acquired it from ABB (Asea Brown Boveri Ltd), one of the most reputed companies in the field. Express Glass Works did not have grid power supply despite Islam's repeated applications over the years to the State Electricity Board for a power connection. Islam, therefore, purchased a diesel generator set to run the blower.

Figure 26
Recuperator

(i) Side view (ii) Front view

Figure 27
Air line

(i) Blower to recuperator (ii) Recuperator to burner

Islam applied to GAIL and obtained sanction for a daily gas supply of 4000 Sm^3 (standard cubic metres). GAIL laid its pipeline up to the factory premises and installed a meter to record gas consumption. Under the project team's supervision, a separate pipe or 'gas line' was laid to take gas from the GAIL connection point to the demonstration furnace's burner. Initially, the project installed a fully automatic system – known as 'gas control skid' – to

Box 20
Ceramic fibre: a heat blanket

Heat losses from a hot surface (such as a furnace wall) can be reduced by increasing the thickness of the surface, and also by insulating the surface, that is, by covering it with a layer of material that does not conduct heat. Like refractory materials, a number of insulation materials are available with a wide range of properties for different applications. Ceramic fibre is a very effective insulator. It is a fluffy white cotton-like fibre that can be spun and fabricated into blankets, boards, strips, sheets, and blocks. Ceramic fibre products are extremely light and chemically stable, making them ideal for use in glass furnaces.

control the flow of gas and air to the furnace, and to optimize its combustion rate. However, discussions with Islam and his workers revealed an unexpected problem: using the gas control skid would also create a major hurdle in terms of smooth operation of the furnace. Hence, the project decided to do without the system (Box 21).

Box 21
Efficiency vs practicability: pros and cons of automatic gas control

In the traditional pot furnace, operators controlled the furnace temperature manually, by adjusting the draft, and by increasing or decreasing the rate at which coal was burned. They had little or no instrumentation to aid them; they drew upon experience alone. To optimize the rate of gas combustion in the new furnace, the project decided to use a fully automated gas control system obtained from Logicon Engineers (P) Ltd, Mumbai. In simple terms, this system regulated the gas–air mixture supplied to the gas burner by constantly measuring the temperature of the furnace (using a thermocouple set into a slot in the furnace crown). Whenever the furnace temperature went either above or below a certain level (preset by the operator), the gas control system automatically adjusted the amounts of gas and air flowing to the burner till the

(Continued...)

Box 21 (*Continued*)
Efficiency vs practicability: pros and cons of automatic gas control

preset temperature was achieved again. The automatic system was expensive (over 0.4 million rupees), but promised to increase fuel efficiency by eliminating human 'error' in maintaining steady temperature.

However, furnace operators pointed out a major practical problem. In actual glass melting operations, workers drew molten glass from the pot furnace on a continuous basis. If the furnace was too hot, it was extremely difficult – indeed, dangerous – for the workers to come close to the glass collection holes. Therefore, the furnace operators deliberately reduced the furnace temperature from time to time (by adjusting the draft and/or rate of fuel burning) to allow the workers to draw molten glass from the collection holes without too much discomfort! However, the proposed automatic gas control system would not allow them to perform this simple but vital procedure. Instead, it would maintain the furnace at a steady high temperature and make it difficult if not impossible for workers to draw molten glass from the collection holes!

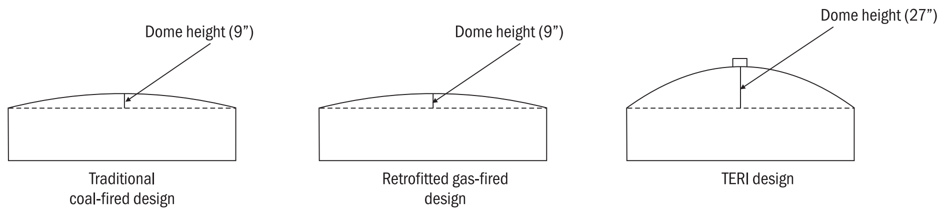
The project weighed the pros and cons of the matter, and decided to do without the automated system. Instead, as described later, the furnace operators were trained on how to optimize the gas–air mixture manually for a range of temperatures, based on a chart specially developed and calibrated for the purpose.

The crown

By November 1998 the demonstration furnace had been constructed up to floor level. The flue gas channel was ready, and the recuperator too had been assembled and was in position. While construction was going on, the project had identified vendors to supply the many pieces of equipment that the new furnace and its ancillary systems required. These had been transported to the factory, and their assembly into the demonstration system only awaited the completion of the furnace crown.

However, construction of the new furnace's rounded crown proved to be a formidable challenge. According to the project's design, the height of the new furnace crown had to be much greater (27 inches or 67.5 cm) than that of the traditional pot furnace (9 inches or 22.5 cm) in order to provide sufficient strength for longer life (Figure 28). Also, the crown had to be made from the

Figure 28
Crown shapes



best quality refractory bricks to ensure long life. No one, not even the local masons, had a clue on how the new refractory bricks were to be cut, or how to assemble them to make such a unique crown! For nearly a year the project had looked for someone in India who could build the required crown, but to no avail. In the meanwhile Pierre sought the assistance of contacts that he already had in the UK.

All the while, the pressure on the project team intensified. The team members were acutely aware that precious time was being lost. They knew that their efforts were being closely watched by other pot furnace owners in the cluster, many of whom had been skeptical about their venture from the very start, and who were progressively adopting the retrofitted gas-fired pot furnaces designed by Patel and other entrepreneurs. The team was also aware that Islam Khan himself was under enormous stress because of the delay. Islam’s agreement with GAIL for gas supply included a clause that if the buyer (Express Glass Works) did not draw gas within three months from the date on which GAIL was ready to commence gas supply, a penalty of 0.6 million rupees would have to be paid to GAIL along with interest at 24% per annum for the delayed period!

Yet, Islam never wavered in his support of the project’s efforts. ‘Indeed, I faced a great deal of cynicism from my fellow factory owners at that time,’ recalls Islam. ‘They kept telling me that I’d made a mistake in trusting the project and its new top-firing gas technology. But I kept my faith in the team.’ Viswadeep Singh, too, constantly advised his friend Islam to be patient when problems and delays arose during the fabrication and commissioning of the demonstration plant.

Finally, in April–May 1999, Pierre found the right person to construct the furnace crown. He was Roy Lee, a mason who had worked for several decades with Chapman and Brack, UK. Lee came to Firozabad and immediately plunged into the task. A dedicated and totally hands-on worker, Lee at once endeared himself to one and all (Box 22). Working with supreme confidence, he built the crown without drawings or notes of any kind to assist him (Figures 29, 30).

'When Lee finished the job, we were nervous about whether the crown was strong enough to support the heavy top-mounted gas burner, and voiced our anxiety,' recalls Islam. 'So Lee clambered on to the top of the crown and proceeded to jump up and down on it. "You see how strong it is?" he yelled. "Why, you could park a fully loaded lorry on this crown…it won't collapse!"'

Box 22
Heat recuperation... for Lee

It was the height of summer when Lee arrived to build the furnace crown. Initially, Lee stayed at a hotel in Agra. Each day he would leave early in the morning for Firozabad, work ceaselessly in the sweltering heat of the factory shed, and return to his room only late in the night. Inevitably, this punishing schedule took its toll. One morning, Lee did not show up at the factory. Inquiries with the hotel over phone revealed that Lee was very unwell.

Deeply concerned, Islam rushed across to Agra. He found a pale and exhausted Lee in his hotel room. It appeared that Lee had tried out some local variety of canned meat the previous day. This dubious diet, combined with accumulated stress and the fierce heat, had played havoc with Lee's metabolism and left him in an advanced state of dehydration. With his characteristic kindness and generosity, Islam bundled Lee into his car and took him back to his own house in Firozabad. Within a few days, Lee was restored to good health and cheer by clean and traditional home-cooked food!

Figure 29
Team spirit: Roy Lee at work

Figure 30
Crown construction

(i) Making a concentric red brick structure

(ii) Using bamboo and planks as support

Figure 30 (*Continued*)
Crown construction

(iii) Filling the structure with mud

(iv) Using a wooden leveller to give a uniform curvature

(v) Plastering the crown with mud

(vi) Fixing silica bricks

(vii) Lee tests the key brick

(viii) Washing the crown with silica mortar

Test firing with light diesel oil

Fabrication of the demonstration furnace was finally completed by June 1999. To check out the performance of the new system and to help choose the right kind of gas burner, the project planned to conduct a preliminary test run on the furnace with oil firing. The question arose: what kind of oil should be used?

In general, the choice of oil for a furnace is determined by its properties and composition. There are two kinds of furnace oils: heavy and light. Heavy oil is viscous, has a high sulphur content, and its viscosity has to be reduced by preheating before it is pumped to the burner. On the other hand, light oil is low in viscosity and sulphur content, and does not have to be preheated. Considering these factors, the project selected LDO (light diesel oil) as fuel. The choice of low-sulphur LDO also satisfied Islam; he had been apprehensive that the use of heavy high-sulphur oil for the test run might ruin the quality of his red glass.

An oil burner had been procured from NU-WAY, UK, for the LDO test run, and was mounted on the furnace crown. The LDO test-firing run started on 6 July 1999 with preheating of the furnace (Figure 31). It was decided to carry out the LDO test run without the use of the recuperator; hence, the bypass line was kept open during the test run, which was carried out over three days. The first two days were filled with challenges for the project team

Figure 31
(i) LDO burner on crown
(ii) LDO-firing under way

(i) (ii)

LDO – light diesel oil

BOX 23
Sometimes, 'top-down' works better

The top-down firing approach had never been tried out in pot furnaces in Firozabad (although there was a concurrent project by the CDGI – and led by a Turkish consultant – which had tried firing a furnace from the side with a kind of tangential burner). When operators started switching from coal to gas, most of them just replaced the coal-firing zone at the bottom of the traditional pot furnace by a gas burner. People were then convinced that this was the only solution.

So, when the time came to test-fire our demonstration pot furnace using LDO as fuel, a number of skeptics remarked that our top-to-bottom firing idea would never work. I was on holiday with family and friends when the actual test-firing took place in Firozabad. I was so anxious about the results that I used to keep in touch with the team regularly through my mobile phone. One night, when all the others were asleep, I got a phone call from the TERI team in Firozabad saying that the system had been test-fired, but didn't work to the satisfaction of the owners. I spent half the night making various sketches to try to figure out why the system had failed. I was still convinced that the system would work; but doubts had begun to fill my mind. Actually, after fine-tuning, the system was operated successfully one or two days later, and the owner was entirely satisfied with it....

—Pierre Jaboyedoff
Sorane SA

(Box 23). There were many 'bugs' to remove from the system. One major problem was the very high draft in the furnace, which prevented the charge from melting at all. Another difficult task was to adjust the burner controls to yield the optimum size of flame during the different stages of heating. Finally, these problems were resolved, and after three days of melting operations, the furnace was shut down on 22 July 1999 to assess and learn from the results of the test run. The following observations were made.

- The top-mounted 'Rotovac QH5' oil burner had built-in systems to control the length of the burner flame. As the burner was exposed to high radiant heat from the furnace, the controls got jammed and as a result, the flame became too long. This in turn led to flames emerging from the glass collection holes, causing great distress to the furnace operators and workers.

- After cooling the furnace and removing its sidewalls, it was found that nearly 40% of the supporting bricks in the crown (called 'sillimanite skewbacks') had developed cracks.

Data gathered during the LDO test run helped determine the specifications of the gas burner that needed to be used in gas firing. The optimal design for the gas burner was arrived at after consultations with Pierre Jaboyedoff and British Glass. It was decided to procure the gas burner too from NU-WAY, UK. The selected gas burner ('MPHA 60 nozzle mix' model) had the following features.

- It would be embedded in the crown (unlike the LDO burner which was placed on the crown).
- It did not have any built-in controls that might get damaged by heat.
- It would give a steady flame, and had the ability to operate with a wide range of air–gas mixtures (a high 'turndown ratio') and at low air/gas pressures as well.
- It could operate on preheated air at temperatures up to 700 °C.
- It had a removable inner assembly to facilitate easy maintenance.
- It was a low-pressure nozzle mix burner.

The test run with LDO helped familiarize the furnace operators and the TERI team with the various features of the new furnace before the actual trials with natural gas. Most of these features remained unchanged when the furnace was converted to natural gas firing; only the control mechanisms changed.

Examination of the damaged bricks in the crown revealed that they had not been shaped correctly and were of insufficient thickness. It was decided to replace them with thicker bricks, shaped so as to give greater strength. This proved to be a very challenging task for the team (Box 24).

TECO, UK, provided guidance while commissioning the recuperator. TECO's services were especially useful, because till then neither the project team nor the local industry had ever worked with metallic recuperators. Indeed, recuperation of waste heat was a totally new concept for Indian pot furnace entrepreneurs (although tank furnaces had regenerators, as mentioned earlier). For this reason, the TERI-designed pot furnace came to be known as 'recuperative furnace'.

Box 24
Rebuilding the crown

The crown of the demonstration furnace was made of silica bricks and IS-8 bricks. The principle behind using these silica-rich materials was simple: silica being the basic constituent of glass, even if these materials melted or corroded, the resultant debris would not affect the quality of glass in the open pots. The bricks that comprised the crown were arranged in concentric rows. The outermost row comprised supporting bricks called 'skewbacks' that were made of sillimanite. The skewback row was followed by three rows of IS-8 bricks, 22 rows of silica bricks, and the central block (called 'quarl') that housed the burner.

After the LDO test run, it was found that almost 40% of the skewbacks had cracked during the test-firing operation. These had to be replaced with stronger and thicker skewbacks. The central block too had to be replaced, because the quarl required by the gas burner differed in shape and size from that for the LDO burner.

Advice was sought from Roy Lee, of Chapman and Brack, UK, on how to go about removing and replacing the damaged bricks in the crown. Lee suggested an elaborate step-by-step procedure by which the complex task could be performed without disturbing other rows of (undamaged) bricks in the crown. However, there were two major practical problems in following this procedure.

1 The project would have to remain in constant touch with Lee for advice/guidance while performing the task. With Lee in the UK, it would be very hard to stay in communication or exchange relevant information with him over telephone or fax, especially given the complex nature of the task.
2 The task meant removal of several outer and inner rows of refractory bricks in the crown, as well as the central burner block. In effect, a substantial portion of the crown would have to be replaced.

After carefully considering the matter, the TERI team reluctantly decided it would be better to dismantle the entire crown, replace the damaged bricks/blocks, and then reassemble the crown. This was easier said than done! As described earlier, Roy Lee had come to Firozabad, built the crown almost single-handedly and without any notes to guide him, and returned to UK without leaving any written details about how he had gone about the complex task of cutting and placing the various kinds of bricks and blocks. The project team, therefore, had to figure out and record exactly how Lee had built the crown – in effect this was a 'reverse engineering exercise' – before making any attempt at dismantling it!

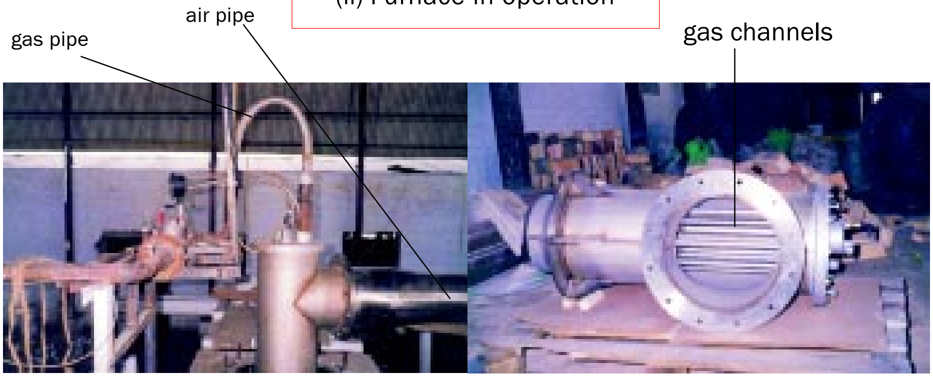
The team devised its own method to do the dismantling job in consultation with the local masons. The space below the crown was filled with straw to prevent breakage of bricks in case they fell during removal. The bricks were numbered, so that they could be replaced in the same positions later. The central block was first removed. Thereafter, the other bricks were removed row by row moving outwards. New skewbacks were cut into the desired shapes, and the crown was finally reconstructed following Lee's original procedure.

Demonstration: gas-firing

The crown was reconstructed in December 1999, the gas burner was mounted in its position in the central block, and the furnace was commissioned in February 2000 (Figure 32). Preheating the furnace began on 12 February 2000. To measure the temperature inside the furnace, a thermocouple was placed with its tip inside a pot. When the temperature reached 1000 °C, the crown was covered with a layer of ceramic blanket (Figure 33). The process was repeated at intervals of 48 hours till three layers of ceramic insulation covered the crown. By this time the furnace was running at melting temperature.

A major challenge for the project team was to find out the rate at which gas should be burned – during the preheating stage as well as during the melting operations that followed – so that the charge in the recuperative

Figure 32
Demonstration
(i) Close-up of burner
(ii) Furnace in operation



(i)

(ii)

Figure 33
Ceramic fibre being laid on the crown

furnace could be heated at the same rate as in the traditional coal-burning pot furnace. This was vital, as the quality of glass depended on both temperature and rate of heating. The problem was that there were no written-down heating schedules for the coal-fired furnaces, or indeed any other kind of data to go by. No records were kept by firemen when they operated the traditional pot furnaces. The firemen judged furnace temperatures, and correspondingly charged the coal during the melting operations, without any instrumentation or written data to guide them. They depended entirely on traditionally acquired wisdom, experience, and the power of observation (Box 25). Hence, the project team had to arrive at a gas flow/preheating and melting schedule for the new furnace based on a 'hit and trial' method during the first few days of commissioning the plant. Annexure 2 describes how the team succeeded in performing this complex task.

'The most nerve-racking part was the furnace heat-up phase, and adjusting the tension in the tie rods to take care of the expansion of the crown,' recalls Mohit Dua, who was then with TERI and a key member of the project team. 'I was so nervous during this phase that I spent many sleepless nights right next to the furnace so that I could check on it every few hours. Thankfully, it was winter, and the furnace provided nice warmth! When we got over the preheating phase, the furnace operators had to get used to adjusting the burner to control temperature during the different phases of operation. This was a new experience for them. They were used to coal-fired furnaces, in which they would estimate the temperature by observing the colour of the flame. Now, they had to learn to read a thermocouple installed in the furnace wall!'

Box 25
Traditional wisdom:
the colours of heat

The quality of glass depends critically on the rate of heating of the pot furnace and its temperature at different stages. Yet, in the traditional coal-fired pot furnaces, firemen did not have thermocouples or any other temperature-measuring devices to help them measure furnace temperature. Instead, they observed the colour of the furnace interior, used that as the basis to judge its temperature, and adjusted their coal firing rates accordingly to increase or decrease the temperature as dictated by their experience! The chart below gives a rough guide on how temperature can be judged by the 'colour of heat'.[15] It may be noted that in a traditional coal-fired pot furnace, the temperature of the glass melt was usually kept around 1250–1300 °C.

Colour of furnace interior	*Temperature* (°C)
Initial red	500–550
Dark red	650–750
Cherry red	790–800
Bright red	850–950
Yellow	1050–1150
Initial white	1300
Full white	1500

Many-hued challenges

As mentioned earlier, Express Glass Works was famous throughout the cluster for the unique quality of red glass it produced to make into bangles. For the project team, the success of the demonstration meant much more than merely proving that the recuperative furnace could improve the efficiency of the glass melting process. Far more important, the new furnace had to be capable of producing precisely the same exquisite shade of red glass that was the hallmark of 'Bhooray Khan's factory'! When glass was first drawn out of the demonstration furnace on 26 February 2000, its quality was excellent in terms of colour as well as clarity. However, almost immediately thereafter, small bubbles started appearing in the glass—a major problem that had to be addressed at once (Box 26).

'We asked TECO (Toledo Engineering Co.) to advise us on how the problem could be resolved,' recalls Islam. 'TECO suggested detailed measures to remove the bubbles—changing the amounts of arsenic, nitrates, and so on in the charge. But these measures would have entirely changed the colour of the

[15] Source: TERI. 2000. **Estimation of furnace parameters,** p.15. New Delhi: TERI [Report number 99CR44]

Box 26
Bubble trouble

When a batch of glass is melted, bubbles are formed in the molten material by the volatile compounds released from the batch materials. In particular, the carbonates release large volumes of CO_2 (carbon dioxide). Atmospheric air too may become trapped in the batch materials, and eventually be released in the form of bubbles. If they remain in the melt, small bubbles are called 'seeds' and large bubbles are called 'blisters'. The presence of bubbles mars the appearance of the glass, and so it is important to find ways to get rid of them.

Large bubbles rise through the molten glass quickly and easily, but very small bubbles may take up to a few weeks to rise to the surface of the melt. Interestingly, large bubbles tend to 'collect' smaller ones as they rise. Hence, an effective way to get rid of small bubbles is to create quantities of large bubbles at the right stage of firing! This process is known as 'fining' or 'refining'.

Usually, fining involves the addition of certain chemicals to the melt to stimulate convection currents in it, bring the bubbles to the surface, and ensure that a homogenous glass is produced. A common practice is to add a combination of arsenic oxide, antimony oxide, and potassium nitrate to the batch. These fining agents release oxygen into the melt late in the firing operation, and this helps the batch materials in absorbing the bubbles that are present. However, fining agents may also alter the colour of the glass and ruin the quality of the end product.

Another way to get rid of bubbles is to vary the furnace temperature in a controlled manner. This increases or decreases the density of the melt, helping the bubbles rise to the surface. Addition of small quantities of calcium fluoride to the batch has a similar effect as it reduces the viscosity of the melt.

glass, so I rejected their advice!' The bubbles were eventually reduced to acceptable levels by fine-tuning the melting schedule of the furnace.

In the meanwhile, though, the red colour of the glass itself began to show inconsistency. 'That was another really serious problem,' recalls Islam. 'Red is the most sensitive hue in glass-making, and red glass is my unit's speciality!' Many attempts were made to fix the problem—by varying the batch composition, by changing the method of adding the chemicals that imparted the red colour—but without success. After nearly four weeks of fruitless struggle, it was Islam himself who finally found the answer. 'I realized that glass melting is best achieved in a reducing atmosphere, that is, in an atmosphere rich in carbon,' he explains. 'In the traditional coal-burning pot furnace, unburned carbon from the coal creates a reducing atmosphere inside the furnace. But there is hardly any unburned carbon inside the much cleaner and hotter gas-fired furnace. So, after all other attempts to tackle the problem failed, I tried adding small quantities of bitumen to the pots at different stages of melting…and sure enough, I finally succeeded in getting back the desired shade and quality of red glass!' Indeed, it was a victory—for Islam, as well as for the project team (Box 27).

Box 27
A red-hot e-mail…

'Red bangles obtained!!'

These were the exact words I used as the 'subject' of an e-mail I sent to Pierre Jaboyedoff in Switzerland on 26 February 2000. I sent that e-mail from an Internet café in Agra at around 9 p.m., using my Hotmail account. It was probably the first and last time I used this personal e-mail account for an official purpose.

I have vivid memories of that evening even now. Certainly, there was joy that our gas-fired pot furnace had been successfully demonstrated; also, there was immense relief from the tension that we in the project team had been undergoing for a few months just prior to the commissioning of the furnace at Express Glass Works. Although we had taken all the precautions that we felt were required during the construction of the furnace, there was always some inherent apprehension regarding the success of our venture.

One main reason for our nervousness was the high level of expectations Islam had from our team's efforts. In fact, Islam had actually shut down his existing coal-fired furnace in anticipation of our success, and his entire business – including the fortunes of nearly 150 workers employed by his unit – depended on the outcome of our efforts. That was of course the immediate concern. The other major reason for our anxiety was the fact that the entire Firozabad glass industry was looking eagerly at us. The technology that we were demonstrating had not been tried out anywhere else in the world; the results of previous attempts by a few others at improving this technology were not encouraging; we had not done any lab trials; above all, we were trying to bring about positive changes in a technology that had not undergone any significant change for over a hundred years.

Looking back now, I can say that I was indeed overjoyed that February night when I sent the e-mail to Pierre. But I am even more contented now, when I see requests for adoption of the TERI design coming from those very entrepreneurs who were initially skeptical about our venture! This has been a long and hard journey for us…

Girish Sethi
TERI

Troubleshooting and fine-tuning

The furnace was thereafter run continuously till May 2000, when it became apparent that the floor of the furnace was suffering progressive damage and needed repairs. However, all of a sudden, a far more serious problem surfaced. The temperature of preheated air from the recuperator fell drastically in the span of a few weeks, greatly reducing the efficiency of the furnace. The team tried several methods to solve the problem, but without success. Not only did the efficiency of the furnace plummet – much to the dismay of Islam – but also the team was unable to fathom the reasons for the drop in preheat air temperature. Slowly, it became obvious that there was something wrong inside the recuperator; but to investigate what was wrong, the recuperator would have to be dismantled, which meant that the furnace would have to be shut down! For the project team, this was indeed a disheartening prospect—particularly so soon after the successful demonstration, and in the light of the trust Islam had reposed in the team's efforts.

By sheer coincidence, however, a section of the bangle-making workforce suddenly decided to go on strike in early June 2000. The strike forced all the glass units in Firozabad to shut down. The enforced shutdown of Express Glass Works allowed the project team to dismantle the new furnace system, including the recuperator, and carry out the required investigations, repairs, and cleaning operations without attracting any undue criticism of the system's performance.

Upon dismantling the recuperator, the team at once discovered the cause of the problem—dust! The raw flue gases that emerged from the pot furnace contained very high levels of particulate matter and volatile chemicals—a fact that the project team had not taken into account while designing the recuperator. Indeed, no one had envisaged this problem—neither TERI, nor Mike, Islam or any other entrepreneur or furnace operator! Inevitably, the particulates and volatile substances had deposited themselves over time on the outside of the combustion air tubes within the recuperator (Figure 34). As the layers of deposits grew progressively thicker, they posed increasing resistance to the flow of flue gases—leading to a sharp fall in air preheat temperature (Box 28).

After reconstructing the furnace floor and cleaning the recuperator modules, the furnace was restarted in August 2000 and run continuously and successfully till July 2001, when it again became clear that the furnace floor had become damaged. After shutdown, it was found that a number of sillimanite blocks on the furnace floor had got dislodged, and that molten

Figure 34
Cleaning the recuperator modules

glass from failed pots had damaged the IS-8 firebricks below these blocks. Molten glass had also entered the bypass line of the recuperator, where it had cooled and hardened, blocking the line (Figure 35).

The bypass line was cleaned. The furnace floor was reconstructed, but the problem of damage caused by molten glass continued to recur. The project sought expert advice from the refractory suppliers – Special Ceramic (P) Ltd, Delhi – and other ceramic specialists to address the problem, specifically, to identify better refractory materials that could be used for surfaces that came

Figure 35
(i) Damaged furnace floor
(ii) Solidified glass melt blocking the bypass line

(i) (ii)

Box 28
Recurring deposits—
and cleaning them up!

From 6 March to 5 May 2000 (that is, for nearly two months) the demonstration furnace operated normally. Thereafter, a sharp and unexpected increase was observed in the gas consumption rate. This was matched by a sharp and continual drop in the temperature of preheated air being fed to the burner from the recuperator. By June, the temperature of preheated air had fallen from a high of 600 °C to barely 125 °C! This severely affected the performance of the furnace. Islam was understandably very upset at this development.

I, along with Somnath and Mohit (my TERI colleagues), spent several days at the site, and tried all kinds of measures to resolve the problem (rechecking the thermocouples, altering the air–gas ratios at the burner, increasing and decreasing the flow rates, and so on) but to no avail. We were baffled. Clearly something had gone wrong in the recuperator. We knew we had to open it up to find out what was wrong...but to do that we would have to shut down the furnace!

This was a really discouraging prospect. We had commissioned the system just a few months earlier, and it had performed superbly since then—much to the delight of Islam, who had reposed complete faith in our efforts. But now, with no idea what was wrong and with Islam getting more and more agitated with each passing day, we steeled ourselves to shut down the furnace.

Just then, a section of the bangle-makers in Firozabad (the *judai* workers) went on strike, forcing closure of glass units all across the cluster. The strike, and the forced closure of Islam's factory, could not have been better timed for us! We shut down the furnace, opened up the recuperator...and were awestruck by the sight that greeted us. Instead of gleaming rows of metal tubes arranged in modules, all that we saw was a thick wall of greyish-yellow dust! We realized that this dust had come from inside the furnace; that it had been carried by the flue gases and deposited inside the recuperator modules, layer upon layer, till the annular spaces through which hot flue gases flowed had become completely choked by thick deposits. These deposits had hardened over a period of time till they blocked the flow of flue gases through the recuperator to the chimney. As a result, the recuperator had become ineffective in preheating combustion air. Also, build-up of flue gases had increased the pressure inside the furnace, making it difficult for the operators to work on the furnace.

This was something we had never anticipated, nor been warned about, while designing the recuperator! The question was: how were we to clean up the modules?

Various methods were tried to remove the deposits – scraping,

(*Continued*)

Box 28 (*Continued*)
Recurring deposits—
and cleaning them up!

washing, hosing down with jets of water, and so on – but the process was slow. Pierre happened to visit Firozabad at that time. He decided to use a heavy-duty compressed air blower to force the deposits out of the modules. The equipment was procured and duly set up; Pierre turned on the blower—and in an instant disappeared from view behind a dense cloud of fine chemical dust. 'In the heat of the moment, I had forgotten to wear a protective mask,' recalls Pierre. 'I should have known better!' Upon his return to Switzerland, Pierre developed a persistent cough; after a series of tests, doctors opined that his cough had been brought about by inhalation of dust containing arsenic and other toxic metals. Pierre was fortunate to have escaped more serious harm.

Indeed, the compressed air blower was most effective in removing the deposits quickly. However, it was expensive to hire or purchase a compressor, and in any case manual labour would be required to rake away the deposits after cleaning the modules. Hence, we decided that manual cleaning, by using metal strips to scrape away the deposits, was a better option for entrepreneurs. Later, we made this simple technique a part of regular maintenance work, with cleaning of modules to be done once every 20 days.

Girish Sethi
TERI

into direct contact with molten glass. Finally, the furnace floor was reconstructed using blocks of zircon-mullite (known as 'Zirmul'). Also, in place of the annular drain earlier built into the centre of the floor, the new furnace floor was provided at its centre with a 35-cm-deep circular pit for collecting molten glass. The pit was made from specially cast Zirmul blocks by local *mistrys* under the supervision of ceramic experts (Figure 36).

The furnace was restarted in August 2001. Its performance was closely monitored, and the results were found satisfactory in terms of energy efficiency as well as product quality. The basic cost of the TERI-designed furnace worked out to around 3 million rupees (compared to around 1 million rupees for the retrofitted furnace). However, the energy consumption of the project's furnace was 16.5 Gcal/day, as against 39.4 Gcal/day in the traditional coal-fired pot furnace. This represented a 58% reduction in energy consumption, of which around 28% came from heat recovery alone. Estimates by the project team indicated that the recuperative furnace was also 34%–38% more energy efficient than the retrofitted gas-fired furnaces (that is, the pot

Figure 36
Floor reconstruction

(i) Circular Zirmul block being laid for central well

(ii) Central well completed

furnaces that had been retrofitted according to Patel's and other entrepreneurs' designs). This translated into considerable savings in fuel costs for Islam, and vindicated the project's decision to develop the best possible gas-firing technology as a benchmark for the glass industry (Box 29). TERI also

Box 29
Patience pays off

When my gas-fired furnace showed all kinds of teething problems, I thought: 'What a headache this furnace has become!' But after a couple of months, its functioning became satisfactory. I now spend around 20 000–22 000 rupees per day on gas. The people who use retrofitted gas-fired furnaces spend 25 000–30 000 rupees per day. The fuel saving is, therefore, around 20% to 30%. In a small-scale industry, that's a lot of money; a saving of 30% is really large. Second, the working of the furnace is very smooth. The temperature can be regulated easily, and the burner and recuperator have a life of more than 10 years!

The cost of making a retrofitted gas-fired furnace is 1 million rupees, and that of the TERI furnace is 3 million rupees. But in the case of the TERI furnace, you get the payback within two years. This is because it yields a saving of something like 5000–6000 rupees a day...or 1.8 million rupees to 2 million rupees in a year.[16]

Mohammed Islam Khan
Express Glass Works

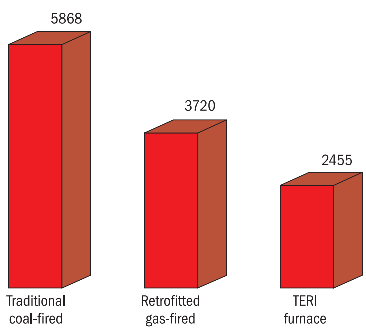
[16] These figures are as quoted by Islam in the film *Changing the Convention* (TERI 2005). However, at today's costs the payback period for the TERI-designed furnace works out to just around six months, on the basis of prevailing gas prices.

received an award of merit from the Consultancy Development Centre for its demonstration furnace (Figure 37).

The project team trained furnace operators at Express Glass Works in monitoring and operating the new furnace. Instruments were set up to measure and monitor various parameters of the furnace, such as temperatures at various locations within the system; rate of gas consumption; and so on. The unit workers were taught how to maintain an optimum air-to-gas ratio; how to maintain a logbook in which to record their observations on a regular basis; and how to take corrective measures in case measurements deviated from the standard norms.

With the successful demonstration of the recuperative furnace and validation of its superior performance, the project was hopeful that replications would soon commence. However, as described later, it was a long time before the first replication took place.

Figure 37
(i) Performances of different pot furnaces
(ii) Certificate of Merit



(i) Energy consumption (kcal/kg melt)

(ii)

Gas-fired muffle furnace

Participatory design competition

In 1998, even as efforts were on in full swing to set up the demonstration gas-fired pot furnace at Express Glass Works, the project team conducted a design competition to help evolve designs for a *pakai bhatti* that could be run on fuels other than coal or coke. The exercise was intended to be as participatory as possible, and the structure of the competition was based on innovative ideas from Pierre (Box 30).

A brochure was prepared and distributed among various technical institutes, engineering colleges, manufacturers, entrepreneurs, and R & D institutions (Figure 38). The brochure gave details regarding the traditional coal-burning *pakai bhatti*, explained why it was imperative for the *pakai bhatti* operators to switch from coal/coke to alternative fuels; and invited participants to design muffle furnaces that could run on alternative fuels with maximum energy efficiency and minimum pollution (Box 31). The brochure announced cash awards for the best three entries, which were to be selected by a core team comprising experts from IIT (Indian Institute of Technology), Delhi; Sorane SA; British Glass; and TERI. It also mentioned that pilot plants based on the winning designs would be set up in Firozabad, and TERI would bear the cost.

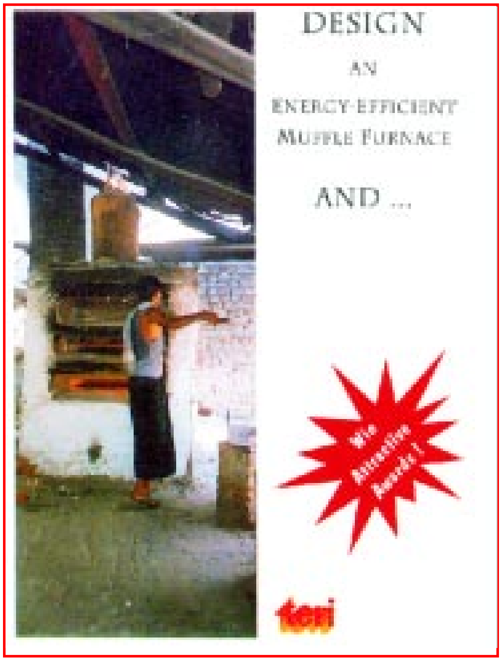
Box 30
Designing the competition

Around the time when the idea for the design competition came up, I was also working with TERI's thermal gasifiers team.[17] Specifically, I was seeking manufacturers who had the potential and wherewithal to make equipment for biomass gasifier systems and other equipment for the small-scale sector. So, I saw the design competition as a possible way by which to seek out such manufacturers. As it turned out, one such manufacturer emerged from among the participants in the competition—Dhananjay Navangul of Dhanaprakash Industrial Corporation, Miraj.

Pierre Jaboyedoff
Sorane SA

[17] See Mande S and Kishore VVN (eds). 2007. ***Towards Cleaner Technologies: a process story on biomass gasifiers for heat applications in small and micro enterprises***. New Delhi: TERI

Figure 38
Brochure for design competition



Box 31
Features of *pakai bhatti*

'The traditional coal-based *pakai bhatti* has dimensions of 1440 × 1440 × 1830 mm.... The temperatures in the trays as measured are 400 °C, 605 °C, and 785 °C in the top, middle, and bottom tiers respectively. Bangles arranged on a steel tray are first baked in the top tier for about 55–60 seconds, on the middle tier for 55–70 seconds, and finally, on the bottom tier for 85–105 seconds. There is no temperature-measuring device, and the actual baking time is decided by the operator based on his experience.

'The furnace operates on natural draught. Fuel (coal/wood) is fed over a fixed grate at the bottom of the furnace. The hot flue gases flow in a zigzag path around the tiers before leaving the chimney at around 880 °C... the present cost of the furnace is around 12 000 rupees.'

Extract from brochure for Design Competition, 1997/98
TERI

A total of 13 entries for the competition were received from various parts of the country. The participants included engineering colleges, manufacturers, and operators in the Firozabad cluster. To assist in evaluating the entries in terms of heat efficiency, the project sought the assistance of Prof S C Mullick of IIT, Delhi. Mullick, an expert in heat transfer, examined each of the submitted designs in detail and assessed them against the criteria set by the project for parameters such as fuel efficiency and heat losses on various counts.

The entries varied greatly in terms of furnace design, structural materials used, fuel characteristics, and so on. Besides, the estimated costs of various components (for instance, of the furnace bodies, chimneys, trays, and insulating materials) varied considerably, not only from one participant to another but also from the more realistic costs as estimated by the project team. Hence, in order to make a fair and realistic comparison of the different entries, it was necessary to 'level' the costs of the different designs. This complex task was assigned to A K Saha, a postgraduate mechanical engineer from IIT Kharagpur, with experience in engineering design.

The separate analyses by Mullick and Saha had to be combined in order to grade the entries according to overall merit and select the best three options. However, from August 1998, the project team became totally occupied in setting up the demonstration gas-fired pot furnace at Islam's factory, and it was only in late-1999 that the best three entries in the design competition could be identified and formally declared (Figure 39).

Figure 39
Design competition award

The awardees were the following.

- Dhananjay Navangul (Dhanaprakash Industrial Corporation, Miraj)
- B C Sharma (Glass Consultant, Firozabad)
- CDGI (Firozabad)

The first two designs were similar; the furnace in each case resembled a tunnel kiln. The CDGI design was based on a modification of the traditional coal-fired *pakai bhatti*, incorporating gas burners.

Preliminary trial versions

The entries received in the design competition, including the winning three designs, lacked detailed engineering drawings and specifications that were necessary to construct pilot plants. There were also anomalies in them that needed to be ironed out. As a first step, the project developed detailed and more accurate configurations for each of the three selected entries.

The next step for the project team was to find a site where it could develop, fabricate, and do preliminary tests of gas-fired muffle furnace models based on the winning entries. The most important criteria for selection of a site were that it should have a gas connection, and sufficient extra gas to ensure that enough was available for the trials. The tests had to be conducted discreetly, for they involved trying out concepts, getting data, experimenting with different materials and models, and so on. Viswadeep Singh promptly offered space, free of cost, in his own tank furnace factory – Electronic Glass Works – for the preliminary tests. A shed was erected in his factory to accommodate the test models, and a pipeline was laid to supply gas for the project's use.

As with the design competition, the project wanted to develop the gas-fired muffle furnace in a participatory manner. This meant working closely with experienced *pakai bhatti* operators during the preliminary trials. Initially, when studying the working of the traditional coal-fired *pakai bhatti*, the project team had worked with a *pakai bhatti* owner named Akhilesh Kumar Gupta. Local consultant B C Sharma identified another *pakai bhatti* owner Foren Singh to assist and advise the project team during the preliminary trials. Along with his workers, Foren Singh helped the project team in fabricating and testing a number of versions of gas-fired muffle furnaces. The contributions made by these local operators and workers were extremely important to the exercise. At every stage they expressed their opinions – positive and negative – about the models in terms of design, performance, and convenience of operation; pointed out aspects that needed improvement and/or rectifications, and made suggestions on how these could be done; and assisted in carrying out the required modifications using local materials and skills (and hence, at minimal cost). Foren Singh's inputs in particular were invaluable in making and modifying structures and components, and in operating the prototype versions of the furnace.

The project team built and experimented with two basic kinds of gas-fired muffle furnaces at Electronic Glass Works: (1) tunnel-type, based on the first two winning entries, and (2) traditional *pakai bhatti* design, based on the third winning entry. Annexure 3 gives a brief description of the work done in developing these prototype muffle furnace models in order to conduct extended field trials on them later. Repeated tests were conducted on the models using different burner types, burner arrangements, combustion chamber and flue path configurations, tray settings, and (in the case of the tunnel furnaces) methods of pushing the trays down the tunnels (Figure 40).

The results of the preliminary trials were evaluated on an ongoing basis. The prototype tunnel furnace proved to be significantly more energy-efficient with higher throughput of bangles, but there were problems faced in moving the trays along the tunnel. Also, the bangles within a tray were not baked uniformly as the tray moved from one end of the tunnel to the other; this led to inconsistencies in quality within a batch of bangles. Another major issue arose from the fact that different types of bangles required different lengths of time and temperatures for annealing; this made it very difficult to use the tunnel furnace model for annealing bangles of different types in one run. Most importantly, the *pakaiyas* found it hard to work with the tunnel design, as it differed radically from that of the traditional *pakai bhatti*. In particular, the *pakaiyas* complained that they could not see the bangles as the trays moved through the tunnel; this made it difficult for them to judge whether and when the bangles were sufficiently baked!

In view of these numerous problems, the team kept the idea of developing a gas-fired tunnel furnace in abeyance, and instead focused its efforts on developing an energy-efficient muffle furnace based on simple modifications of the traditional *pakai bhatti* design.

After exhaustive experiments and tests, three versions of gas-fired muffle furnaces based on the traditional *pakai bhatti* design were developed for extended trials. Each version had dual gas burners developed by TERI, and muffles that improved energy efficiency to varying degrees. The three versions were

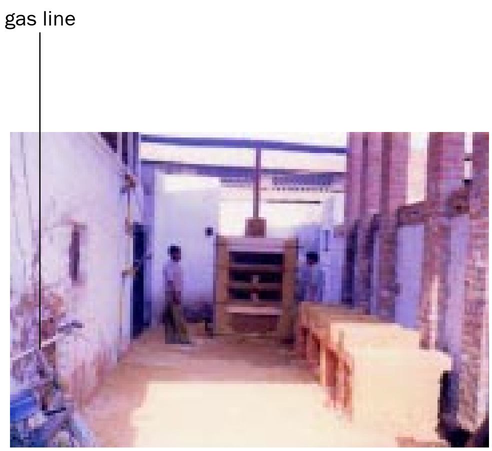
- 3-tier furnace with traditional fireclay muffles;
- 3-tier furnace with SiC (silicon carbide) muffles; and
- 5-tier furnace with two SiC muffles and three fireclay muffles.

Figure 40
Trial of muffle furnace models

(i) Tunnel type: general view

(ii) Tunnel type: top view

(iii) 3-tier version under construction



(iv) 3-tier version completed

Demonstration: identifying the best option

In essence, the preliminary trials at Electronic Glass Works served only to test out different furnace design concepts in a participatory manner over a relatively short period of time, and narrow down the options to three kinds of gas-fired muffle furnaces based on the traditional *pakai bhatti*. In actual field conditions, there are many variables involved in bangle-baking operations. For instance, the heat energy required for baking bangles depends not only on the structure of the furnace but also on the nature of bangles being baked (Box 32). The next crucial step, therefore, was to enable the local operators to use the three kinds of furnaces for long durations under actual field conditions, and allow the operators themselves to decide the best option among the three.

Even while preliminary trials were on at Electronic Glass Works, the project team looked for a site in Firozabad where it could undertake extended trials of the chosen muffle furnace models. Certain criteria were set for selection of the site, as listed below.

- The site should be a centrally located glass unit, one that local *pakai bhatti* owners would find easy to visit and witness the trials.
- A gas connection from GAIL should be available at the site.
- The site should have sufficient working space to accommodate the trial furnace models.

Box 32
Heat for bangle-baking

The heat energy taken up during the bangle-baking process depends on a great number of factors. It varies depending on the thickness and thermal properties of the muffles, trays, and on the skills of the operator (*pakaiya*). It also depends on the nature of bangles being processed. In general, two broad categories of bangles are baked in muffle furnaces: (1) fire-polished bangles and (2) gold-plated or *hil* bangles. The cycle time for fire-polished bangles is nearly 85% longer than for *hil bangles*, and hence the energy consumed in baking them is correspondingly higher.

There are other factors too. Different colours of glass are used for making bangles, and the heat uptake varies according to the colour of the bangles! It also depends on the nature of decorative work done on the bangles, their thickness, and their size—all of which vary from batch to batch. For instance, the diameter of bangles ranges from $1^{7/8}$ inch to 2¾ inch in steps of ½ inch.

- The unit owner should be willing to cooperate in the project, particularly in construction, modification, and trials of the furnaces and in monitoring of their performances. He should also be willing to share the costs for setting up the demonstration furnaces.
- The unit owner should be willing to allow others to witness the furnaces in operation, and to share the results of the trials with others.

The team sought assistance in finding a suitable site from the ever-obliging Viswadeep Singh. He arranged for the project team to meet the General Manager of DIC (District Industries Centre). At that time, a particularly keen and dynamic official held this post. Also by then, news had spread throughout the Firozabad cluster regarding the success of the project's gas-fired pot furnace at Islam's factory. This knowledge certainly must have added to the enthusiasm of the DIC General Manager, for he responded very positively to the project team's request and identified a site that met all the required criteria for conducting extended field trials of the gas-fired muffle furnace models. The site was Saraswati Glass Works, a pot furnace unit owned by Chandra Kumar Jain.

Trials and results

Jain proved to be most supportive of the project's venture (Figure 41). He arranged for a shed and working space in which to conduct the extended trials, and provided the necessary gas connection. Thereafter, the project demonstrated and commissioned the three different models of muffle furnaces. All three models were operated between 28 July and 7 September 2001, and their performances monitored on an hourly basis. Here again, the inputs of the operators and workers were vital in modifying various features of the furnaces on an

Figure 41
Demonstration gas-fired muffle furnaces at Saraswati Glass Works

ongoing basis to improve their performances and make them convenient to operate.

The trials attracted considerable interest in the locality as well as in the local media (Figure 42). 'I remember people climbing the walls of the factory premises to witness the gas-fired muffle furnaces in action,' recalls Mohit Dua, then a member of the TERI team. 'The results of our trials were very encouraging indeed, and the smiles on people's faces were reward enough for all the hard work our team had put into the project.'

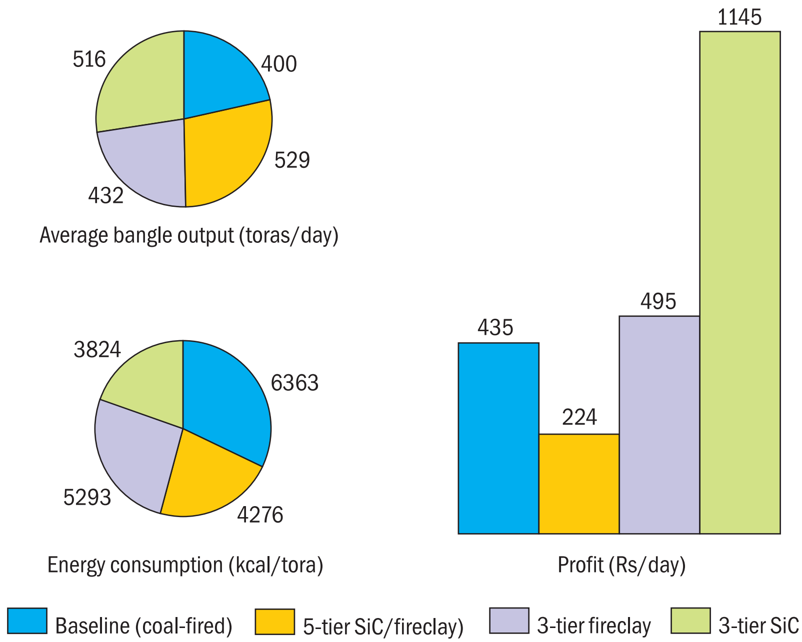
Figure 43 summarizes the results of the extended trials. From the very outset of the trials, it became apparent that all the three model furnaces were performing much better than the traditional coal-fired *pakai bhatti*, a fact that did not escape the attention of the coal merchants in Firozabad (Box 33).

As can be seen, although the 5-tier furnace yielded the maximum daily bangle output (average 529 *toras*), the benefits of this were offset by increased labour costs. Traditionally, bangle workers are paid according to bangle output rather than on the number of hours they put in at work. The 5-tier furnace required five workers per shift (two *pakaiyas* and three assistants). In comparison, the 3-tier furnaces each required only three workers per shift (one *pakaiya* and two assistants).

Figure 42
Report on extended trials


गैस संचालित पकाई भट्ठी निर्मित, गुणवत्ता में निखार

Figure 43
Performances of different muffle furnaces



The extended field trials revealed that the 3-tier furnace with SiC muffles showed the best overall performance among the three models in terms of both energy efficiency and profitability of operations. For the same bangle output, the energy consumed by it (3824 kcal/*tora*) was 40% less than the traditional coal-fired *pakai bhatti* (6363 kcal/*tora*). Its average bangle output (516 *toras*/day) was comparable to that of the 5-tier furnace, and much higher than either the traditional *pakai bhatti* or the 3-tier furnace with fireclay muffles.

Understandably, the local *pakai bhatti* operators too found the 3-tier SiC muffle furnace model the most attractive. Besides yielding higher energy efficiency and improved productivity, this model emitted virtually no black smoke at all (Figure 44). Because SiC muffles cost much more than fireclay muffles, the 3-tier SiC muffle furnace was expensive at around 30 000 rupees, compared to 12 000 rupees for the 3-tier fireclay muffle version. However, the increased earnings from its usage promised a payback in less than four months.

Box 33
Merchants of disinformation

When we began our extended trials at Saraswati Glass Works, it quickly became apparent that all the three gas-based muffle furnace versions we were trying out were performing much better than the coal-fired *pakai bhatti*—in terms of higher bangle output and profits, as well as greatly reduced emissions. Although we did not realize it immediately, the coal merchants in Firozabad saw this as a threat to their interests. Perhaps not without reason...for at that time the *pakai bhattis* alone consumed something like 100 000 tonnes of coal each year!

Very soon, we realized that the coal merchants (and, perhaps, many others who could not get access to gas for the gas-fired model) were engaged in a whisper campaign in the cluster against a gas-fired muffle furnace. Their allegations were wildly imaginative: 'The gas-fired furnaces ruin the colour of the bangles!' 'The flame from burning gas is so hot that it deforms the trays...and the bangles in the trays!' 'The gas-fired furnace requires the *pakaiya* to work so fast that he cannot cope with the higher production rate!' The rumours may have had some impact on *pakai bhatti* operators in distant areas, at least during the early stages of the trials. However, as the trials progressed and the tangible benefits of the gas-fired furnaces became more widely known, the whisper campaign faded as quickly as it had begun!

Girish Sethi
TERI

Figure 44
Contrast in emissions from muffle furnaces


(i) Coal-fired


(ii) Gas-fired

Nevertheless, the project team realized that not all *pakai bhatti* operators would be able to afford the 3-tier SiC muffle model. Instead, they might opt for the 3-tier fireclay muffle model, which too had shown significantly better performance than the traditional *pakai bhatti*. The project, therefore, promoted both the 3-tier SiC muffle version and the 3-tier fireclay muffle version, leaving the choice to the *pakai bhatti* operators.

Spreading the word

In December 2001, the project took stock of the work that had been done in developing and introducing improved gas-based technologies for the glass industry in Firozabad.

With the successful development, demonstration, and validation of two kinds of gas-fired furnaces—one for glass melting and the other for bangle-baking—the stage was set to spread the word about the new technologies and their benefits; to discuss ways by which glass units could adopt them on a wider scale; and to explore the possibility of taking up small initiatives to improve the working conditions and earnings of glass workers engaged in 'downstream' operations such as bangle-making.

On 9 December 2001, the project team organized two half-day 'interaction meetings', one at a *pakai bhatti* unit to discuss the gas-fired muffle furnace (Box 34), and the other at Express Glass Works to discuss the TERI-designed recuperative pot furnace. Viswadeep Singh was the driving force behind both the meetings.

At the meeting on the gas-fired muffle furnace, the project team stressed the following important issues that had to be addressed for the adoption of the new technology.

- It was not possible for *pakai bhatti* owners to get gas connections from GAIL at their existing locations in the densely populated residential areas of Firozabad.
- Therefore, it was vital for *pakai bhatti* owners to form cooperatives that could jointly apply for and obtain gas from GAIL.
- The owners had to find and select suitable locations in the cluster in which to establish their cooperatives; a process that required the assistance of both the DIC and GAIL.
- Registration of the cooperatives was necessary, for which assistance was required from the Department of Industries, the DIC, and the office of the Registrar, Cooperatives.

Box 34
Clear vision amidst smoke

Viswadeep Singh helped TERI locate an ideal venue for the meeting on the gas-fired muffle furnace. It was the yard of Ghulam Nabi's *pakai bhatti* unit located in the midst of Sheetal Khan, the area with the densest collection of *pakai bhattis* in Firozabad! Nabi exercised considerable influence among *pakai bhatti* owners in the area. Another influential *pakai bhatti* owner named Wahabuddin took care of logistics and other arrangements related to the meeting. Starting from the day before the meeting, men armed with loudspeakers went through the narrow lanes of Sheetal Khan on cycle-rickshaws, inviting bangle makers and other interested parties to attend the function. The meeting was conducted in the forenoon, and attended by 60–70 *pakai bhatti* owners. This implied that almost all the units in Sheetal Khan were represented at the meeting; for, there were around 170 *pakai bhattis* in Sheetal Khan and most units had more than one furnace each. At Viswadeep's behest, the then DIC General Manager too attended the function—thus lending it the all important stamp of 'government authority' (Figure 45).

Viswadeep himself delivered the keynote address. Amid the smoke and reek of the coal-burning *pakai bhattis* all around the venue, he described the benefits of the project's gas-fired muffle furnace – affordable price, quick payback, higher productivity of bangles, and drastically reduced pollution – and elaborated upon the hurdles that faced *pakai bhatti* owners who wanted to adopt the new technology. The biggest hurdle, he stressed, was the fact that GAIL could not supply gas to the majority of coal-burning *pakai bhatti* units at their existing locations, because these were scattered across densely populated residential areas in the Firozabad cluster. Only those *pakai bhatti* units that were located in 'gas zones', and that could source natural gas from larger pot furnace or tank furnace units, were in a position to adopt the gas-based muffle furnace.

Viswadeep explained that under these circumstances, the only feasible option was for *pakai bhatti* owners to form cooperative ventures that could then relocate to suitable sites in 'gas zones' and obtain gas from GAIL. He urged the owners to unite in this common cause and pressurize the government to help them establish cooperative ventures so that they could all avail of the benefits of the new gas-fired muffle furnace. 'Constant contact with the *Zila Udyog Kendra* (DIC) is a must,' he declared.

Figure 45
Interaction meet on gas-fired muffle furnace

The interaction meeting on the recuperative pot furnace was held in the premises of Express Glass Works. There were around 20 participants at this meeting; most of them pot furnace operators. The project team made a detailed presentation of the recuperative furnace's performance, and the participants were taken to the site to see the furnace in operation.

The interaction meetings were widely covered by local newspapers. In the months following the meetings, the project team held regular meetings with *pakai bhatti* owners and DIC officials to pursue the possibility of setting up gas-fired muffle furnace units in the Sheetal Khan area of Firozabad—a 'gas zone'. Meetings were also held with local administration officials and with the UPPCB to make them aware of the environmental benefits of the new technologies and to seek their support in spreading the technologies. A brochure in Hindi was prepared for distribution among *pakai bhatti* operators and others. The brochure gave details about the new gas-fired muffle furnace and the benefits it offered in terms of reduced fuel costs, less pollution, and increase in output of bangles.

Spreading the technology

Pot furnace

The project team continued to monitor the performance of the TERI-designed pot furnace at Express Glass Works throughout 2002/03. A detailed energy audit of the furnace was conducted during April–May 2002. The audit confirmed that the system was performing with high efficiency (Figure 46). The average daily consumption of natural gas had been optimized and was around 1990 Sm^3. This was equivalent to burning around 3 tonnes of coal per day, as compared to nearly 7 tonnes of coal consumed per day by the traditional coal-firing pot furnace used in Express Glass Works. In terms of curtailing GHG (greenhouse gas) emissions, this translated to a reduction of 1850 tonnes of CO_2 emissions each year. Also, the shift to gas-fired operation meant that workers were no longer exposed to the dangerously high levels of SPM (suspended particulate matter) and other pollutants that were emitted from the traditional coal-fired pot furnace.

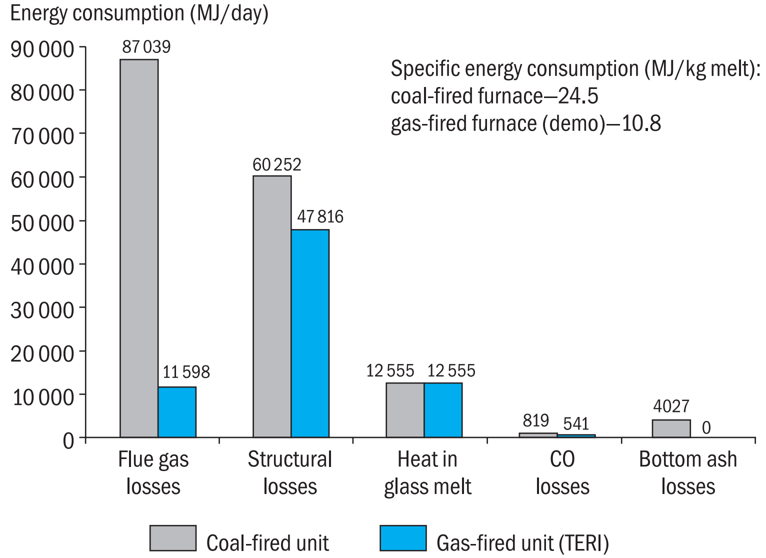
In August 2002, Express Glass Works formally 'bought back' the furnace from TERI in keeping with the agreement signed in December 1996. The proceeds from this transaction were set aside by TERI for use in interventions aimed at improving the socio-economic conditions of glass workers and their families in the Firozabad cluster.

In July 2003 Islam decided to shut down the furnace for overhaul. Examination revealed that its Zirmul floor was still intact even after nearly 22 months' continuous operation. The team, therefore, put the lifespan of the TERI-designed furnace at around two years—a conservative estimate, yet more than double the average lifespan of the traditional coal-fired pot furnace.

The recuperator modules were dismantled and cleaned. The tubes in all five modules were found to be in good shape despite continuous usage for over three years. Upon examining the 'experimental' tubes that had been placed in the modules in February 2000 (see Box 19), the team found that two kinds of tubes showed no damage at all: namely, those made from grades SS-316 and SS-304. Also, the MS tubes used in the first three modules showed no damage except for rusting. These observations provided valuable insights into the corrosive effects of the hot flue gases in the gas-fired open pot furnace. They also opened up possible ways to save costs in future replications, by using different and less expensive grades of steel (such as MS, SS-316 and SS-304) for the recuperator modules.

It was essential to finalize the detailed design specifications for the recuperative furnace. This exercise was undertaken with a view to cutting down

Figure 46
(i) Performance of demo furnace
(ii) Letter of satisfaction



(i)

EXPRESS Glass Works
MANUFACTURER OF FANCY GLASS BANGLES

Ref. No. Date..................
3 July 2002

Mr Somnath Bhattacharjee
Director – [illegible]
Tata Energy Research Institute
New Delhi

Dear Mr Bhattacharjee,

This has reference to your letter dated 5 April 2002 regarding handing over of the demonstration pot furnace set up at our plant with TERI assistance. The pot furnace has been commissioned successfully and fine tuned to our satisfaction and we are now ready to buy back the furnace. We are happy to confirm that the furnace has been consistently working at a low natural gas consumption between 1900 and 2000 Nm³/day. We are ready to buy back the furnace at a concessional rate of Rs 10 lakhs (Rs ten lakhs only) as per the agreement dated 18 December 1998 between Tata Energy Research Institute (TERI) and Express Glass Works. Kindly indicate your acceptance to this effect for further action at our end.

We are also enclosing details of the cost reimbursed to us by TERI during the construction/trial period and statement of equipment supplied by TERI directly to our unit separately as annexure A and B respectively for your reference and records.

We also confirm that this furnace will continue to be available as demonstration unit in the cluster and we will actively work towards disseminating this concept in Firozabad.

Thanking you.

Yours sincerely

Mohd. [illegible] Khan

(ii)

costs, as well as to pave the way for smooth replications of the system. Accordingly, the project team finalized specifications and prepared detailed engineering drawings for the furnace and its different sub-components, including the recuperator, burner with quarl, air and gas lines with blower, and so on. The specifications were drawn up for recuperative pot furnaces with capacities of 6.72, 5.76, and 4.8 TPD (tonnes per day), as the majority of pot furnaces in the cluster fell under these capacities. The team also drew up a tentative list of suppliers/vendors of critical pieces of equipment.

Replications: the long wait

Despite the successful demonstration of the recuperative pot furnace at Islam's factory, the publicity given to it at the interaction meeting of December 2001, and the efforts made by the project team to promote the furnace through one-on-one meetings with entrepreneurs, other pot furnace operators in Firozabad took a long time in adopting the model. Their reluctance to acquire a clearly superior technology has to be seen in a larger context.

By December 2001, almost all the erstwhile coal-burning pot furnace units in Firozabad had converted their furnaces to retrofitted gas-fired designs. The switchover from coal to gas had enabled the units to meet the Supreme Court deadline and, thereby, averted the dire threat of closure. Having achieved this immediate objective, the pot furnace owners reverted to their intrinsic reluctance to consider major changes in their technology.

Also, contrary to the initial apprehensions of entrepreneurs, switching over from coal firing to retrofitted gas-fired furnaces did not reduce the profitability of their units. Instead, entrepreneurs found that they were making greater profits after the switchover, because they were spending 15%–20% less on gas than on coal for the same output of glass melt! No doubt, the typical retrofitted furnace was far less efficient than the TERI-designed furnace (the former consumed an estimated 30%–35% more gas for the same output of glass); but the high cost of the TERI-designed furnace (around 3 million rupees) acted as a deterrent to entrepreneurs.

The switchover from coal firing to gas firing had a considerable impact on the finances and cash flow patterns of the pot furnace units

The switchover from coal firing to gas firing also had a considerable impact on the finances and cash flow patterns of the pot furnace units (Box 35). Earlier, when they used coal-fired furnaces, units usually had a credit period of 3–6 months in which to make payment to coal suppliers for coal consumed (unless

Box 35
New fuel, new costs

When glass-melting units applied for gas connections from GAIL following the Supreme Court verdict, the unit owners did not know exactly how much gas they would need in their gas-fired furnaces to match their existing production levels. (This was the time when coal-fired pot furnaces were in the process of being retrofitted to gas-fired designs). The entrepreneurs only had a kind of 'working formula' given to them informally by GAIL, on the basis of which to work out their approximate gas requirements.[18] Under the circumstances, entrepreneurs based their applications for gas quotas on 'guesstimates', rather than on any precise technical evaluation of how much gas each of them actually needed.

On its part, GAIL laid down certain financial criteria for gas connections. Each applicant had to pay a security deposit to GAIL of 0.2 million rupees; furnish a bank guarantee for three times the value of the security deposit (that is, up to 0.6 million rupees); and open an LC (letter of credit) favouring GAIL for 15 days' gas supply. In order to ensure guaranteed revenues from its gas connections, GAIL also incorporated a clause into its agreement known as MGO (minimum guaranteed offtake). Under the MGO clause, GAIL would bill a unit for a minimum of 80% of its sanctioned quota of gas—even if the unit drew less than 80% of its quota during a given time period! Furthermore, to enforce discipline in gas consumption from 2003 onward, GAIL levied a rate of Rs 9/Sm^3 on the 'overdrawn' amount of gas, that is, on gas consumed in excess of sanctioned quota.

These various conditions and requirements had considerable impact on the financial resources and cash flow patterns of pot furnace units, and influenced the process of replication of the TERI-designed furnace as described later in this book.

of course rail consignments from CIL collieries to Firozabad were delayed, in which case coal had to be purchased from middlemen on cash terms and at very high prices). However, once a unit switched over to gas-firing, in addition to the 'upfront' payments for obtaining a gas connection from GAIL, the unit had to make payment to GAIL every 15 days for the gas consumed during the

[18] On 24 June 1996, a meeting was held in Firozabad between the project team and glass entrepreneurs, including Viswadeep Singh and Islam Khan. While discussing the issue of gas supply at this meeting, the entrepreneurs mentioned that GAIL had informally given them a rough working formula, according to which one tonne of natural gas would be equal to around 2.5 tonnes of coal (this estimate probably included the increased efficiency due to usage of gas).


फीरोजाबाद 16

उद्यमियों का आर्थिक चक्र गड़बड़ा दिया है गैस ने

Figure 47
Report on difficulties in cash flow faced by glass units

fortnight. GAIL allowed an interest-free credit period of only three days beyond due date, after which it levied a very high rate of interest on outstanding dues. Units also faced the additional threat of gas supplies being cut off by GAIL in the event of non-payment of bills.

In short, although their retrofitted gas-fired furnaces did bring pot furnace owners some amount of profit compared to their earlier coal-fired furnaces, the switchover from coal to natural gas during the 'initial period' was difficult for them in terms of managing cash flows (Figure 47).

In this backdrop, pot furnace owners were wary about investing resources in new capital equipment such as the TERI-designed furnace; especially since it cost around 3 million rupees to build, compared to around 1 million rupees for the retrofitted gas-fired furnace. Understandably, the pot furnace owners preferred to 'wait and watch' rather than hasten to invest in the TERI-designed furnace; no-one was willing to make the first move.

Strategy review—cut technology costs, but ensure benchmark performance

Although the payback period for the recuperative furnace worked out to less than two years, there was need as well as potential to reduce the costs of various sub-systems and components. From the feedback the project team obtained during the course of its interactions with other pot furnace owners in the cluster, it was apparent that a number of these entrepreneurs were interested in acquiring the TERI-designed furnace because of its improved fuel efficiency, but were deterred by its relatively high capital cost. This prompted an internal debate within the project, during which a balance was sought between two principles: 1) that replication of the new technology must be promoted by all possible means including cost-cutting measures; and 2) that no compromise should be made on the standards and quality of the new technology that would lead to reduced energy savings. Finally, the project decided that it would consider minor modifications in the design and features of the new furnace system aimed at cutting costs and reducing construction time—but only so long as these modifications did not in any way reduce the energy efficiency and other benchmark performance parameters of the system.

R-LNG...and its fallout

GAIL's announcement of impending R-LNG supply created a groundswell of interest among retrofitted pot furnace owners in setting up TERI-designed recuperative furnaces

In the meanwhile, GAIL was facing an ever-increasing demand for natural gas from across the country even as supplies from within the country remained limited. There continued to be an overall shortage in natural gas allocated for the Firozabad cluster. At the same time, a number of units were drawing gas in excess of their sanctioned quotas. In mid-2003, GAIL announced that it planned to import LNG (liquefied natural gas) and start supply of R-LNG (regasified liquefied natural gas) from 2004 onwards to the Firozabad cluster. GAIL indicated that the price for R-LNG would be determined by the international oil and gas markets, which would make it costlier than natural gas being supplied to existing users (Box 36). GAIL also informed entrepreneurs that once R-LNG supply commenced, gas drawn by units in excess of allotted quotas would be

Box 36
R-LNG facts

As the name suggests, R-LNG (regasified liquefied natural gas) is natural gas that is liquefied to make it easy to transport by ocean tankers. Faced with increasing demand for natural gas on the one hand and shortfall in supplies of gas from Indian sources on the other, GAIL began to import R-LNG in 2004. The R-LNG is received at ports in Gujarat, converted back into gaseous form (regasified), and then distributed across the country through GAIL's pipeline network. As an imported fuel, R-LNG is costlier than the 'subsidized' natural gas supplied to Firozabad from Indian sources. To a large extent, its price reflects the market price of natural gas. In Firozabad, 'overdrawn' gas price was around Rs 9/Sm^3 to start with in 2004 (compared to Rs 6.30/Sm^3 for natural gas). However, the R-LNG price increased very steeply from 2005 onwards till it crossed Rs 20/Sm^3. As of mid-2007 its price was around Rs 19/Sm^3.

billed at the prevailing R-LNG rates (and not at the fixed 'overdrawn' rate of Rs 9/Sm^3 that was till then being applied).

GAIL's announcement had an immediate and lasting impact on pot furnace units in the cluster. Till 2004, the entrepreneur had operated his retrofitted pot furnace as well as auxiliary furnaces without too much concern about paying a higher rate for 'overdrawn' amounts of gas. This was because the rate charged by GAIL for overdrawn gas (Rs 9/Sm^3) was not much higher than the rate charged for his allotted natural gas quota (Rs 6.30/Sm^3). However, his outlook changed dramatically with GAIL's announcement that R-LNG prices would be much higher than the prevailing prices for natural gas, and that overdrawn gas would henceforth be charged at R-LNG rates. The entrepreneur realized that the earlier he improved the energy efficiency of his pot furnace (to make better use of the gas already allotted to him by GAIL at Rs 6.30/Sm^3), the more advantageous his position would be vis-à-vis his rival units in the cluster.

In effect, GAIL's announcement of impending R-LNG supply created a groundswell of interest among retrofitted pot furnace owners in setting up TERI-designed recuperative furnaces. As a result, replications of the TERI-designed furnace began to take place from 2004 onwards—initially in a trickle, and then, as the R-LNG prices started to shoot up from 2005, in large numbers.

Replications begin

The process of each replication began with a series of one-to-one interactions between the entrepreneur and members of the project team. The nature of these interactions, and the time it took for different entrepreneurs to decide on adopting the TERI-designed furnace, varied as widely as the personalities of the entrepreneurs concerned (Box 37). Once an entrepreneur decided to adopt the recuperative furnace, he set about acquiring the materials and equipment for the new furnace system based on the designs and specifications provided by the project team. B C Sharma provided on-site support and advice during construction, fabrication, commissioning, and fine-tuning of each new furnace system, with additional support from project team members as and when necessary. In all the replications, the TERI team ensured that the basic concepts and principles of the TERI design were not compromised.

A number of entrepreneurs wanted the project to bear a portion of the costs of the new furnace. However, the project team did not accede to this request. TERI's view was that the technical, economic, and environmental benefits of its recuperative furnace had been clearly demonstrated, and hence there was no need for TERI to fund hardware in replications.

Box 37
Empathy and patience—
keys to replication

Following the demonstration at Express Glass Works, we found it a real challenge to persuade other pot furnace owners to adopt the recuperative furnace, especially in the initial years. We found that one meeting with an entrepreneur was never enough; repeated meetings were necessary in each case. Some of these interactions were brief; others went on for months on end. Some entrepreneurs were cordial and open with us, and relatively quick in deciding to set up a TERI-designed furnace. Others were guarded and standoffish, even rude at times, and did not give us any indications of their intent. Often, these meetings severely taxed both our negotiating skills and our patience. Yet, we persisted in our efforts. We kept in mind the fact that the relatively high capital cost of the TERI-designed furnace made it a 'risky' investment in the eyes of the entrepreneur; we tried to view things from the entrepreneur's point of view, and did our best to remove all his anxieties and doubts through reasoned argument. It was not easy for us...but this empathetic approach finally paid dividends when replications took off, aided of course by the sharp hike in R-LNG prices from 2005 onwards!

Also, in the course of our interactions we discovered that a number of influential Firozabad families collectively owned a large number of pot furnace units in the cluster. Therefore, we specifically targeted influential members of these families and made special efforts to persuade each of them to adopt the recuperative furnace. This strategy worked! As soon as one member of a family set up a recuperative furnace, it was quickly adopted by other family members. This in turn inspired confidence in other entrepreneurs in the cluster, as they tended to follow the path taken by their more influential colleagues, which led them to adopt the recuperative furnace as well. In a sense, this experience has shown us that even in a largely technology-based intervention, one has to understand the complex hierarchies and interpersonal dynamics that prevail in the cluster in order to succeed in the long term.

Girish Sethi
Ananda Mohan Ghosh
TERI

First replication: early lessons in design improvement

In 2003/04, the project team held a number of meetings with pot furnace owners in the cluster to promote the TERI-designed furnace. Among them was an influential entrepreneur named Lalitesh Kumar Agarwal, owner of Bapu Glass Industries and a friend of Islam. In August 2003, Lalitesh signed an agreement with TERI to set up a recuperative furnace (Box 38). Bapu Glass Industries already had a retrofitted gas-fired furnace, which was found to be consuming 0.49 Sm^3 gas/kg glass melt (against 0.30 Sm^3 gas/kg glass melt consumed by Islam's furnace). In effect, Lalitesh's furnace was burning 38% more gas than Islam's furnace for the same glass melt output on a specific energy consumption basis.

The project team finalized the design specifications for the new furnace. These were given to Bapu Glass Industries, which acquired all the necessary equipment on its own. The project team provided technical support and expert advice during fabrication of the furnace, and supervision was undertaken by B C Sharma, the project's local consultant. The furnace was successfully commissioned on 12 September 2004 (Figure 48). The new furnace yielded a gas saving

Box 38
A wise decision

Our family operates four pot furnaces. Like others in the business, we too were very concerned about shrinking markets and profit margins. One day my friend and colleague Islam told me about a new kind of gas-based pot furnace he had installed in his factory with the help of TERI. I visited his new furnace site, and was very impressed with the setup. But I was a little worried about the cost of the furnace.

A few months later, I chanced to meet the TERI engineers at Monark Hotel, where they were staying. I told them about my family's interest in building a similar pot furnace in one of our sites, but expressed my concern about the capital cost of the furnace. To my pleasant surprise, I learned that the cost of the furnace would be much lower than I had anticipated. Finally, a TERI-designed pot furnace was built in our site with technical support from the project staff.

Today, my family and I are extremely happy with the new furnace. It operates smoothly, does not emit smoke, and is highly profitable too. Now, we are thinking of adopting this new furnace in all our sister concerns.[19]

Lalitesh Kumar Agarwal
Proprietor
Bapu Glass Industries

[19] Indeed, two sister concerns of Bapu Industries have since adopted the recuperative furnace—PLS Autoshell Industries (Pvt.) Ltd (March 2006), and S Rajeev Glass Works (P) Ltd (June 2006). Bapu Industries itself has set up a second recuperative furnace in its premises in 2007.

s

Figure 48
First replication –
Bapu Glass Industries

of 38%. Also, while designing and commissioning this furnace the team discovered ways to reduce costs and make furnace operations easier (Box 39).

Box 39
Cutting costs,
improving design

While setting up the new recuperative furnace at Bapu Glass Industries, the project team found ways by which component costs could be reduced and furnace operation simplified while retaining or even enhancing furnace efficiency.

In the demonstration unit at Islam's factory, the project had incorporated a safety valve in the gas line, which automatically shut off gas supply in case of power failure, or in case the gas pressure went above or below the set pressure limits. This valve operated on externally supplied compressed air, which made it expensive on two counts: (1) capital investment on an air compressor, and (2) recurring costs on the same. Later, the team interacted with various suppliers and realized that the gas line pressure itself could be utilized to operate the safety valve, obviating the need for an air compressor. Hence, an equally effective but much cheaper system was used in the gas line at Bapu Glass Industries.[20]

(Continued)

[20] In later replications, even this system – a pneumatic valve – has been replaced by a solenoid-controlled valve, as described separately.

Box 39 (*Continued*)
Cutting costs, improving design

Efficiency of gas combustion hinges crucially on supplying the right mix of gas and air to the burner at any instant. This requires precise measurement and monitoring of air and gas flows/pressures. The demonstration unit had a U-tube manometer to give air pressure readings (from which air flow was read off based on a calibrated chart), and an online turbine meter for measuring gas flow. This was not a very user-friendly system, particularly for the semi-skilled operators of the furnace, who found it difficult to correlate gas flow rates with the manometer readings. To get around this problem, the team successfully incorporated an online airflow meter in the system at Bapu Glass Industries. This device was slightly expensive, but made it far easier for the operators to control the air–gas mixture that was being supplied to the burner, thereby easing furnace operation and reducing gas wastage. Also, Lalitesh Kumar himself suggested that instead of using a single expensive imported expansion joint for the air line, the team could use a combination of indigenously made expansion joint pieces that were far cheaper. This measure alone reduced the system's cost by around 30 000 rupees!

Second replication: rewards of perseverance

Even as the new furnace was being set up in Bapu Glass Industries, the project team continued its efforts to promote the TERI-designed furnace by one-to-one interactions with owners of other pot furnace units in the cluster. One such unit was Navjeevan Glass Industries, located close to Bapu Glass Industries. The initial meetings with its proprietor, Ravindra Kumar Garg, were not very encouraging. This was in early 2005; like other entrepreneurs Garg too was aware of the need to reduce his unit's gas consumption. However, he mustered a formidable array of arguments against the existing design of the recuperative furnace, and also made a number of suggestions to alter its design—some well reasoned, some questionable. Although disheartened at first, the project team soon realized that the entrepreneur's responses only indicated his genuine desire to understand the new technology fully before adopting it, and his keenness to get the best out of his investment. Therefore, the team persisted in its regular meetings with Garg, fielded all his queries, and with patience and reasoning finally persuaded the entrepreneur to set up a TERI-designed furnace in his unit.

The new furnace, of capacity 5.76 TPD, was constructed at an amazing pace; that too, without interrupting the factory's regular production process, due to some very innovative methods adopted by Garg. The furnace was successfully commissioned in February 2005 (Figure 49, Box 40). In the

Figure 49
Second replication—
Navjeevan Glass Industries

Box 40
Path to profit

My family has been in the business of bangle manufacture for the past 50 years, using the pot furnace technology. The Firozabad glass industry was lagging behind developed nations, so we visited the United States and other countries to study their technology and adapt it to our conditions. However, our efforts did not yield much result.

And then, TERI started an initiative; their hard work bore fruit and we are now reaping the benefits of the TERI-designed pot furnace. TERI had promised us a 25% saving in terms of gas consumption alone: according to this estimate, instead of 2900 Sm^3 of gas, we would have to use only 2100 Sm^3. To our surprise, we have actually been able to cut down gas consumption to 1600 Sm^3. As added bonus, the quality of our products has gone up and so has the quality of our working environment. Our workers and our customers thank TERI for the noble initiative and hope the local glasswork owners will come forward to join TERI in the effort to develop advanced technology locally and to highlight the name of our town on the world map.

Ravindra Kumar Garg
Navjeevan Glass Industries

course of his interactions with the project team, Garg also came up with a number of valuable ideas and suggestions to cut down system costs and make construction of the furnace and fabrication of its sub-systems easier. The team explored some of these ideas in later replications, with considerable success (Boxes 41, 42).

Box 41
Learning with patience

When we approached Navjeevan Glass Industries to promote the TERI-designed furnace, we were initially a bit discouraged by the response of its proprietor, Ravindra Kumar Garg. In meeting after meeting he questioned many features of our furnace design. For instance, he argued against the very idea of a top-firing furnace, suggesting that a burner on the crown would damage the furnace floor much faster than a bottom-fired furnace. He wanted to know why he could not retrofit his existing furnace to suit the TERI design, instead of constructing an entirely new furnace. He asked why a circular refractory block had to be used in the centre of the furnace floor. He also kept suggesting a number of changes in the basic design of the furnace, some of which we felt would lower the performance parameters of the system.

Soon, however, we realized that Garg was not being 'negative' about the new technology. He just wanted to understand it fully, and to be absolutely sure that he was making a good investment by exploring all options for cutting down its cost. We, therefore, continued to meet him regularly. At each meeting we allowed him to talk, answered all his questions, listened patiently to his many points and suggestions, and countered them one by one where necessary. For three months, we followed this approach...and finally our patience was rewarded when he decided to adopt the new furnace! Our interactions with Garg were in some ways an exercise in participatory development. Indeed, they proved mutually beneficial. On the one hand, we provided Garg with knowledge and understanding of the new technology; on the other, he gave us a number of ideas to cut down the furnace system's cost and make its construction easier by modifying its design. The most valuable idea Garg gave us was to consider replacing the circular refractory block at the centre of the furnace floor by a square block. This idea matured during later replications, and today our design incorporates a rectangular, high-alumina block (available off the shelf in the local market) instead of the high-cost, circular, custom-made Zirmul block used in the demonstration furnace.

Garg also questioned the need for having the recuperator fabricated by a

(*Continued*)

Box 41 (*Continued*)
Learning with patience

firm located far away (the recuperators at both Express Glass Works and Bapu Glass Industries were fabricated by Gujarat Perfect Engineering, in Vadodara). 'Why not explore other fabricators closer to our locality?' he asked. 'It will be cheaper.' As a result, the recuperator for his furnace was made, at lower cost and without compromising on quality, by an Aligarh-based fabricator, with assistance from the project's local consultant B C Sharma. Garg himself ensured that the pipes and other components of the recuperator were tested at his unit to ensure that they met the stringent quality conditions set by the project.

In this way, Garg's suggestions have spurred us to widen our sources of refractory material and technical equipment, rather than remaining dependent on a few suppliers...

Ananda Mohan Ghosh
TERI

Box 42
A lesson in incentives: happy workers make better workers

Once he made his decision to acquire the TERI-designed furnace, Ravindra Kumar Garg set about organizing the construction of the furnace with great zeal. However, the task was not easy. He had an operating retrofitted furnace. If he diverted a section of his factory workers to construct the new furnace during regular working hours, it would severely disrupt the ongoing production process in his factory. On the other hand, he did not want to hire outside workers, of unknown capabilities and trustworthiness, to do the job.

Garg solved the problem with a unique blend of managerial skills and incentive schemes. He announced a small daily incentive for workers who were willing to put in extra hours in constructing the new furnace. Once the required number of men came forward, he organized them into four shifts of six hours each, and also made arrangements for a dedicated, non-stop kitchen to be set up for them within the premises. 'My shift workers could get their *chai*, their hot *rotis*, and *sabzi*, right inside the factory shed, and whenever they wanted it!' says Garg with a smile. 'I even told them that they could step out now and then for a quick drink if they felt like it...provided they came back and did their job well! I believe that a worker does his job best when he's happy. In this way, I created a team of willing workers who worked non-stop on the new furnace, 24 hours a day... without interrupting the regular production of my factory!'

Garg's strategy certainly yielded success. His recuperative furnace was completed and commissioned in record time—barely 15 days after digging the furnace pit!

Third replication: tests and lessons in heat recovery

The third replication took place in Shiva Industries, one of several units owned by a well-established family in Firozabad (Box 43). From the outset, its proprietor Promod Kumar Jain was very enthusiastic about the venture and only too willing to accept all the project team's ideas and suggestions. 'Whatever we proposed, Jain's response was a jovial "Yes boy!"' recalls a project team member.

The construction of the furnace went off smoothly, but major problems arose in fabrication of the recuperator. The unit had entrusted the job of fabricating the recuperator to Gujarat Perfect Engineering, Vadodara—the same firm that had made the recuperators for Express Glass Works and Bapu Glass Industries. In due course, the recuperator arrived at Shiva Industries, and was subjected to 'leakage/pressure-holding tests' to ensure its quality. Much to the consternation of Jain and the project team, the recuperator failed

Box 43
A sea change

When TERI stepped in and established a modern, gas-fired furnace at Express Glass Works, it was the first instance of a non-industry organization extending technical help to the glass industry. Not only did TERI introduce these high-tech furnaces in Firozabad, it also got Indian and foreign technical specialists to visit this town to familiarize them with the problems of the glass industry. A laudable effort indeed! TERI was also instrumental in establishing several gas-fired bangle-baking furnaces in Firozabad; one such kiln was established at our own unit too.

I am deeply touched by the concern shown by Girish Sethi, Puneet Katyal, Ananda Ghosh, Brajesh Sharma, and Sachin. Girish Sethi personally guided us through every single step of furnace commissioning. Ever accessible, he always had the right solution handy for each and every problem. We have been able to cut down on gas consumption by 30% and the quality of our products has undergone a sea change.

I am tempted to point out that natural gas is imported from abroad as R-LNG and this accounts for a sizeable chunk of India's foreign exchange expenditure. TERI's technological innovation will go a long way in saving precious foreign exchange for India.

Promod Kumar Jain
Shiva Industries

the tests, indicating certain imperfections in the quality of fabrication. Jain at once informed Gujarat Perfect Engineering of the problem, and sought its immediate rectification on-site. In due course, representatives from the Vadodara firm arrived in Firozabad and repaired the defective portions of the recuperator modules at the factory itself. Thereafter, the recuperator was once again tested for quality – this time successfully – and then integrated with the rest of the furnace system.

When the furnace system was commissioned in June 2005, the gas pressure at the burner was found to be lower than required. After eliminating various other possibilities the team discovered the cause of the problem: the pipe that carried gas from the existing pressure reducing valve or PRV (incorporated into the gas line to regulate the set pressure of gas at the burner) to the burner was much longer in Shiva Industries than in the earlier units. As a consequence, the pressure drop in the line was much more compared to other units! The solution was to change the specifications of the PRV being used so that it could accommodate this greater pressure drop in the line. The team drew a lesson from this experience: PRV specifications had to be site-specific.

A much more serious problem appeared – in the air line – soon after the furnace was commissioned. The furnace fireman reported signs that insufficient air was reaching the burner, even though the blower was supplying enough air into the recuperator for preheating! Having examined and eliminated a number of other possible causes for the problem, the project team realized that the recuperator must be leaking again. Upon opening the recuperator and examining its modules, the team found that the SS-310 tubes in the 'hot end' module were badly corroded, leading to leakage of air. Further investigations revealed that the corrosion had taken place because of a simple yet unexpected reason—the recuperator was positioned too close to the flue gas exit point in the furnace! As a result of this relative proximity, there were certain periods of the furnace operational cycle during which the flue gases reached the hot end module at temperatures well above 850 °C. At these temperatures, the SS-310 tubes were probably unable to withstand attack by the corrosive, alkaline flue gases from the melting furnace. Therefore, the answer to the problem lay in finding the correct position for the recuperator (Box 44).

In the earlier units, the position of the recuperator had been decided on the basis of convenience (space available in the factory, direction of the existing flue path, and so on) rather than on any scientific or technical grounds. The experience at Shiva Industries revealed, for the first time, the

Box 44
Recuperator position:
too close, too hot

The recuperator posed many challenges to the project team at Shiva Industries. First, there were quality problems detected in the modules during the pre-commissioning stage. After the fabricator rectified these problems, the recuperator was brought 'on line' and the furnace commissioned. From the outset, however, the furnace fireman experienced difficulties in adjusting the air–gas mixture at the burner. Very soon, the fireman observed that the burner flame did not have the 'right colour'. He remarked, with typical traditional wisdom, that this was a sure indication of insufficient air supply, probably due to leakage of air somewhere! Both Jain and B C Sharma agreed with the fireman's diagnosis. The project team checked various points where air leakage was possible – joints in the pipes, the air blower, and so on – but found nothing wrong. The team even checked the air flow meter to make sure that it was not giving wrong readings. Finally, with all other possibilities eliminated, the team realized the problem must lie in the recuperator.

As per procedure, the bypass line was opened to allow the flue gases to flow directly from the furnace to the chimney. The recuperator was then opened up and its modules were tested for leakages by a simple but effective traditional method known as *palita*. In this procedure, a cloth was wrapped around one end of a long pole. The cloth was then soaked in kerosene or diesel and ignited. Thereafter, a worker slowly moved the flaming end of the pole along and across the array of tubes in each module. Wherever there was leakage of air from a tube, the flame flared away from the tube due to the force of the escaping air. By means of the *palita* (Figure 50), it was found that the SS-310 tubes in the hot end module had become badly corroded, resulting in leakage of large quantities of air. Leakages of air were also detected from points in between the modules, indicating poor joining of the different sections. Thus, while the blower was supplying sufficient air to the recuperator, not enough air was flowing from the recuperator to the burner, just as the fireman had surmised!

The discovery raised two questions.

1 Why should the SS-310 tubes have corroded at all, when the service temperature of SS-310 was 1100 °C and the flue gas temperatures were no more than 950 °C?
2 Why had this problem not been encountered earlier, at Express Glass Works, Bapu Glass Industries or Navjeevan Glass Industries?

After studying the issue in depth, the team found the answer to both

(*Continued*)

Box 44 (*Continued*)
Recuperator position:
too close, too hot

questions—and a solution to the problem as well. First, the theoretical service temperature of SS-310 (1100 °C) holds true only for 'neutral' hot gases. The flue gases from a glass furnace are strongly alkaline in nature, and apparently corrode SS-310 at temperatures above 850 °C! Second, the flue gases were comparatively much hotter (up to 950 °C) when they reached the recuperator at Shiva Industries, than in the earlier units. This was because the recuperator was placed at a distance of only 12 feet from the flue gas exit of the furnace in Shiva Industries (compared to 21 feet at Express Glass Works and 18 feet at Bapu Glass Industries). This was why the SS-310 tubes were corroded in the recuperator at Shiva Industries—and why the recuperators in the earlier units had remained unscathed.

It was not practical to change the position of the recuperator at Shiva Industries. Instead, the team advised Jain to constantly monitor the flue gas temperatures at the furnace exit point as well as at the hot end of the recuperator, and to open the bypass line whenever the latter reached 850 °C.

Figure 50
Testing for leakages with a *palita*

importance of finding the right position for the recuperator. It should be far enough from the furnace flue exit to allow the flue gases to cool to below 850 °C (preventing damage to the SS-310 tubes); yet it should not be too far away either, for then the flue gases would cool down too much and reduce the effectiveness of the recuperator! After trials over a number of subsequent replications, the project arrived at an optimum position for the recuperator—it should be placed so that the hot end module is 15 feet (4.6 metres) from the furnace flue exit.

From trickle to flood: replications gather momentum

Following the successful replication at Shiva Industries, other entrepreneurs came forward in increasing numbers to set up recuperative furnaces. Their keenness to adopt the new energy-efficient technology owed in large measure to the team's continuing promotional activities—including the efforts made by B C Sharma, the local consultant, in this direction (Box 45). Islam too played a part at this stage by convincing some of his close associates to set up the TERI-designed furnace. The entrepreneurs were also motivated by hard business sense. As mentioned earlier, the price of R-LNG began to skyrocket from 2005 onwards, and the entrepreneurs wished to make the best possible use of their existing natural gas quotas (which they could draw at a much cheaper rate than R-LNG) and thereby acquire an early competitive edge over their rivals. Also, as the number of replications increased, word-of-mouth played a major role in spreading awareness about the benefits of the TERI-designed furnace. As a result, the TERI team's role became a bit easier in persuading hitherto-cautious entrepreneurs, during one-on-one meetings, to adopt the technology.

As with the earlier units, each replication took place after a series of one-on-one interactions between the project team and the entrepreneur, ending with a firm decision by the latter to adopt the TERI-designed furnace. Although a common driving force for replications was the steep and ever-increasing price of R-LNG, each entrepreneur had his own unique reasons for deciding how and when to adopt the new technology, and his own perspective on various issues concerning the glass industry. This point is illustrated by brief accounts of a few replications that have taken place since 2005.

Box 45
Man on the spot

B C Sharma, the project's local consultant in Firozabad, has played a vital role throughout the intervention—supervising furnace construction and fabrication of equipment; assisting in the commissioning of the furnaces and other sub-systems; remaining in touch with the units thereafter for troubleshooting and fine-tuning work; identifying and training local masons in construction and fabrication work; promoting the new energy-efficient technologies among other entrepreneurs in the cluster; and of course monitoring developments and providing feedback to the project team in Delhi. The following brief extracts are taken from Sharma's 'work reports' for March and June 2005, and indicate the challenging nature of his work.

Navjeevan Glass Industries. Gas consumption report was taken on 1 March. Flow meter indicator (for both gas and air) damaged due to high voltage on 4 March. It was taken out from the circuit and sent to Inconel, Pune, for repair....Production is satisfactory since the start of melting operations. The factory owner is satisfied, as gas consumption is below 1800 Sm^3/day. Safety shut-off valve went out of order because of a faulty relay; this was changed.

Express Glass Works. Visited factory on all five Mondays of the month...during Holi vacation, the recuperator was cleaned.

Bapu Glass Industries. After cleaning the recuperator on 28 February, the unit was facing problems in melting operations... on 8 March, I checked the furnace, found leakage in the flue path which was rectified. The furnace functioning became proper on 10 March. On 15 March it was reported that the red colour of molten glass was getting a blackish shade. This problem was overcome on 16 March by adjusting the air–gas rates.

Raja Glass Works. Construction of TERI-designed pot furnace started on 28 March.

Bapu Glass Industries. On 13 June when I met proprietor Lalitesh and his brothers...they all complained to me about the bad quality of glass and blamed it on the design of the new furnace. I replied: 'Okay, I shall myself run your furnace for seven to ten days as a challenge—only thereafter shall I talk to you!' I proved that there was nothing wrong with their furnace...only bad operating practices were responsible for the poor quality of glass....

Anup Glass Industries

This unit is owned by Anil Agarwal. Earlier, the unit operated two retrofitted furnaces. Agarwal explained that his sanctioned natural gas quota was sufficient to run both the retrofitted melting furnaces, but not enough to operate his auxiliary furnaces as well. This limitation, coupled with the high price of R-LNG compared to natural gas, prompted him to replace his retrofitted furnaces with recuperative furnaces. However, he did so in a carefully planned and phased manner to make optimal use of his gas quota. He set up the first recuperative furnace in September 2006, and a second, slightly smaller recuperative furnace was commissioned in August 2007 (Box 46, Figure 51).

Box 46
Sizing them right

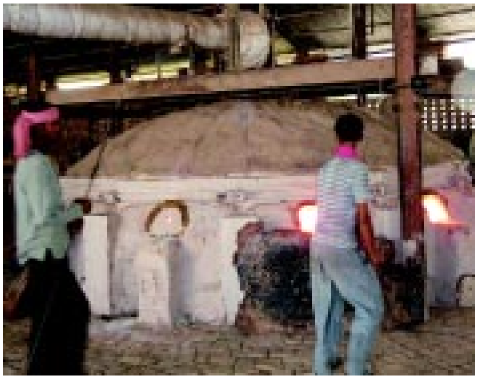
I inherited this unit from my father, and have run it for 15 years now. Earlier, my father manufactured and supplied chemicals for the glass industry such as copper oxide, cadmium sulphide, and zinc oxide. Now, my son runs the chemical business...so we have a kind of synergy!

My unit has a sanctioned natural gas quota of 6000 Sm^3 from GAIL. This much gas was sufficient to operate both the retrofitted furnaces that I had earlier; but to operate the *sekai bhattis* and other auxiliary furnaces I had to draw gas in excess of my quota. This was all right so long as GAIL billed me for the 'overdrawn' amount at Rs 9/Sm^3. But after 2004, GAIL started to bill the excess amount of gas drawn at R-LNG rates, which became very high in 2005! Therefore, I was forced to shut down my furnaces for 5 to 10 days every month. Naturally, this affected my unit's output and reduced my profits. Finally, after interacting with the TERI team in 2006, I decided to replace my retrofitted furnaces, one by one, with TERI-designed furnaces.

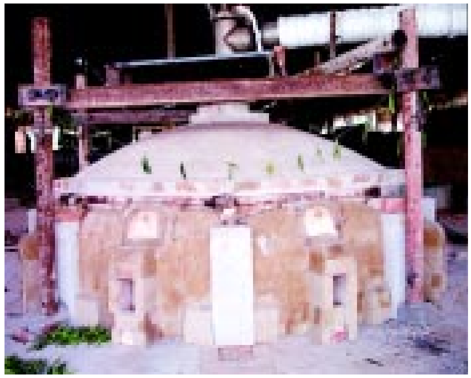
I planned the capacities of my new furnaces in such a way that my gas quota of 6000 Sm^3 would meet the needs of the melting furnaces as well as all my auxiliary furnaces. Thus, my first recuperative furnace, commissioned in September 2006, is a 12-pot furnace with a capacity of 6 TPD; the second furnace is a 9-pot furnace with a capacity of 5 TPD. With these energy-efficient furnaces, I am able to run my entire unit profitably within the sanctioned natural gas quota!

Anil Agarwal
Anup Glass Industries

Figure 51
Anup Glass Industries



(i) First unit



(ii) Second unit

S R Glass Industries

This unit commissioned a recuperative furnace in July 2006. Partner Girish Maheshwari explains why his decision – like those taken by many other pot furnace entrepreneurs – hinged crucially on his sanctioned gas quota.

'Contrary to my fears, the switch to gas-firing actually turned out to be beneficial, at least in the initial years. Like most other pot furnace owners in Firozabad, I adopted the 'conventional' gas-fired furnace, which yielded fuel savings of 20%–25% compared to coal, and that too at very little additional capital cost. My gas quota was more than enough to run my conventional furnace, and I did not mind drawing extra gas to run my auxiliary furnaces (*sekai bhattis* and *belan bhattis*) throughout the month, because the charge for 'overdrawn gas' was only a little higher (Rs 9/Sm^3) than the rate I was paying for my natural gas quota (Rs 6.30/ Sm^3). Even when R-LNG came in 2004, its price was only Rs 9.60/Sm^3.

'By that time word had started to get around Firozabad about the TERI-designed furnace, but I saw no reason why I should pay more money to acquire this new kind of furnace. Not only was it much more costly—say, about 2.5 million rupees more—but I was already making profits from my conventional furnace!

'However, things changed drastically from mid-2005. The price of R-LNG suddenly shot up to Rs 16/Sm^3 and kept on climbing. It was no longer possible for me to draw gas in excess of my quota; this would have entailed heavy losses. On the other hand, I could no longer run my auxiliary furnaces throughout the month—and this too translated into losses! In fact, I had to constantly monitor my gas meter, reserving enough gas for the melting furnace and switching off gas supply to all the auxiliary furnaces as soon as my quota neared exhaustion. Indeed, I could not run my auxiliary furnaces for more than 20 days each month.

'With losses mounting and the R-LNG price continuing to rise, I finally decided to set up a TERI-designed furnace. Thanks to the gas savings it brings, I am now able to operate all the auxiliary furnaces within my gas quota. But as a matter of precaution I still keep an eye on the gas meter, because the R-LNG price is so high!'

G Nath Glass Works

G Nath Glass Works is among the latest units that have adopted the TERI-designed furnace. Pravin Kumar Sharma, partner, is satisfied with the performance of the new furnace, which was commissioned in January 2007: 'Earlier, in the conventional furnace, we used to consume 2 tonnes of gas daily. In the new furnace, we consume about 1.5 tonnes of gas daily. So if we calculate according to the gas rates, we save 3000–3500 rupees per day…there is a significant saving every day!'[21]

Super Glass Works

This unit was set up in 1980 by Ashok Kumar Raniwala and Sudeep Chandra Chaturvedi, who have been business partners for over 30 years. The unit had a sanctioned gas quota of 5000 Sm^3. When R-LNG prices went up in 2005, the partners considered acquiring a TERI-designed furnace but decided against it, as at that point in time they had just shut down their retrofitted furnace and constructed a new one. 'We deliberately delayed acquisition of the TERI-designed furnace,' explains Raniwala. 'We realized it made sense to operate our new retrofitted furnace for its lifetime of 1½ to 2 years, and to switch over to the TERI-designed furnace only thereafter. Hence, although we decided to get a TERI-designed furnace in 2005, we actually set it up only in February 2007.' (Box 47)

[21] As quoted in the documentary film *The Cutting Factor* (working title) under preparation by TERI.

Box 47
Timing it right

Prior to 2005, there was no real pressure on us to acquire the TERI-designed furnace. Our gas quota of 5000 Sm^3 allowed us to operate our retrofitted furnace as well as auxiliary furnaces with ease. At times we had to draw extra gas for the auxiliary furnaces; but the rates charged by GAIL for extra drawings were not too high in those days.

We really felt the pressure only when R-LNG prices were hiked in 2005. Till 31 March 2006, we had paid approximately 2.8 million rupees on excess withdrawal of around 0.3 million Sm^3 of natural gas, that is, on the usage of R-LNG. As a result, the viability of our unit was almost nil. We realized the importance of cutting down on our unit's overall gas consumption. We then went to Express Glass Works and consulted Islam *Bhai*, who is a very respected person of Firozabad. He guided us to contact TERI to convert our unit to TERI design. He managed and approached TERI to give us full technical know-how of the TERI furnace. But at that point of time we had just shut down our earlier conventional furnace, which was costing 0.8 million rupees. It made economic sense to operate our newly constructed conventional furnace for as long as it lasted. However, we used the time to plan on how best we could acquire the TERI-designed furnace. After exploring various financial options, we finally decided to take a bank loan. We calculated – correctly, as it turns out – that the depreciation on our capital investment, at 20%, would more than offset the interest payable on our loan!

Today, we are very happy with our new recuperative furnace. It saves us so much gas that we are able to operate all our auxiliary furnaces well within our allotted gas quota. In fact, we have surrendered 1000 Sm^3 of gas back to GAIL. Also, we have not made any compromises in quality while setting up the new furnace; we have used only the materials and equipment prescribed by TERI in its design documents. For instance, we know some other units have used locally made gas burners costing around 80 000 rupees each; but we imported a gas burner from NU-WAY, UK, as recommended by TERI, even though this cost us around 625 000 rupees.

We are also grateful for the constant support from Mr Ananda Mohan Ghosh and Mr Girish Sethi from TERI. Even now we remember how A M Ghosh of the TERI team spent entire days at our factory while the gas pipeline was being laid, the painstaking efforts he made in checking the layout of the plant, and aligning the pipeline so as to optimize its length, avoid bends in it, and thereby minimize pressure losses in the gas. Indeed, in view of all the benefits the TERI-designed furnace has brought us, we may say that the factors that made us acquire it – the R-LNG price hike and the commission-ing of our conventional furnace in 2005 – were actually blessings in disguise!

Ashok Raniwala
Sudeep Chaturvedi
Super Glass Works

The Amrit Glass Works

The Amrit Glass Works has the distinction of being the very first open pot furnace unit that adopted the 'Patel' design retrofitted furnace. In fact, when the demonstration furnace was commissioned at Express Glass Works, the project team used the retrofitted furnace at the Amrit Glass Works as a base-line against which to assess the performance of the demonstration furnace. It is rather interesting, therefore, that the unit adopted the TERI-designed furnace as late as June 2007!

Proprietor Rajendra Agarwal clarifies that he delayed his decision because in 2005, when R-LNG prices began to soar, he had just commissioned a new retrofitted furnace. 'I would have suffered a heavy loss if I had abandoned that furnace,' he says. 'It made sense to continue operating it—and to adopt the TERI-designed furnace only after its life was over.' (Box 48)

Box 48
Patel's 'unconventional' contribution!

When P M Patel came to Firozabad in 1999, we pot furnace owners were struggling to make profits with our coal-fired furnaces. Our margins were low, mainly because we were forced to buy coal at inflated or 'premium' rates from blackmarketeers, who routinely cornered a substantial portion of the good-quality coal that came to Firozabad by railroad. Often, these blackmarketeers charged rates that were more than double the contracted prices for the coal.

In 1999, my unit became the first open pot furnace unit to install Patel's gas-fired furnace design—which we now call 'conventional' furnace. Earlier that year, Patel had set up similar retrofitted furnaces in a few closed-pot furnace units. To my own surprise, Patel's retrofitted furnace helped me increase my profits. Gas was relatively cheap at that time, and because the heat content (calorific value) of gas is higher than that of coal, I was able to produce much more glass melt for the same expenditure on fuel! Thus, I slowly began to accumulate some cash surplus from my operations...and eventually it was this surplus that helped me in paying for the TERI-designed furnace after R-LNG prices shot up in 2005. The same holds true for other pot furnace owners.

I, therefore, feel that P M Patel really helped us. He came to us at a time of need, and gave us a gas-based technological option when no other option existed. And with it, he gave us the opportunity to make profits as well—something none of us had ever expected.

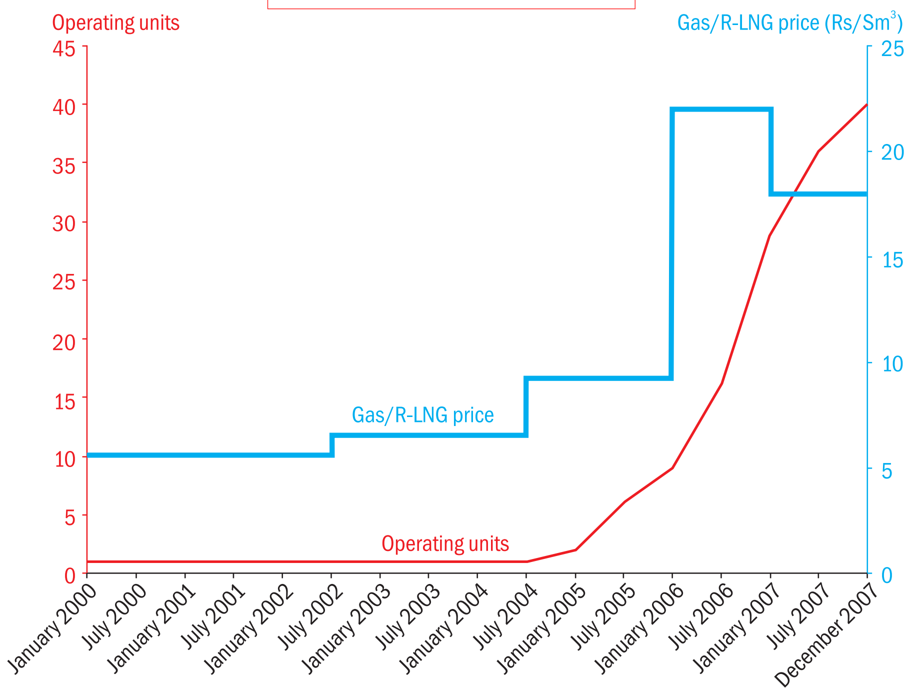
Rajendra Agarwal
The Amrit Glass Works

Agarwal feels that P M Patel's intervention in the Firozabad cluster in 1999/2000 was a great boon to the pot furnace entrepreneurs, because Patel provided the entrepreneurs with a gas-based technology just when they needed it the most (that is, in the wake of the Supreme Court order banning the units from using coal). Agarwal also makes a crucial point: that Patel's retrofitted furnace design enabled units to make more profits, and that these profits in turn helped entrepreneurs to slowly accrue the capital resources that would eventually enable them to acquire the costlier yet even more energy-efficient TERI-designed furnace.

Present status of replications

The growth in replications of the TERI-designed furnace has been quite dramatic in the last two years, as can be seen from Figure 52. After Shiva Industries, five more replications took place in 2005, and as many as 16 more in 2006. As of December 2007, there were at least 40 TERI-designed recuperative furnaces operating in Firozabad, with several others in the process of installation.

Figure 52
TERI-designed pot furnace: growth of replications and status as of December 2007



Annexure 4 gives a complete list of all the replication units as of end-November 2007. At the present rate, a majority of the remaining pot furnace units in Firozabad are expected to adopt the TERI-designed furnace in the next few years (Box 49).

In addition to these 'direct' replications of the TERI-designed furnace, there are reportedly around 30 pot furnace units that have adopted the *concept* of heat recuperation from the TERI-designed furnace.[22] All these units have developed and installed their own kind of heat recovery devices or recuperators without any support from the project team (although a few entrepreneurs from among these units had sought information and advice from the TERI team and from B C Sharma as to how to the TERI-designed recuperator works). Their makeshift recuperators may be much less efficient than the TERI-designed recuperator. Nevertheless, it is a victory of sorts for the project team that the entrepreneurs have learned, from the TERI-designed furnace, the concept and value of heat recovery from flue gases, and

The growth in replications of the TERI-designed pot furnace has been quite dramatic...a majority of the remaining pot furnace units in Firozabad are expected to adopt the TERI-designed furnace in the next few years

Box 49
Further replications: influences beyond the techno-economic realm

Although replications of the TERI-designed recuperative furnace are under way at a brisk pace, around 20–25 units may never adopt the TERI design. This is because the operators of these units are not the owners; they are in fact lessee-operators, and as such have no interest in making large capital investments in energy-efficient technology. According to Sharma, these lessee-operators are quite content with making what profits they can from the existing retrofitted furnaces in their units.

This negative influence of 'lessee ownership' on replications is an indicator that there are factors outside the domain of techno-economics that have a bearing on the outcome of an intervention in a SMiE cluster. These factors are difficult, if not impossible, to anticipate before the start of the intervention. Usually, they come to light only after the intervention is well under way, yet they play a major role in determining the course and extent of replications.

[22] This figure is based on secondary information; the TERI team itself has not visited these units.

that they are developing their own technologies to apply this concept (Box 50). A list of these 'spin-off' replication units is separately shown in Annexure 4.

Box 50
Spin-off replications: local innovations in waste heat recovery

Prior to the project's intervention, the concept of waste heat recovery was never applied in pot furnaces in Firozabad. Indeed, the recuperator holds the key to the superior performance of the TERI-designed furnace—by recovering waste heat from flue gases, it helps in reducing gas consumption by 30%–35%. As mentioned earlier, of the 80 or so pot furnace units in Firozabad, 40 have already adopted the TERI-designed recuperative furnace and many more are in the process of installation.

Interestingly enough, the concept of waste heat recovery seems to have caught on and spread much further and faster than the TERI-designed furnace itself! This is evident from the fact that a large number of locally designed recuperators are being adopted by retrofitted pot furnace units. Among them, six units have installed 'plug-in' recuperators (Figure 53) and several others have installed single/double pipe recuperators. These devices may not be as effective in waste heat recovery as the TERI-designed recuperator; but they do help in reducing fuel consumption to some extent. Most important, they show that the entrepreneurs have shed their traditional reluctance to consider changes in their technology; that now, they are becoming increasingly confident in learning from improved technologies and adapting them to suit their individual needs.

Figure 53
Plug-in type recuperator

Technology improvements

As described earlier, the technology for the TERI-designed furnace system has evolved with each successive replication. Modifications have been made and low-cost options have been tried out and incorporated in different sub-systems of the furnace on an ongoing basis, in close consultation with the entrepreneurs and often based on their own ideas and suggestions. The changes have been carried out in three broad areas: furnace base, gas train, and air train. The primary criteria that have been considered while experimenting with new concepts and making changes are

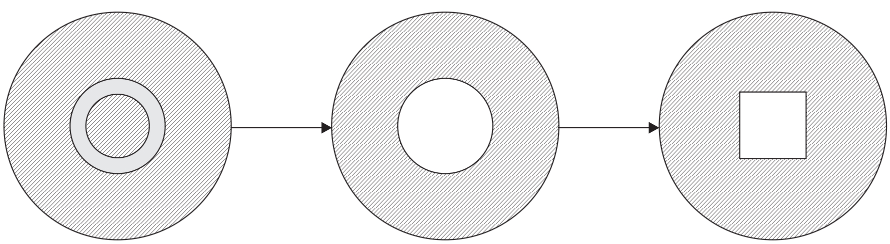
- cost minimization;
- ease of operation; and
- further increasing energy efficiency.

Some important modifications in the technology, and their significance, are briefly explained below. Also described are a few ongoing experiments aimed at further improvements in technology, and some local innovations to improve the performance of auxiliary furnaces.

Modifications in furnace base

- The furnace floor has a refractory block at its centre with a well around it—the central well. This well is meant to collect any molten glass that may overflow or spill from pots, thereby preventing the glass from spreading across the floor and damaging the refractory bricks from which it is made. In early versions of the TERI-designed furnace, a high-cost circular Zirmul block was used as the central block, and the central well too was circular in shape and fashioned from Zirmul blocks. The central block and well are now square-shaped, and made from relatively low-cost sillimanite bricks instead of Zirmul (Figure 54). This makes construction

Figure 54
Evolution of central block/well shapes and characteristics



much cheaper and quicker, as rectangular sillimanite bricks are readily available in the local market (Box 51).

Box 51
Shaping the floors

Perhaps the most significant changes in the recuperative furnace have evolved in the central portion of its floor, directly beneath the burner on the crown. The central part, called the 'central well', is meant to collect molten glass and prevent it from spreading across the floor and corroding its refractory bricks.

In the demonstration version of the TERI-designed furnace (constructed based upon sketches provided by British Glass and AIC), the floor had a circular block at its centre[23] with an annular well around it to collect molten glass. A circular shape gives maximum strength; but it is very difficult to make circular blocks from rectangular pieces! For this reason, it was very difficult to make the circular central block from the rectangular sillimanite blocks available in the local markets—not only was a very high degree of precision required in cutting the bricks, but it also resulted in a great wastage of material. The component pieces of the circular central block were later custom-made by refractory manufacturers located far away from Firozabad. This made the blocks expensive as well as time-consuming to procure and install. Also, experience with the furnace at Express Glass Works showed that the sillimanite central block was prone to damage. It was, therefore, done away with. Furthermore, the central well was constructed using custom-made Zirmul blocks instead of sillimanite. This increased the life of the central well, but further added to the furnace cost, as Zirmul is very expensive!

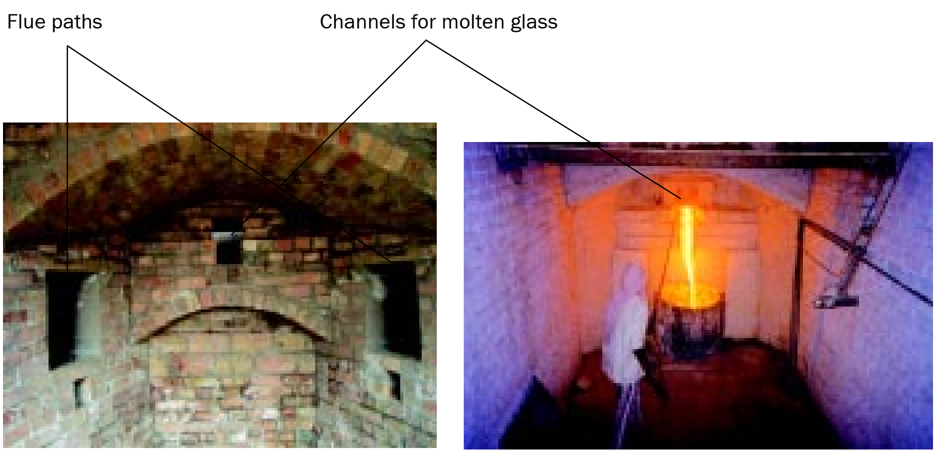
Thanks to an idea first put forward by the owner of Navjeevan Glass Industries, the shape of the central well has now been changed from circular to rectangular. This measure has brought about considerable savings in costs and construction time, as the furnace base and central well can now be made easily by using the rectangular sillimanite blocks that are readily available in the local market. In effect this is a good alternative to long-lasting but high-cost Zirmul.

Girish Sethi
TERI

[23] The central block was called 'Mahadeva' by local people for two reasons: (i) it had the phallic shape that is a symbol of Lord Shiva; and (ii) it was meant to absorb the thermal impact of the flame from the crown burner, just as Shiva absorbed the impact of the Ganga river when she descended from the heavens!

- The recuperative furnace is constructed in such a way that one can descend by a staircase/ramp to a point beneath the base of the furnace for inspection and maintenance work (including removal of molten glass collected in the central well through a channel). This area beneath the furnace base is commonly called '*tri*' (Figure 55). In the demonstration unit, the length of the channel from the central well to the '*tri*' was 54 inches (135 cm). This has now been reduced to 24 inches (60 cm). There are two advantages in this: 1) fewer refractory bricks are needed in constructing the channel (which means reduced costs); and 2) a shorter channel prevents the molten glass from cooling down and solidifying as it flows through the channel, making its removal much easier. As an additional cost-cutting measure, the channel is made from sillimanite bricks instead of Zirmul.
- Molten glass invariably enters the circular flue duct beneath the furnace, where it may solidify. To prevent if not altogether eliminate this problem, the slope of the flue duct is inclined towards the '*tri*' rather than towards the flue path leading to the chimney.

Figure 55
Inside the 'tri'



- A two-inch thick (5 cm) ceramic blanket is placed around the entire outer wall of the flue duct in the furnace, and extends all along the main flue duct up to the recuperator. The blanket minimizes heat losses from the flue gases in the duct, and thereby increases heat transfer to combustion air in the recuperator—increasing the overall energy efficiency of the furnace.
- An anti-abrasive, anti-corrosion coating is used on the surface of the furnace floor to reduce the thermal and pyro-chemical stresses on the sillimanite blocks and increase the campaign life of the furnace. The coating is a zirconium-based material developed by TRL (Tata Refractories Limited).[24] A free sample of the coating was provided to the project team by TRL, and tried out in Express Glass Works in 2006 when the unit reconstructed its furnace floor. Observations suggest that the coating is effective in preventing corrosion. Other pot furnace units are being advised to use this coating.
- The flue gases in the pot furnace enter the flue duct through apertures popularly known as 'flue holes'. In a 12-pot furnace, there are 12 such flue holes. In order to ensure the optimal performance of the furnace, it is very important to control and fine-tune the flow of flue gases during commissioning. To facilitate this task, a sliding brick arrangement is provided for each flue hole. The bricks can be slid in and out over the holes to alter the flow of flue gases till the required rate of flow is obtained. This is a one-time exercise during commissioning; once the flow is optimized, the settings of the different bricks are usually not changed.

Modifications in air and gas trains

- The optimum position of the recuperator has been finalized at 15 feet (4.6 metres) away from the furnace flue exit point. (The process of determining this distance has been described in some detail earlier, under Shiva Industries.) Also, unlike in the demonstration unit, where all five recuperator modules were made of SS-310, now two modules are made of SS-310; two of SS-304; and one of MS. This significantly reduces the overall cost of the recuperator, as MS and SS-304 are cheaper than SS-310. The choice as to which combination to use is left to the entrepreneur; he may decide based upon his financial capacity to invest. As the recuperator is

[24] Tata Refractories Limited was set up in 1958. Today, it is India's leading manufacturer of refractories. The company has a comprehensive range of refractory products to cater to a variety of industries; an experienced design and engineering team; a global marketing network; arrangements for technical collaboration with leading international refractory firms; and state-of-the-art R&D facilities for development of improved and new products.

modular in nature, the entrepreneur has the option to invest initially in lower-grade material, and later upgrade to better quality material like SS-310. However, the TERI team still advises the use of SS-310 for the first ('hot end') module.

- Combinations of expansion joint pieces made of indigenous material are used in the hot air line (from recuperator to burner) instead of the more expensive imported single-piece expansion joints used in the demonstration unit. (This cost-cutting measure was first proposed and successfully tried out by Lalitesh Kumar of Bapu Glass Industries.)
- A pneumatic safety valve was introduced in the gas line at Bapu Glass Industries, instead of the more expensive compressed air valve used in the demonstration unit (see Box 39, 'Cutting costs, improving design'). The pneumatic valve is a cheaper option, and has been adopted by a number of replication units. However, entrepreneurs face delays in procuring the valve, as it is manufactured by an Ahmedabad-based firm. Of late, therefore, a number of units have started using solenoid-controlled safety valves instead of pneumatic valves. The solenoid-controlled valve works on electricity, and automatically switches off gas supply to the furnace during power outages. It is cheap, and has the added advantage of being readily available in the local markets.
- The TERI team made efforts to get some local manufacturers interested in developing and supplying low-pressure burners for pot furnaces, instead of the expensive burners imported from NU-WAY, UK. Following a rather long process of persuasion and follow-up, Wesman Engineering Company – one of the largest burner manufacturers in the country – agreed to supply a burner based on the specifications given by TERI. The 'Wesman' burner was first tried out in the recuperative furnace at Anup General Industries, commissioned in August 2005. In the meanwhile, though, local entrepreneurs started getting a few local fabricators to make burners for them based on the NU-WAY low-pressure burner design. These locally made burners are even cheaper than the Wesman burner, and have, therefore, been used in many replication units (Box 52).
- Low-cost vortex flow meters and indigenous PRVs are now used for the gas train, instead of the high-cost turbine flow meter and imported PRV used in the demonstration unit.

Box 52
Burner issues

As part of our efforts to reduce the cost of the recuperative furnace, we tried to find alternatives for the NU-WAY burner that was used in the demonstration furnace and in the early replications. The NU-WAY burner is very efficient but costly, as it has to be imported from the UK. Through TERI's foundry team we got in touch with Wesman Engineering Company (P) Ltd – a Kolkata-based firm with overseas tie-ups and capabilities in designing and manufacturing a range of equipment related to combustion technology, industrial furnaces, and foundries. We provided Wesman with the specifications for the gas burner we were looking for. Wesman did not have such a burner readily available; but after many interactions the company finally identified a suitable burner from its catalogue.

The first Wesman burner was procured and tried out successfully at Anup General Industries in August 2005. The Wesman burner promised to be a cheaper option to the NU-WAY burner in future replications. However, Wesman did not proactively market its burner thereafter, despite being informed of the potential market for it in Firozabad. In the meanwhile, local Firozabad entrepreneurs have 'reverse-engineered' the NU-WAY burner, and many replication units have adopted these cheaper burners that are fabricated locally.

The advantage with (original) NU-WAY and Wesman burners is that they are made by reputed companies with very tight quality control standards. Although these burners are costlier, they give trouble-free service and are likely to last much longer. Indeed, Islam still recommends the NU-WAY burner to his fellow entrepreneurs, and has even identified an agent in Delhi who procures the NU-WAY burner for his clients from NU-WAY, UK. Nevertheless, the popularity of locally made burners points to the fact that for many entrepreneurs, it is not really important that a component of the furnace (be it the burner or the central well in the furnace floor) should last for a long time. They are accustomed to the practice of reconstructing their furnaces every year or so, and seem to prefer going in for a cheaper, lower-quality option so long as it helps in reducing the upfront cost!

Girish Sethi
TERI

Ongoing experiments to extend campaign life of furnace

In an effort to increase the campaign life of the TERI-designed furnace, a number of modifications have been carried out on an ongoing basis to improve the refractories used and to provide surface linings on the furnace floor. While the modifications mentioned above allow flexibility in choice of materials and make civil work easier, the overall campaign life of the

TERI-designed furnace has not increased beyond 22 months. In 2005, the project conducted a six-month-long study of temperatures at different depths below the ground, beneath the base of the furnace. The study indicates considerable potential to reduce heat losses from the furnace base to the ground beneath—the temperature of the earth is around 570 ºC at a depth of 4 feet, and 400 ºC at a depth of 6 feet! TERI is engaged in consultations with TRL to identify suitable insulating materials that might be used to minimize heat losses from the furnace base and increase its life. The options being considered include

- constructing the furnace base with improved refractory materials;
- use of insulating blocks and ceramic blankets;
- developing and applying an abrasive surface coating to prolong the life of the furnace base; and
- imparting knowledge and training to the masons on better refractory laying practices.

The project team intends to work closely with TRL and other refractory manufacturers to find a solution to this problem. It is also exploring the possibility of availing the services of international experts in this field.

Ongoing initiative to improve quality of pots

Each time a pot fails, it has to be removed from the furnace and a fresh pot introduced in its place. In the course of its work among pot furnace units, TERI recognized the clear need to improve the quality of pots used for melting glass. This aspect was also recognized during the initial Screening Workshop held in December 1994. As mentioned earlier, broken or 'failed' pots lead to considerable losses for a pot furnace owner—in terms of the cost of the pots; the heat energy lost; the molten glass, raw materials and chemicals gone to waste; and the labour required to replace the failed pots. There are also the long-term costs of damage caused to the furnace floor by the molten material that spills from the failed pots. The problem is compounded by the lack of any means to determine the life of a pot in advance. In practice, the operational lifespan is found to vary considerably among the pots used in a particular batch, even if all the pots have been made by the same artisans using the same materials! A pot might last merely 3–5 days, or it might last as long as 60 days. Reports suggest that there a few units in Uttar Pradesh and Gujarat where pots last from 90–180 days. In European countries, the average life of a pot is reported to be around 180 days.

Some progressive entrepreneurs, such as Garg of Navjeevan Glass Industries, change their pots within the average lifespan of a pot. However, even the routine removal and re-introduction of pots during the operating cycle is an arduous and risky job (Box 53, Figure 56).

Box 53
Braving the inferno

The scene: a pot furnace unit. The pot furnace is in operation. The factory shed is filled with the mingled roars from the furnace and the blowers; the heat from the furnace wall is hard to bear even ten metres away.

A failed pot (one that has completed its campaign life) has to be removed from inside the furnace and a fresh pot introduced in its place. Two workers crouch and proceed to dismantle the bricks in the section of the furnace wall behind which the pot is situated. The workers use metal tools to prise out the bricks; they are clad in thin cotton apparel, with rubber sandals on their feet. In lieu of protective gear, one has wrapped a piece of cloth around his face; the other has encased his fingers in wads of cloth. Finally, they remove the last brick in the section and draw back to reveal the interior of the furnace—a blinding yellow-white blaze, radiating terrific heat, the flame from the crown burner a shimmering, wraith-like form that dances over the white-hot floor. The failed pot, itself glowing dully, stands silhouetted against the glare. The two workers stand barely a metre away from the gap; they are exposed to the full blast of radiant heat from the interior, which is at a temperature of 1300 °C.

The overseer barks orders; a third worker pushes an empty steel dolly up to the gap in the wall. Using steel grapples, the first two workers drag the heavy, intensely hot pot out of the furnace and manoeuvre it onto the platform of the dolly. The third worker slowly trundles the dolly away and deposits the pot on to the factory floor some distance off, where it will gradually cool. In the meanwhile, other workers bring along another dolly bearing the fresh pot, which has already been preheated in a pot arch. The fresh pot is manoeuvred off the dolly and positioned inside the furnace. It will be left to soak in heat for several hours, and thereafter charged with cullet and raw materials while inside the furnace.

Now, the first two workers begin to seal the gap in the furnace wall. First, they drape a large gunny bag, soaked in water, over the gap. At once the gunny bag begins to hiss and steam; but at least it gives them some rudimentary protection from the blazing inferno within the furnace. Other workers now race up with fresh bricks and trays of freshly mixed mortar. Working deftly and with great urgency, the two workers seal off the gap, brick by brick; building up the wall over the gunny bag, till by the time they start laying the last layer of bricks, the gunny bag has already begun to smoulder at the edges....

For the workers, this is just another routine pot-changing operation. There is a desperate need to sensitize entrepreneurs to equip their workers with safety apparel. More important, ways must be found to increase the lifespan of pots. This will at least reduce the frequency with which workers are exposed to the drudgery as well as the terrible hazards involved in removing and replacing pots.

Figure 56
Pot change

(i) Dismantling of pot furnace wall begins

(ii) Dismantling of wall progresses

(iii) Wall dismantled, showing failed pot inside furnace

(iv) Workers prepare to drag out failed pot

(v) Workers use grapples to drag out failed pot

(vi) Failed pot on dolly

Figure 56 (continued...)
Pot change

(vii) Preheated fresh pot is removed from pot arch on to dolly

(viii) Fresh pot is introduced into pot furnace

(ix) Soaked gunny bag placed over gap in furnace wall

(x) Rebuilding of wall begins with placing of the centre piece

(xi) Wall rebuilding in progress

(xii) Completed wall

In general, the lifespan of a pot is determined by many factors, including raw material quality; manufacturing procedures; preheating practices; mechanisms for transfer of the pot to the pot furnace from the preheating furnace; loading patterns; and so on (Box 54). A 'good' pot is one that can melt glass of consistently high purity and high quality over many melting campaigns.

Box 54
Potty facts

The quality and lifespan of a pot depend critically on the various stages in its making. Traditionally, pots are hand-moulded from clay. The first step is to select and mix the dry constituent materials of the clay—the mixture is known as 'grog'. The particle sizes in the grog play a very important role in determining the life of the pot; in general, the smaller and more uniform the grog particle sizes, the better the ability of the formed pot to withstand high temperatures.

The grog is then soaked and cured to yield clay of appropriate plasticity for moulding. The moulded pot is polished and dried in the shade for up to four months. The dried or 'green' pots are then fired in a furnace called a 'pot arch'. The pot arch temperature is extremely important: if too high, the pot will crack; if too low, the firing process itself will be ineffective. Firing in the pot arch not only expels water retained within the clay, but also brings about chemical changes in the clay that reduce its porosity. Usually, the pot arch is heated up in stages to ensure that the pot material vitrifies (that is, it assumes a glass-like structure). This process is called sintering. After sintering, the pot is ready for use.

Some of the most common reasons for pot failure are listed below.

- The clay used in making the pot may contain glass pieces or other materials that melt at low temperatures. As a result, the finished pot will have spots in its structure that are vulnerable to heat. When the pot is exposed to the high temperatures inside the melting furnace (1250–1400 °C), these vulnerable spots melt away leaving small holes that grow bigger with time till the pot cracks. Horizontal cracks may also occur due to lack of uniformity in the nature and particle size of materials between successive sections of the pot wall.
- The pot has to be pre-heated to about 700–750 °C before introduction into the pot furnace. Preheating has to be uniform and gradual in order to prevent thermal shocks. In practice, no

(*Continued*)

Box 54 (*Continued*)
Potty facts

proper temperature curve is followed in preheating; instead, the temperature is judged by the colour of the pot surface at various stages, leaving room for error. This weakens the structure of the pot and makes it prone to failure.

- If the furnace pressure is negative, that is, lower than the atmospheric pressure outside, cool air from outside may enter the furnace through the glass collection holes and strike the pot, chilling its edges and causing vertical cracks.
- If the molten glass is allowed to remain for an extended period of time inside the pot at melting temperature, the pot may burst.
- Even under normal working conditions, the inner surface of the pot is attacked by the molten glass and chemicals inside it. Red glass melt and its ingredients are particularly corrosive! Because of corrosion, the thickness of the pot base is progressively reduced till eventually the pot fails.

TERI conducted a survey of around 50 of the 70 'pot rooms' operating in small clusters in various parts of Firozabad and neighbouring villages. The team observed and recorded the traditional processes of pot-making, including the nature, sources, and costs of raw materials used; the composition of the mixtures; the procedures of mixing, moulding, drying, heating, and cooling involved in the many stages; and the dimensions and costs of the finished pots. Samples of materials were collected from the various pot rooms for analysis by TRL. Based on its analyses, TRL evolved an appropriate material composition for making 'improved' pots. TERI decided to test some of these experimental pots at Navjeevan Glass Industries—a unit whose proprietor has devised his own simple but effective way to check losses on account of pot failure (Box 55).

A few pots were made at a local pot room in Firozabad according to the TRL guidelines and under the supervision of a TRL professional. First, the green pots were dried naturally in the shade. One pot was then taken to Navjeevan Glass Industries, where it was further dried by the ambient heat inside the factory. Thereafter, the pot was sintered in a pot arch, charged with raw materials, preheated as per the usual practice in the unit, and placed in

Box 55
Don't wait for failure...
prevent it!

Ravindra Kumar Garg, owner of Navjeevan Glass Industries, possesses an innovative spirit that was very much in evidence when he set up a TERI-designed furnace in 2005. It was, therefore, natural for the TERI team to approach him for testing the performance of the experimental pots made by TRL. Garg readily agreed to cooperate in testing the pots at his unit. In fact, he has evolved his own simple method to cut down on losses due to pot failures.

Garg's system is a classic example of preventive maintenance being superior to breakdown maintenance. He explains: 'I have a simple principle—don't wait for something to break down before replacing it, or else the losses will be heavy. When pots break down inside the furnace, I suffer heavy losses. To get around this problem I've studied the performance of pots, and the rate at which they fail, over a long period of time. I've concluded that the maximum service life of a pot is around 15 days. Therefore, I've made it a part of my routine operating practice to replace a pot 15 days after its commissioning, irrespective of whether or not the pot still appears to be in serviceable condition. With this system, I have cut down my losses on account of pot failure!'

the pot furnace. However, cracks started appearing in the pot after two days of melting. TRL has used data from this test to make suitable changes in its original material specifications and composition. A fresh set of pots has since been made under TRL guidance, and is currently being tested for performance at Navjeevan Glass Industries. The initial results from the new set of pots under testing are encouraging (Figure 57).

Auxiliary furnaces: local innovations

The concept of waste heat recovery has really caught on among pot furnace entrepreneurs, thanks to the recuperator used in the TERI-designed furnace. As mentioned earlier, several 'spin-off' units have been inspired by the TERI-designed recuperator and developed their own kinds of heat recovery devices for use in their pot furnaces. Now, the concept of heat recovery is also being extended to the 'auxiliary' furnaces—that is, furnaces that are used to convert glass melt to finished products.

The *sekai bhatti* is one such furnace. This furnace is used to re-heat globs of glass melt taken from the pot furnace after colours have been added to the

Figure 57
Experiment to improve pot quality

(i) Trial pots arrive from TRL

(ii) Examining dimensions

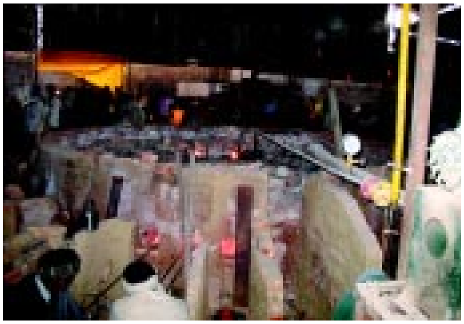
(iii) Preheated trial pot in pot arch

(iv) Introducing trial pot into pot furnace

globs. The majority of *sekai bhattis* are gas-fired, with the burners placed at the bottom/top of the furnaces. In general, these furnaces have low energy efficiencies. In 2002 TERI had monitored the performance of a *sekai bhatti* and found that while the furnace temperature was 1225 °C, the flue gases escaped at a temperature of around 720 °C. This indicated considerable scope to improve the energy efficiency of the *sekai bhatti* by heat recovery from flue gases. However, the

The concept of waste heat recovery has really caught on among pot furnace entrepreneurs, thanks to the recuperator used in the TERI-designed furnace

Figure 58
(i) Gas-fired *sekai bhatti*
(ii) Heat recovery device for *sekai bhatti*


(i)


(ii)

project did not pursue the idea further because at that point of time the team was totally preoccupied with post-demonstration activities in Express Glass Works and with replications of the gas-fired muffle furnace.

In 2005, local consultant B C Sharma helped a pot furnace unit in designing a simple heat recuperator for its *sekai bhatti*. The device consists of a circular MS pipe set into the crown of the *sekai bhatti*. Combustion air passes through this pipe and gets preheated before reaching the burners. This simple device enables a fuel saving of around 5%. Also, there is a substantial reduction in temperature in the vicinity of the *sekai bhatti*, making working conditions much better. Now, almost all the *sekai bhattis* in the cluster have installed such a heat recovery system (Figure 58).

Another local initiative in heat recovery is being undertaken in the *belan bhatti*—the furnace in which the glob of glass from the *sekai bhatti* is drawn out into a spiral for making bangles. In 2006, a fabricator from Aligarh devised a heat recovery system for the *belan bhatti* at a pot furnace unit. However, upon examining the system the TERI team concluded that it had certain inherent deficiencies in concept and design, and would not yield good results. This prediction has since proved correct.

In the meanwhile, B C Sharma designed and developed a new model of *belan bhatti*. It was first tried out successfully at Bapu Glass Industries. This new model not only uses a heat recuperator but also incorporates a number of changes in features and design aimed at improving the overall performance of the furnace. For instance, the size of the combustion chamber

Figure 59
Local innovation:
modified *belan bhatti*

is reduced; a 4-inch thick layer of insulation material is used to reduce structural heat losses; a low-pressure burner replaces the traditional gas burner; and a temperature indicator/controller is provided to enable better monitoring and control of input heat (Figure 59). Trials indicate that the improved *belan bhatti* reduces gas consumption while still yielding the same levels of production. The new model has another advantage; its insulation is quite thick, and therefore, the thermal radiation from its surface is much lower, making working conditions much better.

Capacity building

Throughout the intervention, the project has striven to enhance the capabilities of entrepreneurs and local artisans by providing them with equipment, technical support, and knowledge and skills through interactions and on-the-job training.

Equipment and technical support

The project provided a brick-cutting machine to the Glass Industry Syndicate (an association of glass entrepreneurs, primarily pot furnace owners) in 2005. This machine enables much greater precision in cutting refractory bricks compared to manual cutting, and hence improves the quality of construction. It also saves time. A number of pot furnace units are now using the machine to cut and shape refractory bricks during the construction and/or repair of their pot furnaces, in particular, for crown construction. Recently, the refractory dealers in Firozabad have established an innovative scheme of their own to promote sales and establish goodwill among their clientele. They have got two more brick-cutting machines made by B C Sharma. Now, whenever clients order refractories from them, the dealers send the refractories along with the brick-cutting machines to the clients' factories at a nominal per diem rental!

The project has also provided the local industry with instruments such as temperature probes, temperature indicators, and gas flow meters, to enable entrepreneurs to monitor the operating parameters of pot furnaces.

Refractory know-how

In the course of its interactions with pot furnace entrepreneurs, the project realized that there was a great need to provide them with knowledge and expert advice in the selection of suitable, high-quality refractory materials for pot furnaces, and in the best practices to be followed while laying the refractories. The project, therefore, organized an interaction meet on 15 September 2005 at Firozabad between the Glass Industry Syndicate, experts from TRL, and a ceramics consultant, B N Ghosh. The visiting experts made their presentations in Hindi at the request of the entrepreneurs. As a follow-up measure to this meeting, the project has prepared an informative *Introductory note on refractories*, which will be circulated among the glass entrepreneurs in Firozabad.

QAQC and best operating practices

QAQC (quality assurance and quality control) norms are vital in regard to equipment such as the recuperator and the burners. This was especially highlighted by the experience at Shiva Industries, where the recuperator failed precommissioning quality tests and had to be repaired at the factory site itself, delaying the commissioning of the new furnace system. The project made efforts, through site visits and informal discussions, to assess the QAQC procedures being followed by fabricators, as well as by the masons and operators in the glass units. The project found that fabricators did not adhere to QAQC standards while making the modules for the recuperator. The team has, therefore, prepared a QAQC manual on BOP (best operating practices) to be followed in fabrication of the recuperator.

Similarly, a detailed manual is being prepared on the construction of the TERI-designed furnace. The manual covers civil construction, furnace commissioning, BOP in day-to-day operations, and troubleshooting. Once finalized, this manual will be translated into Hindi and made available to all pot furnace entrepreneurs in Firozabad.

The team has made efforts to impart hands-on BOP training to entrepreneurs and furnace operators in all the replication units. While entrepreneurs follow the recommended BOP to varying degrees, a few entrepreneurs have developed some innovative ideas of their own to improve operating practices in their units (Box 56).

Box 56
Incentives for BOP

Ravindra Kumar Garg, of Navjeevan Glass Industries, is very particular about adhering to BOP. This includes regular removal of molten glass from the central well in the furnace floor. Most units do not follow this practice regularly, as workers do not like entering the '*tri*' to remove the molten glass through the collection channel at the base of the furnace. However, Garg has found a simple method to ensure that this task is done daily, as recommended by the project team. Each day, he gives an incentive of 100 rupees to the worker who removes the glass!

Garg has also devised a unique method to clean the recuperator modules in minimal time. In most other units, the recuperator is allowed to cool down for about 8 hours after being taken off-line, and the process for cleaning the modules starts in situ only thereafter. In Garg's unit, as soon as the recuperator is taken off-line, workers lay a wooden plank along the length of the recuperator in its pit, stand on the plank and clean the modules. 'In this way, my recuperator gets cleaned as soon as it is taken off-line,' explains Garg. 'I save valuable time this way; and time is vital, because as long as my recuperator is off-line I do not get preheated air for the burner!' He adds that when he first mooted the idea, his workers were apprehensive that the recuperator modules would be too hot for them to stand on the plank. However, they discovered that the ambient heat they were exposed to while on the plank was no more than what they routinely faced while drawing glass melt from the furnace.

Strengthening local nodes

During the first few replications, the project team made efforts to train the local masons who were engaged for the civil work and other activities related to furnace construction (Box 57). B C Sharma in particular played a vital role in working with the masons and giving them on-the-job training.

Box 57
Haji Abdul Rashid—Firozabad's master mason

Haji Abdul Rashid is the most well-known and respected mason in Firozabad—his services are always in great demand. Rashid is close to 70 years old, and a third-generation mason. 'From the age of 15 I started to learn the skills of my trade,' he murmurs. Rashid has three sons, of whom two are masons. 'I have taught them what I know… just as my father and grandfather taught me what they knew. There is no end to learning…I was already an old man when I learned to build the TERI-type furnace…'

Till now, Rashid has made at least 15 TERI-designed furnaces, besides a large number of retrofitted furnaces. Although Rashid has had no formal technical education, his vast hands-on experience in building glass furnaces has made him an expert in many other fields related to the glass-making process. 'By looking at a lump of glass from a melting furnace, I can tell the conditions inside the furnace,' he says in a matter-of-fact way. 'The clarity of the glass, the presence of *dana* (seeds or bubbles) in it, the uniformity of colour…all these indicate whether the furnace is being fired at the proper rate, whether air is sufficient, whether it is too hot or not hot enough inside. Just as I, a *mistry*, must know things about glass quality to build my furnace properly, so also a fireman must know the structure of his furnace in order to operate it well; he must understand the nature of the materials with which it is made!'

He recollects how Mohammed Islam Khan of Express Glass Works summoned him urgently in May 2000 when the quality of glass suddenly deteriorated. 'That was the first time I saw a TERI-designed furnace! I examined the red glass that was being drawn from the furnace, and I told Islam *sahib* that the heating was not consistent inside the furnace, and that perhaps it had something to do with air supply. He showed me the recuperator and said: "The air comes to the burner through this." I replied: "I have never seen this thing before…but the problem must lie inside it!"'

Of course, Rashid turned out to be right. The recuperator had become choked with particulates, reducing the temperature of preheated air being supplied to the burner…as narrated elsewhere.[25]

[25] See Box 28.

As the replications have progressed, a number of other masons and local fabricators, too, have taken up the work related to furnace construction, equipment fabrication, and system integration. Most of them have been given training by B C Sharma. At present, there are six masons and six fabricators providing services to entrepreneurs who are setting up new recuperative furnace systems. Further training programmes are being devised for the benefit of these local nodes.

Muffle furnace

Following the successful demonstration of the gas-fired muffle furnace at Saraswati Glass Works in August 2001, the unit's proprietor Chandra Kumar Jain immediately set about installing several more gas-fired muffle furnaces in his factory premises. These furnaces were then rented out to *pakai bhatti* operators. The project team provided technical assistance to Jain in setting up and commissioning the new furnaces. Local consultant B C Sharma ensured that the furnace designs did not deviate from that of the demonstration furnace barring minor modifications.

The project team had designed its own gas burners for use in the demonstration muffle furnace at Saraswati Glass Works. These burners were much more efficient and quieter than locally available gas burners—but they were also more expensive. As a result, barring a few initial replications, others adopted burners available in the local market that were cheaper. Sharma toiled hard to train the *pakai bhatti* operators in using the new furnaces. The team monitored the performance of the new furnaces. The results revealed that on an average, each furnace produced 460 *toras* of bangles per day—nearly 15% more bangles than the traditional *pakai bhatti* (400 *toras* per day). In February 2002, another pot furnace unit, R S Glass, sought the project team's assistance in setting up gas-fired muffle furnaces in its premises.

Replications: a different trajectory

By June 2002, a total of 19 gas-fired muffle furnaces were in operation in Firozabad—14 in Saraswati Glass Works, and five in R S Glass. Other pot furnace units approached the project for assistance in setting up gas-fired muffle furnaces in their premises. By September 2003 the number of operating gas-fired muffle furnaces grew to 35. All these furnaces were installed in pot furnace units that had 'surplus' quotas of natural gas allotted to them by GAIL (Box 58, Figure 60).

Box 58
Profiting from surplus gas—
with one exception!

As described earlier, gas quotas were applied for by glass melting units, and sanctioned by GAIL, without an exact determination of the applicants' actual needs for gas. Because of this, many pot furnace entrepreneurs found that they had 'surplus' quotas of gas, that is, they were in a position where they could utilize more gas than was necessary to operate their (retrofitted) gas-fired pot furnaces and auxiliary furnaces. Saraswati Glass Works was one such unit. In order to derive maximum benefits from their unutilized gas quotas, some of these entrepreneurs set up TERI-designed gas-fired muffle furnaces in their own factory premises and rented them out to *pakai bhatti* owners, while others set up additional pot furnaces.

A notable exception to this rule was Mohammed Islam Khan of Express Glass Works. His allotted gas quota was 4000 Sm^3/day, but the TERI-designed furnace in his plant consumed less than 2000 Sm^3/day. Instead of seeking to profit from his unutilized gas quota, Islam surrendered part of his surplus gas quota back to GAIL—thereby becoming one of the very few glass unit owners in Firozabad to do so!

Figure 60
Replications of gas-fired
muffle furnace

(i) Saraswati Glass Works

Figure 60 (*Continued*)
Replications of gas-fired muffle furnace

(ii) Ajanta Glass Works

(iii) Shri Durga Glass Works

Thus, replication of the gas-fired muffle furnaces began to follow a curious pattern; one that had not been foreseen by the project at the outset of the intervention. The very purpose behind developing the gas-fired muffle furnace was to help the *pakai bhatti* operator switch from coal to gas as and when GAIL was able to supply gas, in keeping with the spirit of the Supreme Court verdict in the Taj Trapezium case. At the same time, the new furnace was designed to increase energy efficiency; to improve the local environment by reducing emissions; and to enhance productivity, thereby increasing the earnings of the *pakai bhatti* operator. The project had achieved all these objectives by developing and demonstrating the gas-fired muffle furnace; yet the *pakai bhatti* operator was unable to acquire and set up the new furnace on his own because he could not get gas from GAIL in his existing location! On the other hand, the pot furnace owner was enthusiastically setting up the new muffle furnace in his own factory because he had surplus gas allotted by GAIL on which to run the furnace, and he could rent it out to the *pakai bhatti* operator and thereby earn steady income with minimal investment. Under these circumstances, the benefits of the new energy-efficient muffle furnace were in fact partly flowing to the pot furnace unit owner rather than to the actual furnace operator—because the latter had to pay a fixed rent to use the improved furnace!

Yet, the *pakai bhatti* operator was quite willing to take the gas-fired muffle furnace on rent. Although he had to pay some initial deposit up front for each furnace rented, and settle rent on a fortnightly basis, these expenses were more than compensated for by the assured supply of gas, improved productivity and quality of bangles, and better working environment. As for the workers, they too were happier because they no longer had to work in a highly polluted environment.

With no alternative in sight, the project continued to encourage this pattern of replication of gas-fired muffle furnaces in the interests of the environment. A brochure on the gas-fired muffle furnace was compiled in Hindi, and distributed to interested stakeholders (Figure 61). The project team regularly monitored the production and gas consumption levels of the replication units. To facilitate replications, the project team decided to identify masons, or *mistrys*, who could act as local nodes in furnace construction. Two masons were identified with the help of B C Sharma. After discussions between the project team, Sharma and the masons, a number of small modifications were made in the gas-fired muffle furnace design so as to reduce its cost.

Figure 61
Brochure on gas-fired muffle furnace

Case for cooperatives—and barriers

It was clear that despite the increasing number of replications, the adoption of the gas-fired muffle furnace, and its benefits to the *pakai bhatti* operators, would be severely restricted until a way was found by which *pakai bhatti* operators could directly obtain gas from GAIL. The *pakai bhatti* operators were very keen on getting gas; but from GAIL's point of view it was neither feasible nor economically viable to supply gas to small individual *pakai bhatti* units (Box 59).

Box 59
Gas for *pakai bhattis*:
two views, no answer...

In 2002/03 the *pakai bhatti* operators were experiencing the benefits of operating the TERI-designed gas-fired muffle furnaces, but they had to rent these furnaces, which were all installed in pot furnace units. Understandably, they were keen on setting up gas-fired muffle furnaces on their own, for which they needed to obtain gas connections of their own from GAIL. However, economic and safety considerations prevented GAIL from considering the supply of gas to individual *pakai bhatti* units at their existing locations amid the densely populated areas of Firozabad. These two divergent views are captured in the words of two stakeholders in 2002: Foren Singh (*pakai bhatti* operator), and Prashanto Bannerji (then Chairman and Managing Director, GAIL).[26]

Foren Singh: 'Around 150 to 175 factories have been given gas through pipelines. We, the *pakai bhatti* operators, also went up to GAIL and said that the pipelines can be extended and brought to our units. But their systems, their rules, are very complex. They ask for a minimum security deposit of 200 000 rupees and another 600 000 rupees as bank guarantee. Their minimum charge is also enormous...'

Prashanto Bannerji: 'Unlike, let's say, a department of the Government of India or a department of the Uttar Pradesh government – which run utilities to supply electricity, to supply water, and where the social objectives of the government are more important – we (GAIL) are a commercial organization. And whatever investments we make must give returns, and they must be protected...'

For TERI, these two views, divergent as they were, indicated a challenge as well as an opportunity for the future. On the one hand, a way had to be found by which the *pakai bhatti* operators could obtain gas connections at affordable prices in order to utilize and benefit from the clean, energy-efficient gas-fired muffle furnace. On the other hand, a way had to be found by which GAIL could supply gas at affordable prices to these *pakai bhatti* operators without compromising on its own bottom-line or its safety criteria. It was clear that these twin issues would have to be addressed simultaneously, at both policy level and cluster level, in order to arrive at a solution.

[26] Quotes taken from the documentary film *Taj Mahal: beyond the love story* (TERI 2002)

From data gathered on the gas-fired muffle furnaces at Saraswati Glass Works, the project team calculated that each furnace required a gas supply of around 220 Sm^3/day in order to produce 400 *toras* or more per day (the average bangle production level of the traditional *pakai bhatti*). Informal discussions with GAIL officials indicated that for a gas connection to be commercially viable to GAIL, a minimum gas demand of 2000 Sm^3/day was needed. Eight gas-fired muffle furnaces could easily meet this level of consumption if they operated from a single location. In turn, this suggested that *pakai bhatti* operators should group together to form cooperatives and set up multiple gas-fired muffle furnaces at locations where GAIL could supply them with gas.

The project team, therefore, initiated discussions with GAIL, the DIC, and *pakai bhatti* associations to explore the possibility of setting up a cooperative of *pakai bhatti* operators. The team even assisted groups of *pakai bhatti* operators in applying to the government for registration as cooperatives. However, efforts to follow up the matter were hampered by procedural delays and the periodic transfer of officials who were otherwise appreciative of the project's efforts.

There was another hurdle as well—GAIL just did not have enough gas to supply to fresh applicants.

GAIL tightens the taps

Confronted with ever-increasing demand for gas from across the country and an overall shortage in natural gas allocated for the Firozabad cluster, GAIL began strict monitoring of gas supplied to and consumed by units in its Firozabad network in 2002/03. Penalties were imposed on units that were found consuming gas in excess of their contracted amounts (that is, on 'overdrawn amounts' of gas). Saraswati Glass Works itself had to stop operations in its gas-fired muffle furnaces for some time because of restricted gas supply.

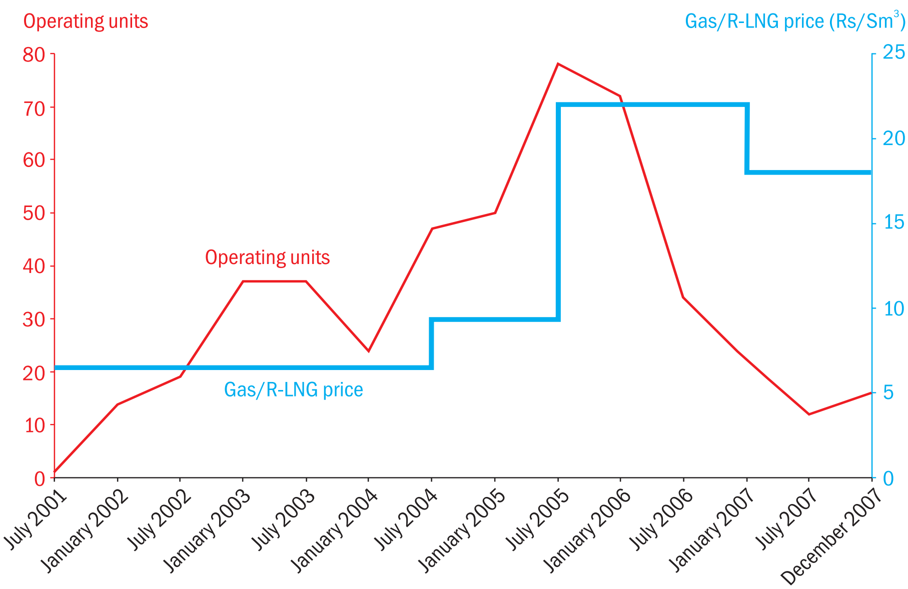
While the coming of R-LNG acted as a spur for retrofitted pot furnace owners to adopt TERI's furnace design, it had the opposite effect on replication of gas-fired muffle furnaces in pot furnace units

Keeping with its announcement made in 2003, GAIL began to supply R-LNG in 2004 to tide over the shortfall in gas supplies to Firozabad. While the coming of R-LNG acted as a spur for retrofitted pot furnace owners to adopt TERI's furnace design, it had the opposite effect on replication of gas-fired muffle furnaces in pot furnace units. R-LNG was costlier (at Rs 9.60/Sm³ initially) than gas being supplied by GAIL under earlier contracts (at Rs 6.30/Sm³). Furthermore, the price of R-LNG escalated very steeply from 2005 onwards till it crossed Rs 20/Sm³ in 2006.[27] This made it unprofitable for pot furnace units to set up new gas-fired muffle furnaces for renting out to bangle makers—unless they still had surplus quotas of gas allotted under earlier contracts with GAIL. It was simply not practical to expect bangle-makers to pay higher rent for using muffle furnaces that burned R-LNG.

As R-LNG prices have continued to rise, the bangle-makers have progressively reverted back to operating coal-fired pakai bhattis, especially because coal continues to be readily available in Firozabad at a relatively cheap price

As a result, the pattern of replication of gas-fired muffle furnaces became more complicated from 2005 onwards, as R-LNG prices climbed (Figure 62,

Figure 62
Pattern of muffle furnace replications: influence of R-LNG price



[27] In mid-2007, the price of R-LNG was around Rs 19/Sm³.

Box 60). On the one hand, new muffle furnaces were being installed in pot furnace units with as-yet unutilized surplus gas quotas; on the other, existing muffle furnaces were progressively being shut down in units where the natural gas quotas were insufficient and had to be supplemented with R-LNG. Figure 62 shows how the number of operating gas-fired muffle furnaces

Box 60
Then...and now

Till 2004/05, when natural gas/R-LNG prices were still relatively low, it made economic sense for pot furnace owners with surplus gas quotas to set up gas-fired muffle furnaces; and for *pakai bhatti* owners to take out these gas-fired muffle furnaces on rent.

Foren Singh earlier operated four coal-fired *pakai bhattis* in his unit in Sheetal Khan. In mid-2005 Foren shut down two *pakai bhattis*, and instead rented two gas-fired muffle furnaces installed at a pot furnace unit. 'I pay a deposit of 50 000 rupees for each muffle furnace,' said Foren at that time. 'I also pay a daily rental of 2200 rupees, settled on fortnightly basis, on each furnace. The arrangement suits me; I still make a profit, and my bangles are of better quality than before. Even my workers are much happier because they suffer much less from pollution, as they breathe easier while at work. This is the greatest blessing. This is what drives me and others like me to shut down our coal-burning *pakai bhattis* and instead take out these gas-fired *bhattis* on rent.'

Chandra Kumar Jain, proprietor of Saraswati Glass Works, was equally enthusiastic in 2005. 'I have installed over a dozen muffle furnaces in my factory,' he said. 'If space permits I shall set up more.[28] In sufficient numbers, they are proving to be more profitable than pot furnaces!' A supervisor at his plant added: 'We allow the muffle furnace operators a fixed quantity of gas. We also provide their workers with fans, lights, and drinking water—amenities they would never have got in their traditional workplaces. Our only condition is that every fortnight they must pay us our rent; or else we switch off gas supply.'

Today, however, Foren Singh has reverted to his coal-fired *pakai bhattis* for a simple reason: it is much cheaper for him to burn coal in his own *pakai bhattis*, than to pay for R-LNG on rented gas-fired muffle furnaces. For the same reason, Saraswati Glass Works, like many other pot furnace units, has shut down all the gas-fired muffle furnaces it had installed earlier.

[28] Indeed, Jain set up 16 more gas-fired muffle furnaces in his sister concern, Shri Durga Glass Works.

peaked in July–August 2005 at 78 units, but has thereafter followed an irregular, declining pattern (barring a brief period in early 2006). A new trend began in 2006, of muffle furnace operators abandoning their rented furnaces because of their inability to clear their gas/R-LNG bills. Thus, in December 2006 the number of *installed* muffle furnaces peaked at 107, but the actual number of *operating* units was only 22.[29] Indeed, as R-LNG prices have continued to rise, the bangle-makers have progressively reverted to operating coal-fired *pakai bhattis*, especially because coal continues to be readily available in Firozabad at a relatively cheap price, in energy terms, compared to gas![30] As of November 2007 there are barely a dozen gas-fired muffle furnaces in operation in Firozabad.

Towards social action

From 1996 till 2001, the project's activities essentially centred on action research in the technological sphere. Close involvement in the cluster over the years, as well as the tangible benefits brought by the new technologies in terms of fuel savings and reduced pollution, helped the project team in acquiring a degree of credibility and trust among glass unit owners and workers in the Firozabad cluster. The intervention had also made the team aware of the grim working conditions of those engaged in 'downstream' activities such as making bangles and decorative items. Following the successful demonstration of the gas-fired technologies for pot furnaces and bangle-baking, the team felt that it was an appropriate time to explore whether and how small initiatives could be taken aimed at bringing about improvement in the lives of these glass workers and their families.

As a first step, the project team critically reviewed a study of sociological issues related to the Firozabad cluster conducted in 1997 by MARG (Multiple Action Research Group), an independent consulting organization. The MARG study itself formed part of a larger study by TERI sponsored by the ADB (Asian Development Bank), titled 'Environmental improvement and sustainable development of the Agra–Mathura–Firozabad Trapezium in UP'.

[29] TERI. 2006. **CoSMiLE operational report**, January–December 2006. p. 13.

[30] Estimated energy costs per 1000 kcal have increased during the period 1996–2007 for coal and gas as follows: coal—0.10 rupees to 0.15 rupees; natural gas—0.76 rupees to 2.30 rupees. It may be noted that for the purpose of comparison, prices for coal are based on standard pithead rates quoted by Coal India Limited; the actual rates paid by *pakai bhatti* units were/are much higher. Also see Footnote 7.

Based on its review, the project decided to carry out two exercises in the cluster.

1 Environmental monitoring in select sites
2 Baseline socio-economic study of bangle workers in the cluster

Environmental monitoring

The aim of the environmental monitoring exercise was to provide deeper insights into the health-damaging effects of pollution from the glass industry, and to sensitize glass workers as well as other stakeholders, including government agencies, on the urgent need for glass units to adopt clean technologies. As mentioned earlier, a large number of pot furnaces, and almost all the tank furnaces, had already switched over to natural gas operation by 2001. However, the vast majority of *pakai bhattis* continued to run on coal. There was no data available – not even with government agencies – on the number of functioning *pakai bhattis*, or their location and distribution. It was a well-known fact, though, that large numbers of *pakai bhattis* were located in small clusters within densely populated localities of Firozabad, and that the AAQ (ambient air quality) in these areas was consequently very poor (Box 61).

As a first step, the project team conducted a 'cluster mapping' exercise to determine the number and location of *pakai bhattis* operating in Firozabad. Data was gathered with the help of local *mistrys*, who went around the cluster armed with a simple questionnaire devised by the team. The data revealed that there were close to 800 *pakai bhattis* operating in Firozabad, with the units scattered across highly congested areas of the town. Nearly half the furnaces were located in just two areas: Sheetal Khan (177 furnaces) and Parmeshwar Gate (182 furnaces).

The team thereafter measured the AAQ in four zones—Sheetal Khan, Parmeshwar Gate, Vakilpura, and the premises of Saraswati Glass Works. The AAQ was also measured in two relatively unpolluted residential areas – Arya Nagar and Shiv Nagar – to provide a benchmark against which to assess the pollution data from the other zones. The pollutants monitored were RSPM (respirable suspended particulate matter), SPM, SO_2 (sulphur dioxide), and NO_x (nitrogen oxides). The AAQ measurements were taken between May 2002 and May 2003 in all the zones, and the results for RSPM compared with norms for emissions set by the CPCB. The levels of RSPM in all the zones were found to be much higher than the limits set by the CPCB (Figure 63).

Box 61
Darkness at noon

I remember my first visit to Firozabad as part of the project team. Sometime in the afternoon, we visited a major cluster of coal-fired *pakai bhattis*. I didn't expect very clean and healthy working conditions—I had spent a lot of time reading previous reports, and on our way my colleague Girish Sethi had explained to me lots of issues relating to the small-scale glass cluster. After reaching there, however, I found the conditions much worse than I had anticipated. Thick black smoke billowed from the chimneys of scores of small furnaces, located in cramped units scattered across a densely populated residential area. A black haze hung over the entire neighbourhood. I didn't need complicated epidemiological studies to tell me that most of the workers there, indeed most of the residents of that area, must be suffering from some kind of breathing ailment.

During the course of conversations, a few furnace owners remarked that a lot of talk had been going on for quite some time to ban coal and to provide natural gas for their furnaces at a separate industrial location but nothing had moved on the ground. I asked a bangle worker whether he knew what he was doing to his health by working there. He replied: '*Saab hum kya kar sakte hain, yeh to jab sarkar karegi, tabhi hoga*.' ("What else can we do, sir…it is all in the hands of the government.") And then he proceeded to place bangles on a tray with amazing skill.

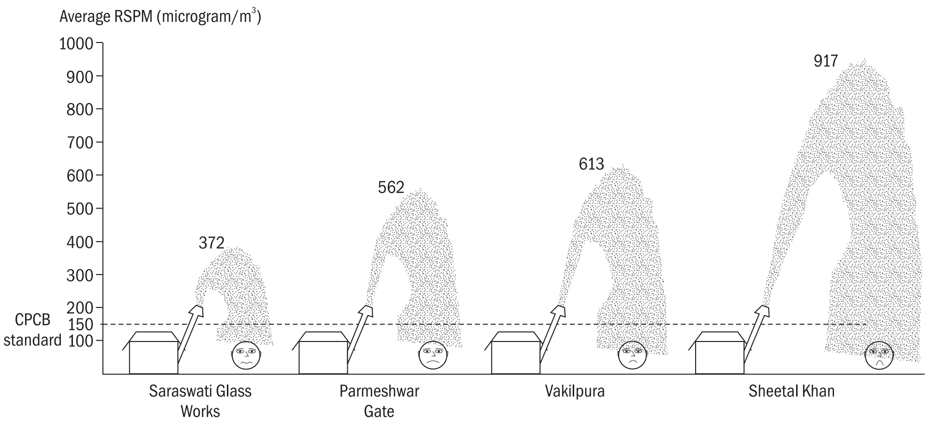
The workers knew that they were reducing the span of their lives drastically; but then the *pakai bhattis* provided the only source of living for them. It was a terrible, tragic irony—they were making beautiful bangles to fill the lives of others with colour, yet their own lives were engulfed in thick black smoke. There's no doubt that there are many issues to be addressed before these furnaces can get natural gas at a safe location. Now that a technological solution is in place, there must be a sense of urgency on the part of all stakeholders to ensure this, so that a young person working on a *pakai bhatti* doesn't perish because of tuberculosis any more.

Puneet Katyal
TERI (2004)

In general, the AAQ in the workplace is affected not only by emissions from factory operations, but also by 'fugitive' emissions from outside the factory area. The project team used personal air samplers to measure the AAQ in a gas-fired muffle furnace unit and in a coal-fired *pakai bhatti* unit. The samplers were either attached to the workers' bodies or placed within their working zones (Figure 64). The results showed that the exposure levels of workers to the RSPM were much lower in the vicinity of gas-fired muffle furnaces, than near the traditional *pakai bhattis* (Table 3).

Figure 63
AAQ study: (i) emissions from *pakai bhatti;* (ii) RSPM levels in different zones

(i)



(ii)

AAQ – ambient air quality;
RSPM – respirable suspended particulate matter;
CPCB – Central Pollution Control Board

Figure 64
Monitoring of workers' exposure to air pollution

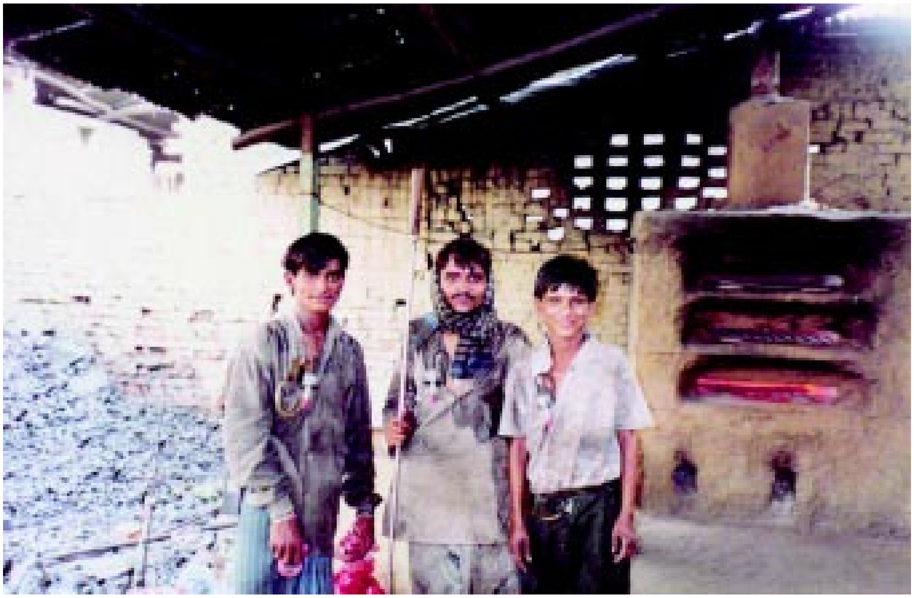


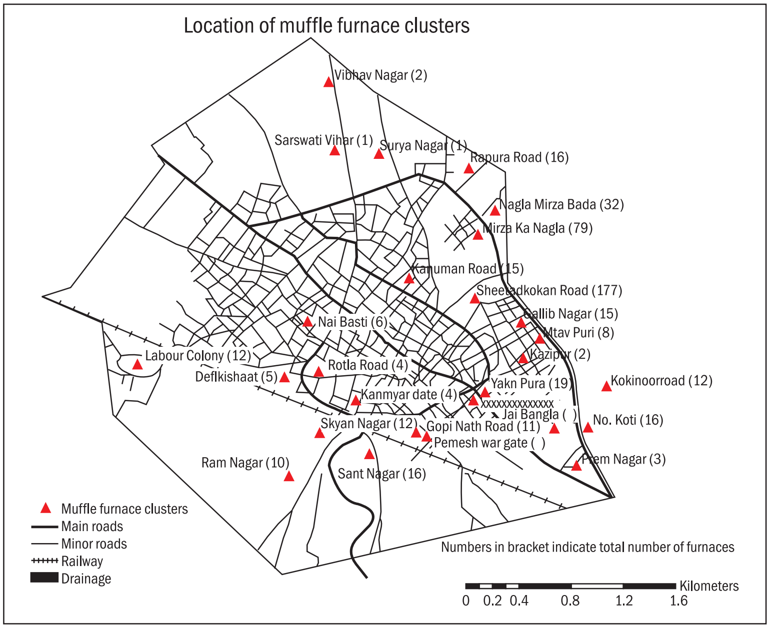
Table 3
RSPM levels in bangle-baking units (µg/m³)[31]

Activity	*Gas-fired muffle furnace*	*Coal-fired* pakai bhatti
Chinnaya (arranging bangles on trays)	479	844
Pakaiya (handling trays in furnace)	431	1024
Ginnaiya (counting bangles)	538	1134
Tray cooling, bangle-shifting	712	1098

Note CPCB standards for RSPM are the following: sensitive area – 75 µg/m^3; industrial area – 150 µg/m^3; and residential area – 100 µg/m^3

[31] As Table 3 shows, the RSPM levels were found to be much higher than the CPCB norms even in the vicinity of the gas-fired muffle furnace. However, these high levels were partly due to the fugitive emissions from the large number of coal-fired *pakai bhattis* in the area, with poor dispersion of RSPM owing to the low height of stacks.

Figure 65
Distribution of *pakai bhattis* in Firozabad



The cluster mapping and AAQ monitoring exercises provided the project team with valuable information as to the number of coal-based *pakai bhattis* that still operated in Firozabad, and the extent of pollution caused by them. In 2004, a detailed GIS (geographic information system) map of Firozabad was procured from an external agency, and the data from the cluster mapping and AAQ exercises were incorporated into it. The GIS map now makes it possible to locate *pakai bhatti* clusters in Firozabad at a glance, and to correlate their locations with pollution levels in different parts of the town.[32] The map will prove useful to all stakeholders as and when future interventions are planned to help *pakai bhatti* operators switch from coal to gas and thereby reduce pollution levels in Firozabad (Figure 65).

[32] Source TERI. 2006. **CoSMiLE operational report for the period January 2006 to December 2006**. New Delhi: TERI

Baseline study of bangle makers

Bangle-making being the most important economic activity in the Firozabad cluster, the project felt that any attempt to improve socio-economic conditions in the cluster needed a thorough understanding of the various activities in the bangle-making process, the profile of workers engaged in these activities, their working conditions, and the impact of the industry on the lives of the workers and their families. The first step was to generate baseline data on the existing conditions. To do this, the project team conducted a survey of various grassroots agencies working in the cluster, to identify one familiar with the socio-economic realities of the cluster and capable of performing this task. Eventually, the project chose Vikas Sansthan, an NGO based in Shikohabad, close to Firozabad. In 2002/03, with the project's support, Vikas Sansthan completed two baseline studies in the Firozabad cluster. The studies helped the project gain an understanding of the bangle-making chain, and of the profiles and plight of workers engaged in various stages of the manufacturing process.

The studies revealed that nearly all the workers in the bangle-making chain are illiterate. Most of them come from Firozabad or its neighbouring districts. There is a sizeable number of migrants from Bihar as well. The majority of families are deprived of basic human needs such as clean drinking water, sanitation, health care, and proper housing. In general, bangle workers have large families; yet they live in tiny, ill-ventilated dwellings in highly congested areas of Firozabad. Worse, their cramped living space is used for bangle-making operations as well. As a consequence, the workers, primarily women and children, are exposed to extremely high levels of pollution in their own homes (Box 62). This makes them vulnerable to a variety of respiratory diseases,

Box 62
Child labour:
alive but less visible

The Firozabad glass industry has long been the focus of attention for the widespread use of child labour. The Child Labour Act, passed in 1986, prohibits employment of children below the age of 14 in hazardous industries. Yet, children continue to work in the household bangle-making sector where conditions are no less arduous and hazardous than they are in the factories. In effect, children may no longer be seen working openly in the glass melting units; but they continue to toil from their own homes.

including tuberculosis. Added to this, the workers use corrosive acids and other toxic chemicals while doing decorative work on bangles. Burn injuries and cuts are common; eye-related ailments too are widespread.

Bangle makers in the household sector are paid piece-rate wages, that is, according to the number of bangles they process in a day. The wages are abysmally low; for instance, in mid-2007 workers were paid a mere 9 rupees per *tora* for both *sedhai* and *judai* work. The workers do not receive even this payment in full. In practice, contractors known as *thekedars* hire the workers. The glass factory owner pays the *thekedar* a lump-sum amount for each batch of work that has to be completed. The *thekedar* pays only a portion of the amount he gets to the workers he has engaged. Furthermore, it is routine for *thekedars* to 'advance' money to bangle-workers at usurious rates of interest, and to deduct the interest dues from the wages payable. The result: workers are trapped in an endless cycle of exploitation and debt.

Social action plan

Vikas Sansthan drew upon the findings of its baseline studies to suggest a few measures that could improve the living and working conditions of bangle workers in Firozabad. Based on Vikas Sansthan's suggestions, in 2003 the project developed a social action plan, or SAP, for the cluster. Under the SAP, field activities were initiated on a pilot scale in two areas where glass workers lived and worked: Makhanpur, and Daukeli. Later, a few social action initiatives were also launched in Kushwhanagar, Azad Nagar, and Asfabad.

Makhanpur—shedding an idea

The main idea of the SAP in Makhanpur was to help *judai* and *sedhai* workers to shift their operations out of their homes to a common workshed (thereby reducing pollution and improving living conditions in their dwellings). In 2003/04, with the project's support, Vikas Sansthan mobilized a number of *sedhai* and *judai* workers in Makhanpur to form SHGs (self-help groups). A shed was taken on rent, and the SHG members were persuaded to shift their work to the shed (Figure 66). To encourage the workers to shift, the project team suggested that all workers who operated from the shed should be paid slightly higher wages than those traditionally paid by *thekedars*. It was hoped that this would counter the lure of 'cash advances' routinely paid to workers by the *thekedars*—advances that, in reality, ensnared the workers in debt

Figure 66
Judai operation at common workshed in Makhanpur

traps. To take care of workers' children, a crèche was set up at a rented place close to the shed, and an educated caretaker hired to manage the crèche.

However, the initial enthusiasm of the SHG members slowly waned. Social customs and cultural barriers made it hard for women to move out from their homes. As a consequence, it was difficult to achieve and maintain the minimum membership required to make the shed a self-sustaining, economically viable venture. Also, the *thekedars* did not take kindly to the SHG initiative, for it sought to bypass them entirely by establishing direct linkages between the glass factory owners and the shed's bangle-workers. Factory owners themselves did not provide much support for the venture. For generations, they had got their bangles made via the *thekedars*, and they saw little reason why they should disturb the 'status quo'. Because of dwindling membership, the hostility of the *thekedars*, the indifference of glass factory owners, and difficulties in day-to-day management, the shed could not achieve a sustainable level of profitable operation even with support from the project. Finally, it was shut down. For the project team, it was a disappointment as well as a learning experience. The team realized that the complex social, cultural, and economic realities that governed the bangle-making community in Firozabad posed a formidable barrier to any social action initiative that involved changes in the established pattern of work.

Daukeli—a good start

Daukeli is a village in the vicinity of Firozabad. About 70 households in the Daukeli area are engaged in making toys and decorative items out of glass (Box 63), and a large number of households are also engaged in *sedhai* and *judai* work. The toys and decorative products are extremely attractive and have the potential to fetch good prices in the market, but the workers lack market visibility. TERI and Vikas Sansthan built upon some preliminary work earlier undertaken by Vikas Sansthan with the assistance of 'Aid to Artisans', a non-profit organization based in the US. Two broad fields of activities were planned.

1 Mobilizing and strengthening the workers in the form of a cooperative
2 Helping the cooperative to develop market linkages for raw materials and products.

The Vikas Sansthan field team interacted extensively with the glass artisans of Daukeli in 2004/05, to make them aware of the benefits of cooperatives. With support from the project, on 12 October 2004, a cooperative of artisans – the Daukeli Glass Toys Workers' Shram Samvida Sahakari Samiti Ltd, with 12 artisans as members and a corpus of 40 000 rupees

Box 63
Poetry in glass

'My heart is in this art...don't let it die!'

This eloquent plea comes from Chaubal Singh, a glass toy-maker of Daukeli. Four decades ago, Chaubal Singh, then a 15-year-old boy, was forced by circumstances to earn a living in the glass industry. He learned to make glass toys from a relative in Firozabad. His toys became such a hit in the local market that others in Daukeli approached him to learn the art. Today, about 70% of the residents of Daukeli make glass toys for a living.

Glass Toy Worker's Cooperative Catalogue, 2003/04 provided by the project – was registered with the local administration under the Uttar Pradesh Cooperative Society Act, 1965 (Figure 67). The project hoped that as registered cooperative society, the artisans would gain visibility and credibility in the market. To further strengthen its market linkages, the project engaged a Delhi-based agency to prepare a brochure show-casing the artisans' various products (Figure 68).

The membership of the Daukeli cooperative has increased from 12 to 50 over the years. The cooperative provides the artisans with a platform on which to discuss toy-making, markets for their products, improving and widening their skills, and other related issues (Figure 69). In 2006, the cooperative succeeded in generating a small surplus with the artisans' own efforts. The wives of the cooperative members, as well as other women in the village, belong to four SHGs that have now come together to form a federation, or *sangh*. The *sangh* members pool their resources so that they can raise small loans at reasonable interest rates to help the cooperative members as well as for various domestic purposes. Thus, the cooperative and the *sangh* are together bringing about small but significant improvements in the lives of the Daukeli glass artisans. The growth in their business turnover may be small; but their confidence has been greatly boosted by the intangible benefits of cooperative action (Boxes 64, 65, 66). However, the Vikas Sansthan field staff report that it is difficult to sustain the enthusiasm of the cooperative members, to persuade them to purchase raw materials from the raw material bank of the

Figure 67
Registration certificate of Daukeli Cooperative

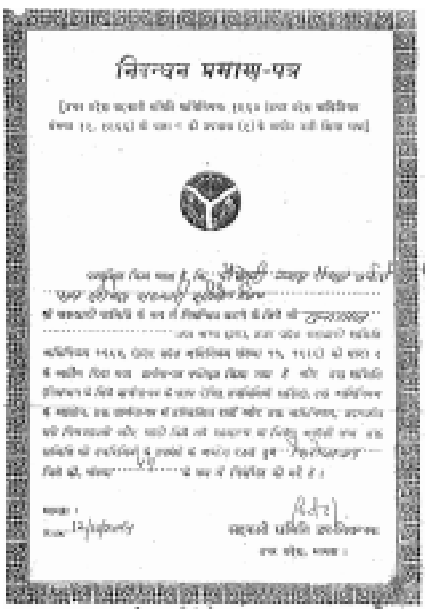

निबन्धन प्रमाण-पत्र

Figure 68
Poetry in glass

Figure 69
Meetings in progress
(i) Women's SHG
(ii) Artisans' cooperative

(i)

(ii)

Box 64
United we stand

The craft-workers of Firozabad produce a wide range of decorative glass items. Earlier they were disorganized, and used to face many business-related problems. The craft-workers of Daukeli village were no exception. For instance, they used to buy raw material at higher rates, because they bought the stuff in small quantities for individual requirements.

But that was in the past. Now, with a cooperative society of their own in place, there are positive changes in the lives of the Daukeli craft-workers. They sit together to discuss and solve their problems. At a cooperative meeting, they decided to start a shop that would buy raw material in bulk (at cheaper rates) and distribute it to individual craft-workers at reasonable rates. It is a win–win situation for all—the craft-workers save on travel time and prices to procure raw material; the cooperative makes a profit (however small); everyone is on a better financial footing!

Sarita D
Vikas Sansthan

Box 65

Engendering strength

The wives of the Daukeli craftsmen actively help their husbands in glassware production, but also have to do all the household work. When the project team advised them to form SHGs of their own and participate in cooperative meetings, it raised something of a hornet's nest. Daukeli, like so many of India's villages, is an extremely conservative society. How could women attend meetings and sit with men? This was the most frequently asked question.

The project team did a door-to-door campaign to persuade and train the women to form SHGs. The first SHG was started by 15 women. Initially hesitant, they even attended a few cooperative meetings. In February 2005, they astounded everyone by participating in the district-level meet. Sumitra Devi, President of the Glass Toys Workers' SHG of village Daukeli, addressed the meet. She appealed to all craftsmen present to encourage their wives to come forward and be active participants in their own advancement.

The members of the SHG practice inter-loaning to fulfil their financial needs. The women are beginning to enjoy their new-found independence and power, and have earned respect and esteem. Their participation in development activities is on the rise.

Dilip Sevarthi

Vikas Sansthan

Box 66

The power of financial independence

We are 13 women in the group and now we have a saving of more than 15 000 rupees. So, whether it is for education of children or for some house expenses, we take a loan from the group. If we have to buy raw material or gas cylinders (for glass decorative work), we buy them collectively. Not like earlier times, when we had to beg people for money at a rate of interest of 5 rupees or 10 rupees for every 100 rupees per month! Now we pay only 2 rupees...I am really happy![33]

Sumitra Devi

Glass Toy Workers' SHG

[33] Quoted in the film *Changing the Convention* (TERI 2005)

cooperative, or to obtain regular orders for their products from markets beyond the existing local market.

Other initiatives: many challenges to overcome

With the Daukeli cooperative experiment showing small but visible signs of success, in early 2005 the project along with Vikas Sansthan organized a district level meet of glass artisans engaged in making decorative items (Figure 70). A number of participants were from Kushbah Nagar, a locality in Firozabad. The artisans in this locality specialize in making decorative items out of borosil; these items look like crystal and are relatively expensive compared to the soda-lime glass items made in Daukeli. In March 2005, an artisan's cooperative—the Glass Handicrafts Workers' Sahakari Shram Samvida Samiti Ltd—was formed in Kushbah Nagar with 24 artisans as members. With assistance from the project, the cooperative was also successfully registered in 2006 under the Uttar Pradesh Cooperative Society Act, 1965, and at present has 41 members. The Kushbah Nagar cooperative initially decided not to set up a raw material bank. Instead, it has established a bank of oxygen gas cylinders (and possibly, LPG cylinders as well in future), which the artisans need for their decorative work. The Kushbah Nagar cooperative members have been able to save around 70 000 rupees till date. They are utilizing this amount successfully to meet their regular business

Figure 70
District-level meet

expenses, as evidenced by the fact that the cumulative disbursements add up to around 115 000 rupees.

Also in 2005, the project initiated activities with more than 100 select families in Azad Nagar, Sant Nagar, and Asfabad aimed at sensitizing *sedhai* and *judai* workers to issues related to occupational health. Posters, door-to-door visits, and presentations at SHG meetings have been used in a mass awareness campaign on the dangers of prolonged exposure to emissions from kerosene lamps, and on postural problems due to long hours at *sedhai* and *judai* work.

As at Makhanpur and Daukeli, these initiatives in the field of social action have had some limited success—in terms of changing attitudes towards cooperative ventures, spreading awareness about health issues, and so on. The SHGs formed at Makhanpur and Daukeli (totalling 10 in number comprising 121 members) have 150 000 rupees as savings and have disbursed around 500 000 rupees cumulatively through inter-loaning for various domestic needs. A few of these SHGs have also obtained bank loans—an indication of their growing creditworthiness. However, the project experiences again point to the fact that the cultural and socio-economic complexities of the Firozabad glass cluster pose immense barriers to any social action initiative aimed at improving the quality of life.

The way forward

Over a decade has passed since the project began its intervention in the Firozabad glass cluster. It is an appropriate time to take stock of progress, and to draw upon the experiences gathered and the lessons learned in order to determine the road ahead and chart the course for future activities—not only in Firozabad, but also in the SMiE sector in general.

Lessons and challenges

Although the TERI–SDC intervention in Firozabad began before the final Supreme Court verdict in the Taj Trapezium case, the activities of the project were greatly influenced by the verdict: specifically, by the Court's directive to the government to supply natural gas as a fuel to industries located in the Trapezium. By carrying out systematic action research in a participatory manner, and by pooling the competencies of various Indian and international experts, the project succeeded in designing, developing, and demonstrating two gas-based energy-efficient technologies for the glass industry by 2001—the recuperative pot furnace, and the gas-fired muffle furnace.

Since then, nearly half of the 80-odd operating open-pot furnace units in the cluster have adopted the TERI-designed furnace. At the present rate of replication, most of the remaining pot furnace units are expected to follow suit over the next few years. However, the picture is not as encouraging in regard to the TERI-designed muffle furnace. *Pakai bhatti* operators have been unable to obtain gas connections from GAIL at their existing locations. As a result, gas-fired muffle furnaces came up only in the premises of pot furnace units, and were rented out to *pakai bhatti* operators. After an initial flurry of replications, which at one time saw over 100 muffle furnaces installed in the premises of different pot furnace units, the replication process has slowed down and actually reversed itself till at present, there are barely 10–12 gas-fired muffle furnaces in operation.

A number of factors have influenced the course of the intervention and determined the pattern and the extent of replications in regard to both the TERI-designed recuperative furnace and the muffle furnace. These factors and their impacts hold lessons, not only for future activities in Firozabad but also for interventions in the Indian SMiE sector in general.

Cluster-level factors

Importance of an ice-breaker/facilitator

Viswadeep Singh, tank furnace entrepreneur and a widely respected person in Firozabad, played a vital role in facilitating the project's activities in the cluster in numerous ways throughout the intervention. He attended the Screening Workshop of December 1994, where he spoke about the problems and concerns of the Firozabad glass industry. Viswadeep helped 'break the ice' when the project team found it hard to establish linkages and interact with the pot furnace owners and other entrepreneurs in the cluster. He played a key role in persuading the pot furnace owners' association to choose a demonstration site for the TERI furnace; identified a local consultant who would play a vital role in the course of the intervention; offered his own factory, free of charge, to conduct trials on preliminary versions of the gas-fired muffle furnace; helped the project team in interacting with government officials and other stakeholders; participated enthusiastically in public meetings at which he spoke out forcefully in favour of the energy-efficient technologies developed by the project; and so on. The experience with Viswadeep underlines the importance of gaining the confidence and having the backing of mentors – ideally, entrepreneurs who are also well known and widely respected members of the local community – while undertaking an intervention in the SMiE sector.

Demonstration site: owner's commitment is the key

Express Glass Works, the demonstration site for the TERI-designed recuperative furnace, was prima facie unsuitable because it was not representative of the typical pot furnace unit in Firozabad. For instance, Express Glass Works operated the largest pot furnace in the whole cluster! Also, Express Glass

Works specialized in melting a very special shade of red glass—and red glass is not only the most corrosive in molten state, but also probably the most difficult colour to obtain. These factors certainly amplified the challenges faced by the project team during the technology development and demonstration process.

However, it is important to note that the project team did not choose Express Glass Works as the demonstration site; rather, the unit's name was proposed by the local glass entrepreneurs' association, that too because Mohammed Islam Khan, the owner, was the only pot furnace entrepreneur in Firozabad who had the courage to step forward and express his willingness to participate in the project as a pioneer. Islam provided unstinting support to the project team both before and after the demonstration. He did not hesitate to invest his own money in acquiring equipment that helped support the demonstration project; for instance, he set up a new factory shed and acquired a new DG (diesel generator) set at his expense for the specific purpose of ensuring uninterrupted power supply to the demonstration unit. He placed complete trust in the team's efforts, provided encouragement when needed, and exhibited enormous patience when there were setbacks. Following the demonstration, he facilitated the project's efforts in disseminating the technology by hosting the 'interaction meeting' of December 2001 at Express Glass Works, by speaking strongly in favour of the TERI-designed furnace on the occasion, and by helping to persuade Bapu Glass Industries to set up the first replication unit.

All in all, Express Glass Works proved to be an ideal demonstration site. The enthusiasm and support of its proprietor contributed in great measure to the morale of the project team. In the ultimate analysis, these personal attributes in Islam enabled the project to overcome the technological challenges and conduct a successful demonstration of its new technology.

Technology: benchmark vs functional

The project set out to develop a gas-fired technology for the pot furnace at a time when pot furnace units were progressively adopting the retrofitted gas-fired pot furnace designed by P M Patel. The retrofitted furnace was the sole technological option available to the entrepreneurs, at a time when they were under pressure to switch from coal firing to gas firing. It also increased their operating profits to some extent by offering a degree of savings in fuel costs compared to coal firing.

However, there was still considerable potential to improve the energy efficiency of the retrofitted furnace. Therefore, the project decided to develop a gas-fired technology for the pot furnace that would set a benchmark in terms of energy efficiency. This benchmarking approach entailed much more intensive R&D and field work, more time, and correspondingly greater expenditure that ultimately reflect in the cost of the TERI-designed furnace. When the recuperative furnace became ready for dissemination in 2002, entrepreneurs were reluctant to adopt it—for they were already making profits on their retrofitted furnaces, and although the TERI-designed furnace offered them much greater fuel savings compared to their retrofitted furnaces, they were deterred by its cost. However, the entrepreneurs' outlook changed drastically when the fuel price, specifically, the price of R-LNG, sharply rose from 2005 onwards. Suddenly, they saw the true value of the energy efficiency promised by the TERI-designed furnace! They also realized that its relatively high capital cost was balanced by a short payback period. The pattern and pace of replications of the TERI-designed furnace thereafter has vindicated the benchmarking approach adopted by the project. At a deeper level, the experiences with the Patel-designed furnace and TERI-designed furnace also reveal that entrepreneurs are capable of adapting to changed circumstances; that they are open to learning new practices and skills; and that they are willing to adopt new technologies, provided that these offer financial benefits in terms of increased profits and attractive payback periods, and fall within their resources.

First benchmark, then explore cost-cutting

In the course of designing and developing both the improved technologies (that is, the recuperative pot furnace and the gas-fired muffle furnace), the project team was aware of the importance of keeping costs low, but its primary focus was on maximizing energy efficiency in the demonstration furnaces. To ensure successful demonstration, reliability and quality were factors of paramount importance in regard to materials and equipment. Hence, these were sourced from reputed firms, often, located far from Firozabad, at relatively high cost. (For example, the recuperator for the demonstration pot furnace was ordered from Gujarat Perfect Engineering in Vadodara; the burners were imported from NU-WAY, UK; the SiC muffles for the gas-fired muffle furnace were obtained from Grindwell Norton). However, once the new furnaces were successfully demonstrated and the benchmark parameters set for their performance, the project was able to weigh these parameters against the need to cut costs, and explore and identify suitable cost-cutting measures in a participatory manner, that is, in consultation with the local entrepreneurs. (For instance, gas-fired muffle furnace operators were given the option of using locally available fireclay muffles instead of the long-lasting but expensive SiC muffles; this greatly reduced the furnace cost. In the case of the pot furnace, local fabricators were identified and trained to make the recuperator, and cheaper, readily available refractory materials were tried out and used to construct the furnace floor in place of the much costlier Zirmul refractories.)

The lesson: first, develop and demonstrate the technology to instil trust among the local entrepreneurs and to benchmark performance parameters; thereafter, explore cost-cutting measures in a participatory manner.

The multiplier effect: incremental approach vs leapfrogging?

In addition to the 40-odd pot furnace units that have replicated the TERI-designed recuperative furnace, over 30 pot furnace units have drawn inspiration from the TERI-designed furnace and set up, on their own, locally designed heat recovery devices to improve the efficiency of their retrofitted pot furnaces. This 'multiplier effect' in fact represents a victory of sorts for the project. It shows that the project's work has had a positive influence that extends beyond the 'direct' replication units; that it has created awareness about waste heat recovery as a method to increase fuel efficiency, and triggered a spirit of innovation and a growing confidence in the use of technology among other entrepreneurs in the cluster. Indeed, entrepreneurs are now extending the idea of heat recovery, step by step, to the auxiliary furnaces as well. It is desirable that this innovative spirit, this willingness to experiment with and adopt modifications in technology, also leads to the units adopting better operating practices.

The project's work has had a positive influence that extends beyond the 'direct' replication units…it has triggered a spirit of innovation and a growing confidence in the use of technology among other entrepreneurs in the cluster

On a broader plane, this kind of step-wise or 'incremental' approach towards increasing energy efficiency may be more practical in many of the SMiE sectors than the 'leapfrogging' approach (in this case, the term means making a quantum jump in energy efficiency) that is so often suggested. Of course, leapfrogging is desirable—it promises to bring about positive change in the quickest possible manner. However, by their very nature, SMiE units find it hard to absorb rapid change; they are inhibited by factors such as lack of technical knowledge, resource constraints, low productivity, and so on. A step-wise, incremental approach allows them to adopt and absorb better technology/operating practices at their own pace, and based on their own unique (unit-specific) requirements; all that they require is the necessary technical backup support to be able to do so. The incremental approach also imparts a growing confidence in the entrepreneurs to experiment with, evolve, and adopt their own cost-effective technological solutions—for instance, a relatively cheap, locally made gas burner is now available in Firozabad, which many pot furnace owners are using in their recuperative furnaces.

Financial assistance: assumptions and reality

At the outset of the intervention, the belief among the project team was that entrepreneurs in SMiE clusters such as Firozabad not only lacked the financial resources to invest in new technology but also found it difficult to access credit from banks and other financial institutions for technology upgradation. The team, therefore, made efforts to cut costs while developing the new technologies, in order to assist entrepreneurs in adopting them.

The project also interacted with a few banks and financial institutions to explore ways by which it could facilitate entrepreneurs in obtaining financial assistance for acquiring the improved technologies—but without much success.

Nevertheless, the pattern and extent of replication of the TERI-designed pot furnace reveals that contrary to the initial belief of the project team, a section of the entrepreneurs in Firozabad – at least, many among those who own/operate larger plants such as pot furnace units – do not lack the financial resources to invest in improved technology. Indeed, almost all the replications of the TERI-designed pot furnace have taken place without the entrepreneurs taking loans from banks or other financial institutions! As explained earlier, replications were slow to begin with only because the entrepreneurs were making profits from their (Patel-designed) furnaces at a time when gas was cheap; they took off when escalating gas prices added weight to the imperative to increase energy efficiency.

However, a number of pot furnace owners are not so well off, and have, therefore, not yet adopted the TERI-designed pot furnace. Also, the smaller entrepreneurs in Firozabad such as *pakai bhatti* operators and glass artisans in household-level processing units operate on thin margins. These entrepreneurs will need financial assistance to acquire improved technologies, even if these technologies are low in cost.

In general, banks appear to be extra cautious in advancing loans to entrepreneurs in the SMiE sector. Not only do the banks satisfy themselves about the entrepreneurs' credit-worthiness; they take the new equipment/machinery itself as security for the loans, and often ask for additional collateral from the borrowers in the form of mortgage of factory shed, land, and so on. This 'security-driven' approach results in an ironical situation. The smaller, resource-poor entrepreneurs are the ones who need financial assistance the most; yet they are unable to access loans from banks because they cannot provide the required collateral. On the other hand, entrepreneurs who own larger, well-established units do not really require financial assistance—yet banks are eager to extend loans to them because they can put up adequate collateral!

Understanding cluster dynamics

The Firozabad experience clearly shows how the course of an intervention can be deeply influenced by the complex economic and socio-cultural currents, some subtle, others more apparent, that run through a SMiE cluster and determine the behaviour of entrepreneurs and other stakeholders. It is only through sustained engagement with the cluster that these field realities can be fully understood and factored into project strategy.

It must be mentioned here that TERI's engagement with Firozabad over the years has been greatly facilitated by the fact that Firozabad is a close-knit cluster, not very far from Delhi and, therefore, relatively easy to access. It would be far more difficult to remain in touch for extended periods with larger SMiE clusters, especially if they are located far from Delhi.

Familial ownership

It took a while for the project team to learn that a number of wealthy families control a large proportion of pot furnace units in Firozabad, and therefore exercise considerable influence over the entire glass industry. Once this discovery was made, the team identified prominent members among these families and made extra efforts to persuade them to adopt the TERI-designed furnace. The strategy has worked. Replication by one family member has a domino effect—other members of the family adopt the new technology on their own, and this in turn encourages other entrepreneurs in the cluster to follow suit. However, the team has learned that this pattern of familial ownership has a downside as well. The enormous influence that these families wield in the cluster makes it very important for the team to exercise utmost tact and caution in its interactions with them. Just as family members act in concert in adopting improved technology, so too they concertedly express their dissatisfaction in regard to problems with the technology—real or perceived. An adverse opinion expressed by them has far-reaching effects in the cluster, and can seriously hinder the replication process.

Energy efficiency: undone by field realities

The inability of *pakai bhatti* operators to obtain gas connections from GAIL has resulted in replications of the gas-fired muffle furnace taking place exclusively within the premises of pot furnace units. In this pattern of replication, the pot furnace owners effectively take up a portion of the benefits brought by the muffle furnaces. This has gone against the very purpose of developing the new technology; that is, to bring direct and sustainable benefits to the *pakai bhatti* operators by reducing fuel consumption and emissions (Box 67). Also, while replication of gas-fired muffle furnaces showed an upward trend till 2006, the steep hike in R-LNG prices thereafter has halted and reversed the replication process, leading to the closure, and in many cases, dismantling, of the existing muffle furnaces in pot furnace units. Almost all the muffle furnace owners have now reverted to their coal-fired *pakai bhattis*. The experience clearly shows the impact of external factors – specifically, fuel pricing policies – on patterns of energy use at the unit/operator level (as discussed later). It also points to the fact that the future of the gas-fired muffle furnace vitally depends on

- enabling small muffle furnace operators to access gas/R-LNG directly and on convenient commercial terms; and
- competitive pricing of gas/R-LNG compared to coal.

Working with tradition

Long-term engagement with the cluster has also led to the realization that at times, tradition and custom wield far more influence than improved technology. As a result, the team has had to shed certain seemingly logical assumptions made at the outset of the intervention, and instead modify the improved technologies to suit these local traditions and customs. For example, it seemed perfectly logical to assume that an entrepreneur would like his recuperative pot furnace to last as long

Long-term engagement with the cluster has also led to the realization that at times, tradition and custom wield far more influence than improved technology…

Box 67
Dividing the benefits

The unexpected course taken by replications of the TERI-designed gas-fired muffle furnace – with units coming up in pot furnace factories rather than in the premises of existing *pakai bhatti* units – has undermined the very purpose behind developing the energy-efficient technology for the reasons summarized below.

- The pot furnace owner allots a fixed amount of gas to the muffle furnace operator. All that matters to the pot furnace owner is that he gets his rent (that is, payment for the gas allotted, plus a premium) on time; he does not care whether or not the muffle furnace operator uses his allotted gas efficiently or in full.
- The muffle furnace operator pays a fixed rent for a fixed amount of gas. He tries to get the maximum out of the gas he has paid for, by driving his workers hard to increase the overall bangle output. In effect, he does not try and reduce his gas consumption; on the contrary, he only strives to increase his production.
- The muffle furnace workers are paid piece-rate wages, that is, according to the number of bangles they produce. Therefore, they too stand to gain by increasing production rather than reducing gas consumption.

Thus, under the existing pattern of replication, the energy-efficient gas-fired muffle furnace has become a source of steady rental income, or a device to increase bangle production, rather than a means to reduce gas consumption. It is clear that for the muffle furnace operators and workers, the primary imperative is to maximize earnings rather than save fuel. As for the pot furnace owner, setting up muffle furnaces is a purely commercial venture. In fact, the muffle furnace operator is wary about revealing his increased bangle output to the pot furnace owner...lest the latter increase the rent!

as possible. Accordingly, while modifying the floor of the recuperative furnace following the demonstration, the team tried out a long-lasting central block/well made of Zirmul with good effect. However, in the course of replications the team has discovered that most entrepreneurs prefer using lower-grade sillimanite for the central block/well, even though sillimanite does not last as long as Zirmul. The primary reason, of course, is that sillimanite is readily available and cheaper than Zirmul, but interactions with entrepreneurs reveal another rather unexpected reason: tradition! It appears that some entrepreneurs are accustomed to shutting down and rebuilding their pot furnaces every year, in a kind of annual cycle that centres on certain festivals like Raksha Bandhan or Holi. Thus, they see no point in using a costly, long-lasting Zirmul block in a furnace that they intend to dismantle and rebuild anyway within a year. Accordingly, the team has left the choice of material for the furnace floor to the entrepreneurs. At the same time, though, trials are being conducted jointly with a refractory manufacturer to improve the performance of the floor.

The importance of adhering to traditional designs and practices emerged during technology development as well. While experimenting with preliminary versions of a gas-fired muffle furnace, the team found that the tunnel-type design gave good results in terms of energy efficiency and bangle output. However, the *pakai bhatti* operators working alongside the project team were not happy with the tunnel-type model because it was totally different in design and operation from their traditional *pakai bhatti*. Further work on the tunnel-type model was, therefore, shelved; instead, the team developed the 3-tier muffle furnace model that closely resembles the traditional *pakai bhatti* in both design and operation.

Local customs and traditional mores also had a major influence on the activities undertaken by the project in the social sphere, as described in the next section.

Social action: barriers and challenges

The pilot social action initiatives taken by the project in Kushbah Nagar, Makhanpur, and Daukeli have revealed the formidable economic, social, and cultural barriers that have to be crossed to make such initiatives meaningful in the long term. The workers in the household bangle-processing units are primarily women and children. Their working conditions are both unhealthy and hazardous. Child labour still exists, minimum wage laws are often violated; indeed, the exact status and nature of household units and their operations are uncertain. Access to the workers is severely restricted by walls of community orthodoxy. The networks of *thekedars* are strong and hard to break or bypass.

The sheer scale of the problems faced by the glass workers in Firozabad – air pollution, hazardous working conditions and practices, lack of health care, abysmal wages – requires that they be addressed at the field level as well as at policy level

In this backdrop, the activities of the workers' cooperatives and women's SHGs in Daukeli and Kushbah Nagar represent a small but significant step forward in economic empowerment of glass workers. Yet, the sheer scale of the problems faced by the glass workers in Firozabad – air pollution, hazardous working conditions and practices, lack of health care, abysmal wages – requires that they be addressed at the field level as well as at policy level. For instance, the cooperative route offers an avenue for workers towards better margins and improved working conditions; but this will require sustained interactions between NGOs, factory owners, and workers' representatives, backed by active and sincere support from the government. Similarly, concerted efforts will be required to develop and demonstrate technological solutions that make the household workers' jobs easier and less hazardous. Furthermore, delivery of these solutions to the workers must be facilitated at low cost by the government or under state-sponsored schemes.

Sustained field presence: the role of SDC

SDC has a principle of long-term engagement in its funding programmes; a principle that enables the formulation of flexible, participatory schemes and programmes that can run for extended durations. Thus, working with SDC has helped TERI in remaining closely engaged with the Firozabad glass cluster for over a decade (Box 68). This continuity in involvement has brought positive results, as evidenced by the ongoing replication of the TERI-designed pot furnace. In turn, these long-awaited replications have greatly boosted the confidence of the TERI team members

SDC has a principle of long-term engagement in its funding programmes....Thus, working with SDC has helped TERI in remaining closely engaged with the Firozabad glass cluster for over a decade, and this continuity in involvement has brought positive results

Box 68
Staying power

I remember how when we went back to Firozabad after our first visit in the mid-1990s, more than one entrepreneur asked us: 'What...you've come back? Why, you are the only people we've ever seen return...most visitors never come back after their first trip!'

Pierre Jaboyedoff
Sorane SA

and strengthened their conviction that sustained efforts and long-term involvement in the field will eventually yield results.

Working with local consultants: benefits and challenges

The key to a successful technological intervention in a SMiE cluster lies in identifying and working closely with local consultants/LSPs (local service providers), that is, technically capable persons who belong to the cluster, and who are already familiar with the ground realities of the cluster—including the nature of the industry and its processes, the entrepreneurs, the technologies in use, the existing markets for raw materials and finished goods, and so on. As described earlier, TERI has worked closely with B C Sharma, an experienced fabricator familiar with the glass industry. As the project's local consultant, Sharma has played a vital role throughout the intervention. He has provided on-site technical support to entrepreneurs, trained local nodes, and helped in promoting the improved technologies. Indeed, the continuing technological support to the entrepreneurs has largely depended on Sharma's local presence and his networking in the cluster. On the other hand, association with the project has certainly enhanced Sharma's stature in Firozabad and added to his capabilities.

In general, it is important to recognize that just as the project benefits from its association with LSPs, so too should LSPs obtain benefits from their association with the project. As the intervention progresses, the LSPs acquire added expertise, as well as stature within the cluster, through their association with the project. From the project's viewpoint, this can make the LSPs more sensitive to, and effective in, furthering the developmental goals of the project. On their part, however, the LSPs understandably use their increased skills to improve their own earnings through their interactions with entrepreneurs and other stakeholders. The challenge is to find a synergistic balance between these two perspectives; that is, to empower the LSPs with new skills and knowledge to further the project goals, yet allow them the freedom to use those skills and knowledge to pursue their own vocations.

In a sense, the LSPs always wear two hats. On the one hand, they are skilled specialists in their own right. On the other, they represent the 'face' of the project in the SMiE cluster concerned. On occasion, this dual role may lead to divergent opinions. Such situations need to be handled with tact and empathy, keeping in view the larger interests of the intervention. Indeed, this only further emphasizes the need for projects to remain engaged with clusters for long durations; to constantly interact and build one-on-one relationships with entrepreneurs, industry associations, and other stakeholders, and thereby understand and keep apace with the complex, ever-changing dynamics of the clusters. This kind of sustained contact becomes particularly important in larger SMiE clusters, since the implementing agencies and the related knowledge banks are invariably located far away from the clusters.

Policy-level factors

Fuel supply and pricing policies

Issues related to the supply and pricing of coal, natural gas, and R-LNG have played a major role in determining the course of the intervention, as revealed in the pattern and extent of replications of the energy efficient gas-based technologies developed by the project. The changes in fuel supply/pricing policies, and their impacts, can be summarized in three broad phases, as described below.

1st phase (1997–2002)

This was the phase following the Supreme Court verdict, when glass units applied to GAIL for natural gas quotas. With the TERI-designed pot furnace still under development/fine-tuning, and in the absence of any alternative technology, all pot furnace units adopted the 'retrofitted' Patel-designed gas-fired furnaces. The units were not sure of their natural gas requirements and applied for gas based on rough estimates. Natural gas was supplied to them under the APM (administered price mechanism) at Rs 6.30/Sm^3. During this phase, a unit could draw gas in excess of its allotted quota without having to pay any penalty. However, the MGO clause (by which GAIL billed a unit for a minimum of 80% of its allotted gas quota) made entrepreneurs nervous about applying for larger gas quotas.

This led some pot furnace entrepreneurs to apply for insufficient gas quotas, and others to apply for excess gas quotas. In effect, some pot furnace units started out with an intrinsic disadvantage compared to others because of the unequal distribution of APM gas allotments among them; a disadvantage that persists till today.

Pakai bhatti units were not even considered by GAIL for gas supply, and continued to operate on coal, which was still available in Firozabad. However, some pot furnace units with excess gas quotas saw an opportunity to profit by setting up TERI-designed gas-fired muffle furnaces (which had by then been demonstrated) in their own factories and renting them out to *pakai* *bhatti* operators. Thus, replications of the muffle furnace took off—not in *pakai bhatti* sites as intended by the project, but in pot furnace factories! This pattern of replication only encouraged both pot furnace owners and muffle furnace operators to utilize their gas quotas to the full.

2nd phase (2002–2004)

As part of its efforts to tackle growing gas shortages in this phase, GAIL charged a higher rate of around Rs 9/Sm^3 on 'overdrawn' gas, that is, gas drawn in excess of sanctioned quotas. This led pot furnace units to become more cautious about gas usage in their auxiliary furnaces. However, the difference between APM price and overdrawn gas price was small—certainly not enough to persuade pot furnace owners to switch to the TERI-designed furnace. Pot furnace owners were content with the profits they were making from their retrofitted furnaces.

In the meanwhile, replications of the gas-fired muffle furnace continued in pot furnace factories, even as coal-fired *pakai bhattis* continued to operate in the cluster.

3rd phase (2004–present)

GAIL commenced supplying R-LNG to Firozabad, and announced that henceforth any overdrawn gas would be billed at the prevailing R-LNG rate, which would vary according to international oil and gas market trends. In 2005, the R-LNG price crossed Rs 20/Sm^3 (as of August 2007, R-LNG cost around Rs 18/Sm^3). The sudden increase in R-LNG price has spurred the replication of the TERI-designed pot furnace from 2005 onwards. The impact has been equally dramatic, but opposite, on replication of the muffle furnace. With the high R-LNG price reducing the profitability of gas-based operation compared to coal-based operation, the number of gas-fired muffle furnaces has dwindled rapidly, and now there are barely a dozen units functioning in the cluster. On the other hand, there is a steady increase in the number of coal-fired *pakai bhattis* because of the continued availability of coal at affordable prices.

The human dimension, and the question of energy security in Firozabad

The intervention in Firozabad has revealed the fact that different players were motivated by differing perspectives and priorities regarding issues such as energy efficiency, fuel supply, pollution at local and global levels, and livelihood issues. In the process, the human dimension to the whole picture got obscured. Figure 71 shows the TERI team's perception of how different stakeholders in Firozabad had different priorities regarding different issues. Even today, over a decade after the Supreme Court verdict in the Taj Trapezium case, the impact of its fallout is visible in the changes brought about in the lives of people who were, and continue to be, dependent on the glass industry for their livelihood (Boxes 69, 70).

In the ultimate analysis, the Firozabad experience brings home a stark truth that applies to the entire SMiE sector in India: low-capacity end-users find it extremely difficult to access cleaner fuels at affordable prices on a sustainable basis

The primary focus of the Taj Trapezium case—and therefore, of the Supreme Court verdict—was on protecting the Taj Mahal and other World Heritage monuments from damage by emissions from coal-burning industries in the Trapezium. On the other hand, the glass entrepreneurs, workers, and other stakeholders, including the general public in Firozabad, were primarily concerned about saving their sole means of livelihood. They were little concerned about the Taj and the effects of coal-based emissions on the monument; indeed, many felt (and still feel) that emissions from the thousands of DG sets in Agra, and from the thousands of trucks and other vehicles that passed through Agra daily, had a far greater impact on the Taj than the emissions from Firozabad.

When the Court verdict finally came, the glass entrepreneurs' primary concern was to find alternative (non-coal) technologies to turn to, gas-based or otherwise. It was precisely for this reason that the project changed track and helped in developing gas-fired technologies for the coal-burning pot furnace units and *pakai bhatti* units. These units were chosen because they respectively constituted the apex and the base of the multiple-level bangle-making industry that sustained the entire Firozabad cluster.

For the government, the only imperative was to implement the Supreme Court verdict. Implementation took the form of arrangements for gas supply via GAIL, primarily to the larger glass melting units. The differential pricing regime for gas supplied to pot furnace units today is a continuing reminder of the uncertain times in the aftermath of the Court verdict—when pot furnace entrepreneurs were not sure how much gas to apply for from GAIL, and when GAIL itself faced a shortfall in natural gas supply.

The *pakai bhatti* units, which were individually small in size yet collectively burned an estimated 100 000 tonnes of coal each year, were completely excluded from the purview of gas supply. Therefore, they continued to operate on coal. The project developed an energy-efficient

Figure 71
Issues of concern in Firozabad—
many stakeholders,
differing priorities

Stakeholders	***Issues of primary concern***							
	Protecting the Taj	*Environmental pollution*		*Energy efficiency*	*Higher productivity/ profits*	*Workers' livelihood*	*Fuel pricing and availability*	*Finance for improved technology*
		Local	*Global*					
Supreme Court	●	●	○	○	○	○	●	○
Government (Union and state)	●	●	○	○	○	○	●	○
GAIL and other fuel suppliers	○	○	○	○	○	○	●	○
Pot furnace owners	○	●	○	●	●	○	●	●
Pakai bhatti owners/operators	○	●	○	●	●	●	●	●
Workers in pot furnace units	○	●	○	○	○	●	○	○
Household unit workers/ owners	○	●	○	○	●	●	●	○
Financial institutions/banks	○	○	○	○	○	○	○	●
Marketing chain (glass products)	○	○	○	○	○	○	○	○
Firozabad citizens	○	●	○	○	●	●	●	○
TERI and partner NGOs	○	●	●	●	●	●	●	●

● = High concern; ○ = Low concern

Box 69
A life transformed:
Piyush, the coal merchant

Piyush Paliwal is the owner of a bangle godown located in Bohran Gulli, the busiest lane in the famous Chudi Bazaar (bangle market) of Firozabad. Piyush learned and inherited the business from his father, who was a coal merchant in the mid-1990s and executed orders for coal on behalf of client glass-melting units. Piyush recalls that in those days, around 25 rakes carrying 2000 tonnes each of good-quality coal used to come to Firozabad each month from CIL collieries in Bihar and Bengal. In addition, he says, around 150 tonnes of lower-grade coal came in by trucks each day.

Following the Supreme Court verdict of 1996, the government directed coal-burning industries in the Taj Trapezium to switch to gas, destroying Piyush's coal business. The decision came at a time when Piyush owed large sums of money to coal suppliers; on the other hand, his own clients owed him large sums of money. 'I repeatedly visited my debtor glass melting units to collect my dues...but they kept asking for time,' he recalls. 'Finally, I started to collect my dues in the form of bangles, which I redeemed for cash with which to settle my own debts!' By this unorthodox method, Piyush not only proceeded to clear his debts, but also acquired considerable knowledge about bangle processing. With no prospect of the coal trade being revived, he decided to operate a large bangle godown.

'Many coal merchants like me were directly affected by the Supreme Court order,' he reflects. 'Some have become traders in glass chemicals; others operate bangle godowns like I do.' Piyush handles over 15 000 *toras* (4.5 million bangles) per month in his godown. The bangles come to his godown for storage after *sedhai* and *judai*. The business is profitable; the bangle industry is growing as always; but Piyush is still open to the idea of returning to the coal business, provided it is legalized.

'The irony is, coal is still freely available in Firozabad,' he points out. 'Besides the *pakai bhattis*, there are a number of other industries that run on coal. But now, the quality of coal is not good. Good quality coal is hard to find...and it costs Rs 5500 or more per tonne. In the old days, the same quality of coal that came in by rake cost just Rs 300 per tonne...”

Box 70
'No-gas-zone' victim

From 1968 Brij Bihari Gupta operated a traditional coal-fired pot furnace at his unit, K B Glass, located in the Parmeshwar gate area of Firozabad. Following the Supreme Court verdict, Gupta put in a formal application to GAIL for gas supply, but was informed that GAIL could not give him a gas connection because Parmeshwar Gate was a 'no-gas' zone. Gupta continued to operate his unit on coal till 2004, when mounting losses, a result of unequal competition with gas-based pot furnace units, forced him to shut down his unit. Today, he too owns a bangle godown....

gas-based technology for them in the shape of the TERI-designed muffle furnace. However, *pakai bhatti* owners could not acquire and install these muffle furnaces at their own units, primarily because of non-availability of natural gas. For a number of years, some *pakai bhatti* operators were able to rent and operate gas-fired muffle furnaces installed at pot furnace units; but the rising price of R-LNG has forced the closure of almost all these muffle furnaces. Indeed, today the R-LNG price is so high that it is more profitable to operate the coal-fired *pakai bhatti* than the TERI-designed muffle furnace. Yet the price of coal too is increasing, reducing the profit margins of the *pakai bhatti* operators. Understandably, their frustration is mounting...even as pollution from their coal-burning *bhattis* grows by the day.

As for the household units that process bangles and other glass items, they continue to use a range of fuels in a variety of inefficient and highly polluting lamps/burners. For instance, the *sedhai* workers use LPG cylinders; the *judai* workers use kerosene; and units making decorative items and toys use LPG, kerosene, and even oxygen and acetylene. To add to this diverse fuel mix, most households burn fuelwood for cooking purposes.

In sum, the larger glass units are able to access clean fuel (natural gas/R-LNG) but at different prices that are a fallout of circumstances that prevailed, and choices and decisions that were made, over a decade ago. The hundreds of *pakai bhatti* units are unable to access natural gas/R-LNG at all even though an energy-efficient gas-based technology has been developed for them. The tens of thousands who toil in household units too are unable to obtain clean fuels such as natural gas/R-LNG for their work.

Can a rational fuel supply and pricing policy be evolved to cater to all these diverse needs of the Firozabad cluster? Can suitable clean and energy-efficient solutions be found for the multitude of applications in the household processing units, so as to reduce air pollution and other health hazards while saving on fuel costs? These are imperative needs; these are the challenges for the future. In the ultimate analysis, the Firozabad experience brings home a stark truth that applies to the entire SMiE sector in India: low-capacity end-users find it extremely difficult to access cleaner fuels at affordable prices on a sustainable basis.

Addressing needs: a stakeholder analysis

TERI's clean, energy-efficient gas-based technologies offer glass entrepreneurs a way to reduce their fuel costs, increase profits, and cut down on emissions. From its experience in Firozabad, TERI has learned that the acceptance and spread of improved technologies critically depend on a variety of complex, interrelated issues at the grass roots, as well as apex levels (Box 71). All these issues are intertwined, and must be addressed simultaneously in a holistic manner if the improved technologies are to bring sustainable, tangible socio-economic benefits to the 150 000 people dependent on the Firozabad glass industry.

The industry stakeholders within the cluster may be viewed under three groups.

1 Glass melting units
2 *Pakai bhatti* units
3 Household-level processing units

Each of these stakeholder groups has differing needs, involving other stakeholders (state as well as non-state). In each case it is essential that the industry stakeholders themselves articulate their specific needs, for only then may strategies be developed to find participatory (and therefore sustainable) solutions to address them. It is clear that the needs of different industry stakeholders can be addressed only with the active involvement of other non-industry stakeholders—government agencies at both state and union levels, NGOs, academic institutions, manufacturers, and others. While the technology-related needs of the glass melting units (specifically the pot furnaces) and *pakai bhatti* units have clearly emerged through extensive interactions with their workers and owners during the course of the intervention, the household-level units pose a special challenge. Any

Box 71
Key to replications: market-determined fuel pricing

The project has achieved around 50% penetration level in the pot furnace segment. In all the TERI-designed furnaces, the energy savings are of the order of 25%–30% as compared to the retrofitted furnaces operating in the cluster. TERI's dissemination strategy in Firozabad has been based on three pillars: (1) optimizing furnace design parameters in consultation with the entrepreneurs to suit the needs and demands of local industry; (2) ensuring the success of the first few replications through closer monitoring both during construction and operation; and (3) regular one-on-one interactions with pot furnace owners.

The change in the external environment, in terms of higher natural gas price, has helped in propagation of the TERI-designed furnace. The industry owners in Firozabad now have to use R-LNG – the price for which is three to four times more than the price for natural gas under APM – in case their consumption exceeds their contracted demand. Although this differential pricing regime leads to unfair competition, it has provided the much-needed impetus to the energy efficiency movement. The spurt in adoption of recuperative pot furnaces in Firozabad during the last two years is a good example of how market-determined fuel pricing positively influences the adoption of energy-efficient technologies. [34]

Girish Sethi
TERI

interventions by the project in this sector will have to form part of a much larger social action initiative, perhaps to be undertaken in concert with government agencies and NGOs.

Glass melting units

After a hesitant start, replication of the project's pot furnace design has gathered considerable momentum in recent years. TERI will continue to support the replication process by way of technical advice and capacity building. The intervention has also revealed considerable scope to increase the energy efficiency in tank furnaces and in the auxiliary furnaces used in glass melting units. Based upon the needs expressed by the entrepreneurs, efforts will be made to support development of improved designs and better operating practices for these auxiliary furnaces.

[34] As quoted in the editorial of the newsletter *CoSMiLE Update* **1**(2) in December 2006.

Entrepreneurs face great difficulty in obtaining good quality refractory materials, and in putting them to proper use, leading to sub-optimal performance of their furnaces. To address this vital issue, TERI will supplement its knowledge resources by networking with refractory specialists and refractory manufacturers. This will help in building the capacity of entrepreneurs and masons on various refractory engineering aspects such as material characteristics, physical and chemical properties, specifications, and laying of refractories for different applications and operating parameters. To reduce the drudgery associated with frequent replacement of failed pots, TERI will continue to work with refractory experts and R&D establishments in its efforts to increase the campaign life of pots.

Pakai bhattis

The single greatest need of *pakai bhatti* units is for access to gas at affordable price. Only then can operators acquire and use the TERI-designed gas-fired muffle furnace, which brings benefits in the form of increased productivity as well as drastically reduced pollution in comparison to coal firing. The major challenge, therefore, is to evolve a mechanism through which GAIL can supply gas at affordable price for use by *pakai bhatti* units.

TERI will, therefore, focus on advocacy and networking with various government agencies to enable *pakai bhatti* operators to obtain gas supply; to facilitate the formation of collectives; and where necessary, to identify suitable sites to which they may relocate. UNIDO and DCMSME (Office of the Development Commissioner, Micro, Small and Medium Enterprises) have recently shown some interest in this idea. In effect, this is a fresh window of opportunity for TERI to help improve the lives of *pakai bhatti* operators at the grass roots level, as well as reduce the levels of environmental pollution in Firozabad at the micro level.

Household-level processing units

As mentioned earlier, rigid cultural and socio-economic barriers make it very hard for the workers in the household-level units to even interact with the project team and other 'outsiders'. While drawing up plans for intervention in this sector, TERI will build upon the lessons that have been learned in the pilot social action initiatives that have been undertaken with Vikas Sansthan. The workers in downstream glass-finishing operations – *sedhai*, *judai*, and other household-level activities – toil in appalling conditions, and there is desperate need for measures that can reduce health hazards as well as bring about socio-economic benefits to their lives. The measures could be aimed at providing workers with opportunities to improve their existing skills and acquire new skills; at developing and disseminating simple, affordable technological devices that they can use in their work; and so on. Also, ways will be explored to link their products with markets; for this holds the key to generating regular income and helping their businesses grow. TERI will continue to work with suitable NGOs and academic institutions in this sector to facilitate such measures.

The road ahead: knowledge-sharing frame

TERI's role in Firozabad is likely to shift in the coming years. From being primarily a developer and implementer of technology, TERI will henceforth act more as a facilitator and institutional force to help anchor the acquired knowledge with the local industry. In other words, the focus will be to consolidate the knowledge that has been acquired during the intervention and to enable all stakeholders – the Firozabad glass industry, equipment and refractory manufacturers, government agencies, researchers, NGOs, and others – to access and utilize this knowledge to mutual benefit.

In the course of the intervention, TERI has established a large informal network of partners—workers, entrepreneurs, consultants, Indian and international experts, government bodies, fabricators, refractory manufacturers, and NGOs. TERI proposes to expand this network and strengthen the capacity of the stakeholders through knowledge-sharing initiatives. Efforts will be made to blend and synergize the existing knowledge of workers and entrepreneurs at the cluster level with additional knowledge that is made available by stakeholders from 'outside' the cluster. Capacity building and awareness generation will, therefore, form a vital part of future activities.

Information provided in the public domain will assume different forms for different stakeholders. For workers and masons, it will take the form of simple leaflets/pamphlets and guidebooks published in the local languages; for pot furnace owners and policy-makers it may take the form of comprehensive manuals, brochures, structured presentations, and so on. Efforts will also continue to sensitize policy-makers and the general public on the socio-economic and livelihood issues related to Firozabad that require urgent, sustained attention and action (Box 72).

To sum up, TERI's future activities in the Firozabad glass cluster will take place in a 'knowledge-sharing frame' and comprise two key elements:

Box 72
Spreading awareness

TERI has prepared three documentary films in the course of the intervention to generate awareness, among policy-makers and others, on the problems being faced by the Firozabad glass industry and the measures taken by the project to address some of these problems. The films are

- *Taj Mahal: beyond the love story* (2002)
- *Through the smokescreen* (2003)
- *Changing the convention* (2005)

In order to sensitize the public on these issues, TERI has made shorter TV film capsules based on these documentaries, which were aired by the Doordarshan News Channel in 2007. At present, case studies are being prepared based on experiences in the glass and ceramics industry sectors.

1) networking; and 2) distribution of knowledge. To ensure that mainstreaming of the improved technologies is sustainable in the long run, efforts will be made to strengthen local industry associations; to provide knowledge through manuals and one-to-one interactions; to promote cooperative networks; to work with community-level organizations; and to advocate changes at policy level that will promote adoption of the technologies and thereby benefit the community at large in terms of increased earnings and cleaner environment. A multi-stakeholder partnership is necessary in order that these activities can succeed. Hence, the activities will form an integral part of the ongoing initiative titled CoSMiLE (Competence Network for Small and Micro Learning Enterprises) launched by TERI and SDC in 2005. The ultimate aim is to ensure that the low-capacity energy users in Firozabad are able to access cleaner fuels and energy-efficient technologies. This is the answer to Firozabad's problems; this is the hope for the future.

The experience and lessons gained in Firozabad may be extended to possible interventions in other SMiE sectors that offer great potential for improvements in energy efficiency and socio-economic benefits for the entrepreneurs and the workforce. At the policy level, an important component of TERI's future activities will be to work with various government agencies to facilitate the formulation and implementation of strategies and programmes for the sustainable development of the small and micro enterprises sector. Perhaps, this is also an appropriate time to revisit the macro-level study of energy consumption patterns in the SMiE sector conducted in 1992, and undertake a fresh and comprehensive diagnosis in order to provide an updated analysis of energy use in the MSME (micro, small, and medium enterprises) sector in India.

ANNEXURE 1

ALL ABOUT GLASS

The exact date when glass was first discovered is still a mystery. We do know that glass was used around as a glaze for beads as far back as 4000 BC. One of the oldest methods to make glass products was 'core forming', believed to have been practised around 1500 BC. A coating of mud, clay, or a similar substance was formed around a metal rod. Heated (semi-molten) glass was then wrapped around this form. Once the external shape was clearly defined and the glass cooled down, the core of the material was scraped out leaving the desired hollow glass form.

The introduction of the blowing-iron in the 1st century BC was a major step forward in glass production. Glass could now be blown into desired shapes, enabling the manufacture of a vast range of hollow vessels and other products. The blowing-iron also led to the production of the first glass windows. A bubble of glass was blown, and then spun while still hot until it assumed the shape of a flat disc. This was then cut into square windowpanes as it cooled down.

HOW GLASS IS MADE

A noted technologist made the interesting observation that the six elements most commonly used in making glass and ceramics – oxygen, silicon, aluminium, calcium, magnesium, and sodium – also happen to be among the eight most commonly occurring elements in the earth's crust.[35]

Glass is a product obtained by the fusion (melting together) of several inorganic substances, of which the main one is silicon dioxide (silica, SiO_2) in

[35] Bray C. 2000. ***Ceramics and Glass: a basic technology***. Sheffield, UK: Society of Glass Technology

the form of sand. The molten mass is cooled to room temperature at a rate that prevents crystallization. This produces transparent glass. If translucent or opaque glass is required, the molten mass is cooled at a rate that allows a predetermined level of crystal formation.

Sand by itself can be fused to make glass; but this requires a very high temperature, around 1700 °C. The temperature for fusion can be reduced considerably by adding substances known as fluxes. Sodium carbonate (soda ash, Na_2CO_3) is commonly used as a flux. A mixture containing 75% SiO_2 and 25% Na_2CO_3 reduces the fusion temperature to about 800 °C. However, a glass with this composition is water-soluble (and hence known as 'water glass'). To give the glass stability, other chemicals such as calcium oxide (CaO), and magnesium oxide (MgO) are needed—the raw materials usually used are their carbonates, $CaCO_3$ (limestone) and $MgCO_3$ (dolomite). Most kinds of glass also contain a small quantity of aluminium oxide (alumina, Al_2O_3).

Besides the above chemicals, another raw material is added to the mixture for melting—broken glass, also known as cullet. The cullet may comprise factory rejects as well as glass collected from the public. Almost any proportion of cullet can be added to the fusion mixture. However, it is important that the cullet should be of the right colour and free from impurities, especially from metals and ceramics.

Kinds of glass

There are three common types of glass.[36]

1 Soda-lime-silica glass ('soda-lime glass')
2 Lead glass or lead crystal
3 Borosilicate glass

Soda-lime glass

Soda-lime glass is by far the most common kind of glass. It is used to make products such as bottles, containers, and the cheaper kinds of tableware and decorative ware. Soda-lime glass transmits a very high percentage of visible light, making it ideal for windowpanes. It is also virtually inert to chemicals, and so containers made from soda-lime glass do not contaminate their contents or affect their taste. However, soda-lime glass has one major disadvan-

[36] The descriptions of different kinds of glass, including the figures, are based on the book *Ceramics and glass: a basic technology*, by Charles Bray (Sheffield, UK: Society of Glass Technology, 2000).

tage—a relatively high thermal expansion. Because of this property, containers made from soda-lime glass tend to crack with quick changes in temperature. Silica itself does not expand much when heated, but the addition of Na_2CO_3 dramatically increases the expansion rate. In general, the higher the proportion of Na_2CO_3 (in the form of sodium oxide, Na_2O), the more the vulnerability to sudden change in temperature (known as 'thermal shock').

A typical soda-lime glass bottle may have the following composition.

Constituent	*Percentage*
SiO_2 (silicon dioxide)	70%
Na_2O (sodium oxide)	23%
CaO (calcium oxide)	5%
Al_2O_3 (aluminium oxide)	2%

Lead glass

The use of lead oxide (PbO) instead of CaO, and of potassium oxide (K_2O) instead of Na_2O, gives the type of glass commonly called lead crystal or lead glass. As a rule, any glass that contains at least 24% PbO is called lead crystal. When some or all of the PbO is replaced by varying amounts of zinc oxide (ZnO), barium oxide (BaO) or K_2O, the glass is simply called 'crystal'. Lead glasses have very high refractive indices and relatively soft surfaces, and so they are easy to shape and decorate by grinding, cutting, and engraving. Lead glass is mainly used for making expensive tableware, cut and engraved glass items, some kinds of optical glass, and as 'high-lead' glass (65% or more PbO) for its radiation-resistant properties in the nuclear industry.

A typical lead crystal object may have the following composition.

Constituent	*Percentage*
SiO_2	56.6%
Al_2O_3	1.4%
PbO (lead oxide)	29.0%
Na_2O	4.5%
K_2O (potassium oxide)	8.5%

Borosilicate glass

As the name indicates, borosilicate glass is made up mainly of SiO_2 and boric oxide or B_2O_3 with small amounts of Na_2O, K_2O, and Al_2O_3. Borosilicate glass has a low alkali content, which gives it high chemical durability and resistance to thermal shock. It is hence ideally suited for making a wide range of chemical industry equipment, laboratory apparatus, pharmaceutical containers such as ampoules, and so on. At home, borosilicate glass finds use in ovenware and other heat-resistant vessels. The famous 'Pyrex' brand name of heat-resistant borosilicate glassware was created by the US glass firm Corning (Box A1-1).

A typical borosilicate glass object may have the following composition.

Constituent	*Percentage*
SiO_2	66.0%
B_2O_3 (boric oxide)	22.7%
Al_2O_3	4.5%
Na_2O	6.8%

Box A1–1
Ovenware story

Borosilicate glass is renowned for its toughness and ability to withstand extreme changes of temperature. Otto Scott and Ernst Abbe developed it in the 1890s. Corning, the American glass company, used the same material in making lantern glass for the American railways, as it could withstand the high temperature of the lanterns as well as rough weather conditions. Yet, the very success of this durable glass made it bad for business—for, once fitted into the lanterns, it never needed replacing! Corning therefore sought other markets for borosilicate glass.

The story goes that the wife of a Corning scientist, Bessie Littleton, tested the new glass by baking a cake in two sawn-off battery jars made from borosilicate glass. She discovered that the cake was evenly baked, the baking time was shorter, and the cake did not stick to the sides of the glass. Corning built upon Bessie's discovery, and in due course developed and marketed a range of ovenware and other heat-resistant glass products under the famous brand name 'Pyrex'.[37]

[37] This anecdote is drawn from the book *Glass—material for inspirational design*, by Chris Lefteri (Rotovision SA: Mies, Switzerland, 2002).

ANNEXURE 2

EVOLVING A GAS FLOW/ MELTING SCHEDULE FOR THE DEMONSTRATION FURNACE

When the project team commissioned the demonstration pot furnace at Express Glass Works in February 2000, a major challenge was to establish a proper melting schedule for the furnace, that is, to determine the rate at which gas should be supplied to the burner at different stages of the preheating and melting operations. To do this, the team first had to find a way to measure the temperature inside the furnace on a continuous basis. It then had to study how and why the heat requirement of the furnace varied over a period of time. Finally, based on this study, it had to evolve a method by which the varying amounts of heat required by the furnace, at different stages and for different durations, could be matched with the quantity and rate of gas supplied to the burner. This complex task was especially difficult because there was no data whatsoever to go on. The *mistrys* used no instrumentation at all to measure temperatures in the traditional coal-fired pot furnaces; nor did they record any data on the quantities of coal burned during the preheating and melting operations.

MEASURING FURNACE TEMPERATURE

To find a way to measure the temperature inside the furnace on a continuous basis, the project team used two thermocouples. One was positioned with its

Figure A2–1
Measuring furnace temperature

tip inside the furnace while the other was inserted into a cleft made in the crown, so that its tip was separated from the interior of the furnace only by a few centimetres of crown material (Figure A2-1).

The preheating gas burner was then switched on to start heating up the furnace. As the furnace temperature increased, readings were taken at periodic intervals from both the thermocouples. By establishing a relationship between the two sets of readings, the project team was able to develop a chart whereby the actual temperature inside the furnace could be determined by reading the temperature of the thermocouple in the crown.

Preheating schedule

Preheating the furnace in a smooth and carefully phased manner was important: for, rapid or uneven heating could cause thermal shocks and damage the structural material of the furnace. The project team requested Andrew Hartley of British Glass to provide a safe preheating schedule. The team tried to strictly follow this preheating schedule for the demonstration furnace (Table A2-1).

Initially, the preheating was done by means of a simple, locally made 'inspirator type' gas burner that was positioned at the glass collection hole at

Table A2-1 Preheating schedule for the gas-fired pot furnace

Rate of heating (°C/hour)	Duration *(hours)*	Furnace temperature achieved *(°C)*	Cumulative time *(hours)*
4	25	100	25
3	40	220	65
6	48	500	113
4	60	750	173
10	25 (+)	1000 (+)	198 (+)

Source Table 11, TERI Report 99CR44

the base of the furnace. To maintain the rate of heating along the recommended curve (Table A2-1), the gas supply to the burner was increased periodically by means of a valve. When the temperature crossed 1000 °C, the preheating burner was turned off and removed, and the main gas burner was switched on.[38]

Gas flow/melting schedule

To arrive at a proper gas flow/melting schedule for the demonstration furnace during melting operations, the project team first had to study the complex rhythms of charging the furnace and drawing the molten glass from it. Unlike tank furnaces, pot furnaces use a batch melting process with a 24-hour period: that is, the furnace is loaded with pots containing raw materials and cullet on a continuous basis, with each pot at a different stage of melting during a 24-hour period! Thus, the thermal requirement of a pot furnace varies constantly over each 24-hour period. It is maximum when all the pots contain only raw material for melting, and it is minimum when the contents of all the pots are molten and are being held at melting temperature.

The demonstration furnace had 12 pots, each with a capacity of 560 kg (or 14 *mann*; 1 *mann* = 40 kg) to match the existing traditional furnace at Express Glass Works. Normally, six pots were used to make clear glass and six to make red glass. The practice at the unit was to draw molten glass from two pots at a time: one of clear glass and the other of red glass. After all the glass was drawn from a pot, it was again recharged with raw materials. Usually, it

[38] For subsequent replications, the main gas burner itself was used for the preheating at lower temperature since it had a high 'turn-down' ratio.

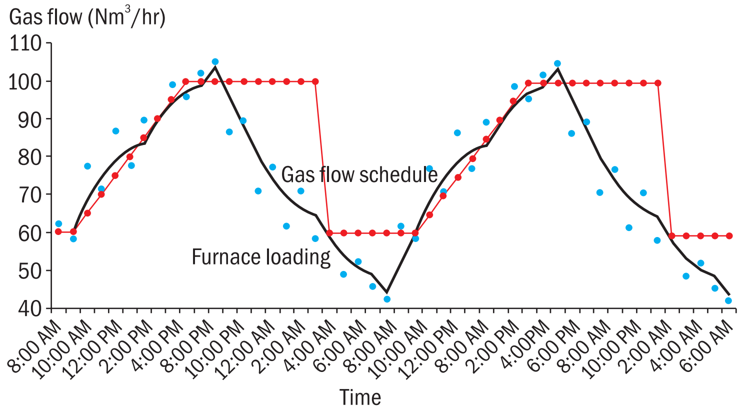
took seven hours to melt charge in a 'fresh' pot; four hours to melt the second charge in it; and three hours to melt the third charge.

The project team reasoned that at any point in time, the heat required by the furnace depended directly on the total amount of charge that remained to be melted—and hence, on the total time required for this charge to be melted. Based on this reasoning, a profile of the hourly heat requirement of the furnace over a 24-hour period was obtained by drawing up a chart showing the TFL (total furnace load) on an hourly basis (Figure A2-2).

Figure A2–2
Profile of furnace loading

Time/ Pot No.	1	2	3	4	5	6	7	8	9	10	11	12	Total furnace load
8:00 AM	7				7								14
9:00 AM	6				6								12
10:00 AM	5	7			5	7							24
11:00 AM	4	6			4	6							20
12:00 AM	3	5	7		3	5	7						30
1:00 PM	2	4	6		2	4	6						24
2:00 PM	1	3	5	7	1	3	5	7					32
3:00 PM	4	2	4	6	4	2	4	6					32
4:00 PM	3	1	3	5	3	1	3	5	7		7		38
5:00 PM	2	4	2	4	2	4	2	4	6		6		36
6:00 PM	1	3	1	3	1	3	1	3	5	7	5	7	40
7:00 PM	3	2	4	2	3	2	4	2	4	6	4	6	42
8:00 PM	2	1	3	1	2	1	3	1	3	5	3	5	30
9:00 PM	1	3	2	4	1	3	2	4	2	4	2	4	32
10:00 PM		2	1	3		2	1	3	1	3	1	3	20
11:00 PM		1	3	2		1	3	2	4	2	4	2	24
12:00 AM			2	1			2	1	3	1	3	1	14
1:00 AM			1	3			1	3	2	4	2	4	20
2:00 AM				2				2	1	3	1	3	12
3:00 AM				1				1	3	2	3	2	12
4:00 AM									2	1	2	1	6
5:00 AM									1	3	1	3	8
6:00 AM										2		2	4
7:00 AM										1		1	2

Figure A2–3
Relation between furnace loading and gas flow



In the first few days of commissioning the furnace, the project arrived at a rough gas flow schedule based on a 'hit and trial' method. Thereafter, this schedule was fine-tuned by comparing it with the TFL chart (Figure A2-3).

ANNEXURE 3

GAS-FIRED MUFFLE FURNACE: PRELIMINARY TRIALS

As described in the main text, the project team built a number of prototype gas-fired muffle furnaces (based on the three winning entries in the design competition conducted in 1998/99) in order to conduct tests on them and evolve improved models for extended field trials. The prototype furnaces were set up at the premises of Electronic Glass Works. The furnaces were of two kinds: tunnel type and traditional *pakai bhatti* design. In all the models, the emphasis was on keeping costs low at every stage of evolution.

GAS-FIRED TUNNEL-TYPE MODEL

In essence, this furnace comprised a tunnel, about 2.6 metres long, that was heated up by hot flue gases from two gas burners placed at one end of the tunnel. Raw bangles were placed on trays, which were then passed through the tunnel from the cold end to the hot end so as to bake the bangles.

The basic structure of the furnace was made using locally available fireclay bricks. Locally made gas burners were used for the trials. In order to determine the thermal efficiency of the furnace, it was necessary to measure the temperature in different parts of the tunnel. Three 'trailing' thermocouples were tied to a rod, and the rod was slowly pulled through the tunnel. Temperatures were recorded at points placed at uniform distances along the tunnel. The temperature increase was found to be gradual and steady, with the hot end reaching 930 °C.

It proved a major challenge to figure out the best mechanism by which the trays could be moved along the tunnel. After trying out many methods, the project team found a relatively effective solution. The trays were designed so that they could be joined to one another by detachable slotted hooks; this allowed an entire train of trays to be pulled slowly along the tunnel from the cold to hot end, using either manual or mechanized means. *Pakai bhatti* owners Akhilesh Gupta and Foren Singh expressed their satisfaction with this model's performance. Rough estimates showed that the tunnel furnace consumed 8–9 Sm^3/hour gas; this translated into 30% improvement in energy efficiency over the traditional coal-fired *pakai bhatti*.

However, there were considerable problems faced while fitting and removing the hooks on the trays, making this system impractical for use in a field model. There were other problems as well. The metal trays tended to warp as they moved through the tunnel. The bangles themselves became misshapen because of the uneven, jerking motion of the trays when pulled manually through the tunnel. Also, due to the linear increase in temperature within the tunnel, the bangles within a tray were not baked uniformly—the row of bangles at the front or 'hot' end of the tray always received more heat than the row of bangles at the rear or 'cold' end of the tray!

After the project team conducted preliminary tests on the tunnel-type model at Firozabad, TERI also worked with Dhanaprakash Industrial Corporation – one of the winners of the design competition – to build a tunnel-type muffle furnace at its plant in Miraj, and conducted preliminary trials on it. Based on the results, a modified version of the tunnel-type furnace was constructed at Electronic Glass Works under the supervision of engineers from Dhanaprakash Industrial Corporation. This modified model had burners with automatic controls, ceramic fibre insulation around the tunnel, and a system that enabled mechanized pulling of the trays. However, these modifications only increased the cost of the furnace considerably. The project also realized that it was not practicable to use a mechanical system for pulling trays, given the fact that different kinds of bangles required different degrees of exposure to baking temperatures (see Box 32, 'Heat for bangle-baking', in the main text).

In the light of these problems, the project team discontinued further work on the tunnel-type muffle furnace.

Gas-fired model based on *pakai bhatti* design

Alongside the experimental tunnel-type furnace, the project team built and experimented with a prototype gas-fired muffle furnace. The basic design and structure of the model was similar to that of the traditional *pakai bhatti*. To begin with, the team used locally made 'inspiring' burners but found that these produced copious quantities of CO (carbon monoxide). This translated into high heat losses, because instead of being burned to generate heat, carbon was being allowed to escape in the form of CO which made up as much as 2% of flue gas content! After trying out alternative burners without much success, the team finally developed its own version of a low-cost inspiring burner that yielded satisfactory performance. This burner reduced CO emissions to less than 250 PPM (parts per million). Two such inspiring gas burners were used in the model to provide better heat distribution across the muffles (Box A3-1).

The project team also experimented with different numbers and kinds of muffles. The traditional *pakai bhatti* uses relatively cheap fireclay muffles. However, the life of the hottest (lowermost) fireclay muffle is highly unpredictable and usually not more than 15 days. With each fireclay muffle costing around 225–250 rupees, constant replacement of muffles creates a drain on the operator's resources. Also, each time a muffle needs to be changed the furnace has to be shut down and cooled, the damaged muffle removed and replaced by a new muffle, and the furnace heated up again to baking temperature. Thus, the use of shortlived fireclay muffles results in considerable financial losses for the operator in terms of fuel wasted, time lost, labour costs, and fall in production—besides of course the recurring costs of new muffles.

Box A3–1
Inspiring burner

An inspiring burner is a gas burner that uses the kinetic energy of the gas flowing through it to draw in just the right amount of air needed for combustion. This kind of burner is ideal for applications that do not require variations in the rate of gas flow, such as for baking bangles! It is relatively cheap and easy to fabricate and does not require a blower to operate, making it suitable for low-cost applications.

The project team, therefore, experimented with muffles made of SiC (silicon carbide), a refractory material that conducts heat almost 10 times more effectively than fireclay and is extremely resistant to chemical attack and thermal stress. The SiC muffles were expected not only to transfer heat to bangles more effectively (thereby improving energy efficiency), but also to last around two years and thereby bring considerable savings for the operators. On the other hand, SiC muffles were much more expensive than fireclay muffles, and so the team decided to try them out only for the lower muffles in the prototype models.

After repeated tests and progressive modifications, three improved models of gas-fired muffle furnaces were developed for extended field trials.

1 3-tier furnace with fireclay muffles
2 3-tier furnace with SiC muffles
3 5-tier furnace with two SiC muffles and three fireclay muffles

The main text describes how comparative field trials were conducted on all three models at Saraswati Glass Works, and how the results of the trials clearly identified the best option among the three, namely, the 3-tier furnace with SiC muffles.

ANNEXURE 4

GAS-FIRED POT FURNACE—REPLICATION UNITS

UNITS THAT HAVE ADOPTED THE TERI-DESIGNED RECUPERATIVE FURNACE

S. No.	*Name of unit*	*Owners/Partners*	*Date of commissioning*
1	Express Glass Works	Mohammed Islam Khan	February 2000
2	Bapu Glass Industries	Lalitesh Kumar Agarwal	September 2004
3	Navjeevan Glass Industries	Ravindra Kumar Garg	February 2005
4	Shiva Industries	Promod Kumar Jain	June 2005
5	R S Glass Industries	P K Jindal	July 2005
6	Raja Glass Works	Mukesh Kumar Jain	July 2005
7	R S Glass Industries (2nd unit)	P K Jindal	August 2005
8	Anup General Industries	Prabhas Kumar Jain	August 2005
9	Yadav Glass Works	Ramesh Mittal	November 2005
10	Raja Glass Works (2nd unit)	Mukesh Kumar Jain	February 2006
11	PLS Autoshell Industries (Pvt.) Ltd	Lalitesh Kumar Agarwal	March 2006
12	Caprihan Chemical Glass Works	Pradeep Kumar Jindal	April 2006

Continued

Units that have adopted the TERI-designed recuperative furnace (*Continued*)

S. No.	*Name of unit*	*Owners/Partners*	*Date of commissioning*
13	Jain Industries	Rahul Jain	June 2006
14	S Rajeev Glass Works (P) Ltd	Lalitesh Kumar Agarwal	June 2006
15	S R Glass Industries	Girish Maheshwari	July 2006
16	Navjeevan Glass Industries (2nd unit)	Ravindra Kumar Garg	July 2006
17	Prem Glass Works	Rakesh Kumar Agarwal	August 2006
18	Fine Glass Beads Manufacturers	Liyaquat Ali	August 2006
19	Akashdeep Pottery (Shivam Glass)	Dilip Chaturvedi	August 2006
20	Santosh Glass Works	Subhash Gupta	August 2006
21	Anup Glass Industries	Anil Agarwal	September 2006
22	Ajanta Glass Works	Girish Maheshwari	September 2006
23	Purushottam Glass Works	Anil Agarwal	September 2006
24	Ellora Glass Industry	Syed Shahzad Ali	November 2006
25	Shivcharan Lal Ambika Prasad Glass Works	Janaki Prasad Garg	November 2006
26	Bapu Glass Industries (2nd unit)	Lalitesh Kumar Agarwal	January 2007
27	Ansar Glass Works	Mohd. Swaleen	January 2007
28	G Nath Glass Works	Vinod Jain	January 2007
29	Irfan Glass Works	Naved Mukarram	January 2007
30	Adarsh Glass Industries	Sanjay Jain	February 2007
31	Super Glass Works	Ashok Kumar Raniwala	February 2007
32	Akashdeep Glass Works	Vikas Mittal	February 2007
33	International Glass Works	Shailendra Paliwal	April 2007
34	Labour Glass Industries	Praveen Kumar Jain	May 2007
35	Suhag Kaanch Udyog	Sachin Gupta	May 2007
36	The Amrit Glass Works	Rajendra Agarwal	July 2007
37	Anup Glass Industries (2nd unit)	Anil Agarwal	August 2007
38	Gyanchand Mahavir Prasad Jain Industries	Surendra Gupta	August 2007
39	Shri Bardwan Products India	Mohan Kishan Gupta	August 2007
40	Dinesh Glass	Nassiruddin Siddiqui	October 2007
41	Shri Durga Glass Works	Chandra Kumar Jain	December 2007
42	Shanti Glass (Irfan Glass Works) (2nd unit)	Naved Mukarram	Ongoing
43	Seema Glass Works	Syed Shahzad Ali	Ongoing
44	National Glass Industries	Kamarul Hasan	Ongoing

'Spin-off' replications—units that have installed their own variants of the TERI-designed recuperator[39]

S.No.	*Name of unit*
1	Ganesh Beads
2	J P Glass/Saraswati Beads
3	Oriental Glass Industry
4	Padmavati Glass Works
5	Popular Glass Works
6	Technical Glass Works
7	A-One Glass Works
8	Alok Glass
9	Bajarang Glass
10	Empasil Glass
11	Shringar Glass Works (Popular)
12	Sitaram Glass Works
13	Kadari Glass
14	Mathur Glass
15	Narain Glass
16	Neelam Glass Industries
17	Patel Glass
18	R R Glass Works
19	Ram Hari
20	Ruby Novelties Glass Works
21	S B Glass Works
22	Saraswati Glass Works
23	Satyanarayan Glass Works
24	Shyama Glass Works
25	Raghav Glass Works
26	Bright Glass
27	Govind Glass Works
28	India Optical

[39] As compiled by local consultant B C Sharma in September 2007.

Bibliography

Printed documents

Albu M. 1997
Technological Learning and Innovation in Industrial Clusters in the South
[Paper no. 7]
Brighton: Science Policy Research Unit, University of Sussex

Bray C. 2000
Ceramics and Glass: a basic technology
Sheffield: Society of Glass Technology

Foundation for MSME Clusters. 2007
Policy and Status Paper on Cluster Development in India
New Delhi: Foundation for MSME Clusters
[Draft paper presented at the study workshop, TERI, India Habitat Centre, New Delhi, 10 July 2007]

Gulati M. 1997
Restructuring & Modernization of SME (small and medium enterprises) Clusters in India
New Delhi: United Nations Industrial Development Organization

Kishore V V N, Bhandari P, and Gupta P. 2004
Biomass energy technologies for rural infrastructure and village power: opportunities and challenges in the context of global climate change concerns
Energy Policy **32**(2004): 801–810

Kock J and Sode T. 1994
Glass, Glass Beads and Glassmakers in Northern India
Bellahojvej, Vanlose (Denmark): THOT Print

Lefteri C. 2002
Glass—material for inspirational design
Mies, Switzerland: Rotovision SA

Mande S and Kishore V V N (eds). 2007
Towards Cleaner Technologies: a process story on biomass gasifiers for heat applications in small and micro enterprises
New Delhi: TERI

MoSSI (Ministry of Small-scale Industries). 2006
Annual Report 2005/06
New Delhi: MoSSI

Patel S U, *et al*. 2006
Estimation of gross calorific value of coals using artificial neural networks
Fuel **86**(3):334–344

Rathod R A, *et al*. 1987
Thermal stress and physiological strain in the glass bangle industry
European Journal of Applied Physiology, 1987: pp. 56, 58–63

TERI (Tata Energy Research Institute). 1995
Energy sector study phase 1
Report submitted to Swiss Agency for Development and Cooperation
[TERI Project Report number 93IE56 (1995)]

TERI (Tata Energy Research Institute). 1998
Energy Conservation in Small and Micro Enterprises: an action research plan
New Delhi: TERI. 187 pp.
[Proceedings of the Screening Workshop, 8–9 December 1994, New Delhi, edited by V Joshi, P Jaboyedoff, N S Prasad, N Vasudevan]

TERI (Tata Energy Research Institute). 1998
Action research programme in glass industry (TA2)
Report submitted to the Swiss Agency for Development and Cooperation
[TERI Project Report number 95IE59 (1998)]

TERI (Tata Energy Research Institute). 1999
Energy efficiency and renewable energy sources – TA2 – Glass Sector – Phase 3
Report submitted to the Swiss Agency for Development and Cooperation
[TERI Project Report number 98IE42 (1999)]

TERI (Tata Energy Research Institute). 2000
Demonstration and development of a dissemination package for pot furnace and muffle furnace in glass industry at Firozabad—energy sector Phase 4 – Glass TA2
Report submitted to Swiss Agency for Development and Cooperation
[TERI Project Report number 99CR44 (2000)]

TERI (Tata Energy Research Institute). 2000
Environmental improvement and sustainable development of the Agra–Mathura–Firozabad Trapezium in Uttar Pradesh—an Action Plan
Report submitted to the Asian Development Bank
[TERI Project Report number 97CR51 (March 2000), Volume 1]

TERI (Tata Energy Research Institute). 2000
Environmental improvement and sustainable development of the Agra–Mathura–Firozabad Trapezium in Uttar Pradesh—an Action Plan
Report submitted to Asian Development Bank
[TERI Project Report number 97CR51 (March 2000), Volume 2]

TERI (Tata Energy Research Institute). 2001
Demonstration and development of a dissemination package for pot furnace and muffle furnaces in the glass industry at Firozabad (Extension Phase – from July 2000 to March 2001)
Report submitted to the Swiss Agency for Development and Cooperation
[TERI Project Report number 1999CR44]

TERI (Tata Energy Research Institute). 2001
Demonstration and development of a dissemination package for pot furnace and muffle furnaces in the glass industry at Firozabad (Extension Phase – from April 2001 to November 2001)
Report submitted to the Swiss Agency for Development and Cooperation
[TERI Project Report number 2001CR41]

TERI (Tata Energy Research Institute). 2002
India: cleaner technologies in the small-scale glass industry (action research and pre-dissemination); progress report (for the period January 2002 to June 2002)
Report submitted to the Swiss Agency for Development and Cooperation
[TERI Project Report number 2002CR42 January 2002 to June 2002]

TERI (The Energy and Resources Institute). 2003
India: cleaner technologies in the small-scale glass industry (action research and pre-dissemination); operation report (for the period July 2002 to April 2003)
Report submitted to the Swiss Agency for Development and Cooperation
[TERI Project Report no. 2002CR42 (July 2002 to April 2003)]

TERI (The Energy and Resources Institute). 2003
India: cleaner technologies in the small-scale glass industry (action research and pre-dissemination); operation report (for the period May 2003 to September 2003)
Report submitted to the Swiss Agency for Development and Cooperation
[TERI Project Report number 2002CR42 (May 2003 to September 2003)]

TERI (The Energy and Resources Institute). 2004
India: cleaner technologies in the small-scale glass industry (action research and pre-dissemination); operation report (for the period October 2003 to September 2004)
Report submitted to the Swiss Agency for Development and Cooperation
[TERI Project Report number 2003CR42 (October 2003 to September 2004)]

TERI (The Energy and Resources Institute). 2004
Competence Network for SMiEs (Mainstreaming of resource efficient technologies for improved economic, environmental, and social conditions in small and micro enterprises), **project document, January 2005–December 2008**
[Report submitted to the Swiss Agency for Development and Cooperation]
New Delhi: TERI

TERI (The Energy and Resources Institute). 2006
Competence Network for Small and Micro Learning Enterprises (CoSMiLE)—Glass. Operational report for the period January 2005 to December 2005
[Report submitted to Swiss Agency for Development and Cooperation]
TERI Project Report number 2005CR21 (January 2005 to December 2005)

TERI (The Energy and Resources Institute). 2006
Editorial
CoSMiLE Update **1**(2)

TERI (The Energy and Resources Institute). 2007
Competence Network for Small and Micro Learning Enterprises (CoSMiLE)—Glass. Operational report for the period January 2006 to December 2006
Report submitted to the Swiss Agency for Development and Cooperation
[TERI Project Report number 2005CR21 (January 2006 to December 2006)]

Audio-visual documents

TERI (Tata Energy Research Institute). 2002
Taj Mahal: beyond the love story
[Documentary film in compact disc format]
New Delhi: TERI

TERI (The Energy and Resources Institute). 2003
Through the smokescreen
[Documentary film in compact disc format]
New Delhi: TERI

TERI (The Energy and Resources Institute). 2005
Changing the convention
[Documentary film in compact disc format]
New Delhi: TERI

Websites/web pages[40]

Centre for Development of Glass Industry
www.cdgiindia.com

IndiaSocial.org
www.firozabadcluster.org

'Substances used in the melting of coloured glass' by David M Issitt
1st Glass
www.1st.glassman.com

The Infinity Foundation
(i) 'Story of glass in India & the World', by Pankaj Goyal; article posted on 29 July 2003
(ii) 'Ancient glass and India' by Sen S N and Chaudhary M (1985); book reviewed by D P Agrawal and Manikant Shah
www.infinityfoundation.com

The Child Labour (Prohibition and Regulation) Act, 1986 and Rules
Ministry of Labour and Employment, Government of India
www.labour.gov.in

M C Mehta Environmental Foundation
www.mcmef.org

[40] All visited last on 31 October 2007.

Ministry of Micro, Small and Medium Enterprises, Government of India
www.msme.gov.in

'Exploitation of child labour is a grown up problem for India', by Rajiv Malik
National Institute of Rural Development
www.nird.ap.nic.in

Toledo Engineering Co., Inc
www.teco.com

Integrated energy and environment programme for the glass industry, 2001
United Nations Industrial Development Organization
www.unido.org

'Temperature of a "Red Hot" Object'; In *The Physics Factbook*, edited by Glenn Elert
www.hypertextbook.com

CONTRIBUTORS

The following is a list of people who have made substantial contributions to the success of the Glass project in various capacities and at different stages of its execution. This list is not comprehensive. There are several others who have helped the project over the years.

Name	*Affiliation*
Anil Agarwal	Purushottam Glass Works, Firozabad
Anil Agarwal	Anup Glass Industries, Firozabad
Ashok Agarwal	Fabricator, Aligarh
Lalitesh Kumar Agarwal	Bapu Glass Industries, Firozabad
Rakesh Kumar Agarwal	Prem Glass Works, Firozabad
Rajendra Agarwal	The Amrit Glass Works, Firozabad
S K Agarwal	Special Ceramics (P) Ltd., Delhi
Liyaquat Ali	Fine Glass Beads Manufacturers, Firozabad
Syed Shahzad Ali	Ellora Glass Industry, Firozabad
Richa Arora	TERI, New Delhi
Mohd Azim	Mason, Firozabad
V Balaji	Consultant, TERI
Ruby Banerjee	TERI, New Delhi
Vipul Bansal	TERI, New Delhi
Vijay Bapat	IDC-IIT, Mumbai
S P Basu	TRL, Kolkata
Amitabh Behar	SDC, New Delhi
Somnath Bhattacharjee	TERI, New Delhi
Francois E Binder	SDC, New Delhi
Madhurima Sen Bose	Earthcare Films, New Delhi

K Chatterjee	TRL, Belpahar
AK Chattopadhyay	TRL, Belpahar
Sudeep Chandra Chaturvedi	Super Glass Works, Firozabad
Dilip Chaturvedi	Akashdeep Pottery, Firozabad
Sunita Chaudhry	SDC, New Delhi
Rudolf Dannecker	SDC, New Delhi
Keshav Dev	Muffle furnace mason, Firozabad
Premvir Dev	Vikas Sansthan, Shikohabad
Roma Devi	Vikas Sansthan, Shikohabad
Jed Dogget	British Glass, UK
Mike Dogget	British Glass, UK
Mohit Dua	TERI, New Delhi
Suresh Chandra Dubey	Saraswati Glass Works, Firozabad
Jean-Bernard Dubois	SDC, Berne
T K Ganguly	Consultant, TERI
Ravindra Kumar Garg	Navjeevan Glass Industries, Firozabad
Janaki Prasad Garg	Shivcharan Lal Ambika Prasad Glass Works, Firozabad
Jacob George	TERI, New Delhi
Ananda Mohan Ghosh	TERI, New Delhi
B N Ghosh	Consultant, TERI
G Gopalakrishnan	TERI, New Delhi
Akhilesh Kumar Gupta	Muffle furnace owner, Firozabad
Mohan Kishan Gupta	Shri Bardwan Products India, Firozabad
Sachin Gupta	Suhag Kaanch Udyog, Firozabad
Subhash Gupta	Santosh Glass Works, Firozabad
Surendra Gupta	Gyanchand Mahavir Prasad Jain Industries, Firozabad
Vinay Gupta	Anup Glass Industries, Firozabad
W Andrew Hartley	British Glass, U K
Kamarul Hasan	National Glass Industries, Firozabad
Urs Heierli	SDC, New Delhi
Pierre Jaboyedoff	Sorane SA, Switzerland
Anil Jain	Rachana Industries, Firozabad
Chandra Kumar Jain	Saraswati Glass Works, Firozabad
Deepankar Jain	Saraswati Glass Works, Firozabad
Manish Jain	Durga Glass Works, Firozabad
Mukesh Kumar Jain	Raja Glass Works, Firozabad
Prabhas Kumar Jain	Anup General Industries, Firozabad

Promod Kumar Jain	Shiva Industries, Firozabad
Vinoy Kumar Jain	Shiva Industries, Firozabad
P K Jindal	R S Glass Industries, Firozabad
Pradeep Kumar Jindal	Caprihan Chemical Glass Works, Firozabad
Praveen Kumar Jain	Labour Glass Industries, Firozabad
Sanjay Kumar Jain	Adarsh Glass Industries, Firozabad
Rahul Jain	Jain Industries, Firozabad
Vinod Jain	G Nath Glass Works, Firozabad
R K Joshi	TERI, New Delhi
S P Joshi	Inconel, Pune
Veena Joshi	SDC, New Delhi
Siglinde Kalin	SDC, New Delhi
Harpreet Singh Kandra	TERI, New Delhi
Ajit N Kanitkar	SDC, New Delhi
Puneet Katyal	TERI, New Delhi
Kamlesh	Fitter, Firozabad
Anand Kumar	Triratna Consultants Limited, Lucknow
Kulbushan Kumar	TERI, New Delhi
Sachin Kumar	TERI, New Delhi
Sanjay Kumar	Operator, Firozabad
Sarvesh Kumar	Operator, Firozabad
Ravi Kumar	Fitter, Firozabad
B Vinaya Kumar	TERI, New Delhi
Arshad Khan	Express Glass Works, Firozabad
Faisal Khan	Express Glass Works, Firozabad
Mohd Farooq Khan	Express Glass Works, Firozabad
Mohd Islam Khan	Express Glass Works, Firozabad
Naurin Khan	Vikas Sansthan, Shikohabad
Parwez M Khan	Caprihan Chemical Glass Works, Firozabad
Mohd Usman Khan	Express Glass Works, Firozabad
Moonna lal	Fitter, Firozabad
Naxe Lal	Furnace operator, Firozabad
Roy Lee	Chapman & Brack, UK
Anil Maheshwari	Liberty Glass Works
Girish Maheshwari	S R Glass Industries, Firozabad
Anand Majmudar	Gujarat Perfect Engineering Ltd, Vadodara
Adrian Marti	SDC, New Delhi
Ajay Mathur	TERI, New Delhi

B R B Mathur	Consultant, TERI
Abdul Mazid	Muffle furnace mason, Firozabad
J Misra	TERI, New Delhi
Jayanta Mitra	TERI, New Delhi
Ashok Kumar Mittal	Electronic Glass, Firozabad
Ramesh Mittal	Yadav Glass Works, Firozabad
Vikas Mittal	Akashdeep Glass Works, Firozabad
Naved Mukarram	Irfan Glass Works, Firozabad
S C Mullick	IIT, New Delhi
K S Muthukumar	TRL, Belpahar
Ghulam Nabi	Muffle furnace entrepreneur, Firozabad
Dhananjay Navangul	Dhanaprakash Industrial Corporation
Prosanto Pal	TERI, New Delhi
Shailendra Paliwal	International Glass Works, Firozabad
Parsa	Minority Glass Development Society, Firozabad
Pradeep Phadke	Unitherm, Mumbai
Debashish Pramanik	TERI, New Delhi
Siya Ram	Mason, Firozabad
Ashok Kumar Raniwala	Super Glass Works, Firozabad
Mohmmed Rasheed	Mason, Firozabad
Anisul Hasan Rizvi	Special Ceramics (P) Ltd, Delhi
A K Saha	Consultant, TERI
Girish Sethi	TERI, New Delhi
Dilip Sevarthi	Vikas Sansthan, Shikohabad
Kiran H Shah	Darling Muesco (India) Pvt Ltd, Ahmedabad
Mohd Shamim	Mason, Firozabad
Hari Shankar	Mason, Firozabad
B C Sharma	Consultant, TERI
Hari Om Sharma	Fitter, Firozabad
Ved Prakash Sharma	TERI, New Delhi
Piyush Sharma	Glassco Engineers, Firozabad
Saubhagya Sharma	Saubhagya Glass Works, Firozabad
Vivek Sharma	TERI, New Delhi
Shivcharan	Mason, Firozabad
Abhinendra Singh	Vikas Sansthan, Shikohabad
Foren Singh	Muffle furnace entrepreneur, Firozabad
Haakim Singh	Muffle furnace entrepreneur, Firozabad
Narauttam Singh	Fitter, Firozabad

Viswadeep Singh	Electronic Glass, Firozabad
R K Sinha	TRL, Belpahar
P R K Sobhanbabu	TERI, New Delhi
Madhyama Subramanian	TERI, New Delhi
M Y Sulemani	Gujarat Perfect Engineering Ltd, Vadodara
Mohd Swaleen	Ansar Glass Works, Firozabad
Prahlad Kumar Tewari	TERI, New Delhi
Umashankar	Vikas Sansthan, Shikohabad
N Vasudevan	TERI, New Delhi
Kurt Voegle	SDC, New Delhi
Rayeen Wahabuddin	Muffle Furnace Entrepreneur, Firozabad
Mohd. Washid	Universal Glass Works, Firozabad
Sukesh Yadav	Vikas Sansthan, Shikohabad
Mohammed Zahid	Mason, Firozabad

In addition to the above individuals, special mention must be made of the contributions by the following organizations during the course of the intervention in Firozabad.

Muffle Furnace Associations, Firozabad

Allied Coal Consumers' Association
The Firozabad Coal Consumer Association
Kada Bangle Association
Laghu Udyog Pakai Bhatti Chamber
Kaanch Audyogic Sehkari Samiti Ltd
Bajrang Pakai Bhatti Samiti
Sahara Nagla Mirza Churi Pakai Bhatti Samiti
Durbin Samiti
Janhit Pakai Bhatti Seva Samiti
Firozabad Sangh
Kada Chaal Pakai Bhatti Cottage Works

Artisans' cooperatives

1. Daukeli Glass Toys Workers Shram Samvida Sahakari Samiti Limited, Daukeli
2. Glass Handicraft Workers' Sahakari Shram Samvida Samiti Limited, Kushbah Nagar

Self-help groups and federations

Aman Self-Help Group, Daukeli
Ameen Self-Help Group, Makhanpur
Kalyani Self-Help Group Federation, Makhanpur
Guru Gorakhnath Self-Help Group G, Makhanpur
Jaharvir Self-Help Group, Makhanpur
Jai Lakshmi Self-Help Group, Daukeli
Parvati Self-Help Group, Daukeli
Saheli Self-Help Group Federation, Makhanpur
Touheed Self-Help Group, Makhanpur
Glass Toys Workers' Self-Help Group, Daukeli
Madina Self-Help Group, Makhanpur
Dyare Madina Self-Help Group, Makhanpur

Abbreviations

AAQ	Ambient air quality
ABB	Asea Brown Boveri Ltd
ADB	Asian Development Bank
AIC	Abbeville Instrument Control Ltd
APM	Administered price mechanism
ASTM	American Society for Testing and Materials
BOP	Best operating practices
CDGI	Centre for Development of Glass Industry
CFC	Chlorofluorocarbon
CIL	Coal India Limited
CoSMiLE	Competence Network for Small and Micro Learning Enterprises
CPCB	Central Pollution Control Board
DA	Development Alternatives
DCMSME	Office of the Development Commissioner, Micro, Small and Medium Enterprises
DG	Diesel generator
DIC	District Industries Centre
FGCCI	Firozabad Glass Chamber of Commerce and Industry
GAIL	Gas Authority of India Ltd
Gcal	Gigacalories
GEP	Global Environment Programme
GHG	Greenhouse gas
GIS	Geographic Information System
HBJ	Hazira–Bijaipur–Jagdishpur
HID	Human and institutional development

HP	Horsepower
IDC	Industrial Design Centre
IIT	Indian Institute of Technology
kcal	Kilocalories
kW	Kilowatt
LC	Letter of credit
LDO	Light diesel oil
LPG	Liquefied petroleum gas
LSP	Local service provider
MARG	Multiple Action Research Group
MGO	Minimum guaranteed offtake
MJ	Mega joules
MMSCMD	Million metric standard cubic metres per day
MS	Mild steel
MSME	Micro, small, and medium enterprises
NGO	Non-governmental organization
PIL	Public interest litigation
PPM	Parts per million
PRV	Pressure reducing valve
QAQC	Quality assurance and quality control
R&D	Research and development
RFO	Residual fuel oil
R-LNG	Regasified liquefied natural gas
RSPM	Respirable suspended particulate matter
SAP	Social action plan
SDC	Swiss Agency for Development and Cooperation
SHG	Self-help group
SIDBI	Small Industries Development Bank of India
Sm^3	Standard cubic metre
SMiE	Small and micro enterprises
SPM	Suspended particulate matter
SS	Stainless steel
TECO	Toledo Engineering Co. Inc.
TERI	The Energy and Resources Institute (formerly, Tata Energy Research Institute)
TFL	Total furnace load
THC	Total hydrocarbons
TPD	Tonnes per day
TRL	Tata Refractories Limited

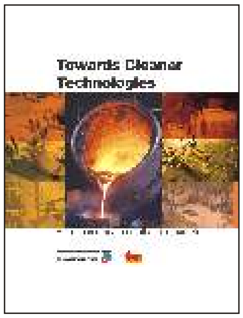
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
UPPCB	Uttar Pradesh Pollution Control Board
UPSIDC	Uttar Pradesh State Industrial Development Corporation
US EPA	United States Environmental Protection Agency
WHO	World Health Organization

Glossary

belan	long mild steel rod that is rotated to draw glass melt into spirals, which are then cut to make raw bangles
belan bhatti	furnace in which bangle spirals are made
belanwalla	worker who rotates the belan
bhainsa bhatti	a glass melting furnace used in ancient times to make glass beads
bhai	brother
chai	tea
chatai	sorting of broken bangle shards into separate piles according to colour, size or thickness
chinnaya	worker who arranges raw bangles on trays for baking in the bangle-baking furnace (muffle furnace/*pakai bhatti*)
ginnaiya	worker who counts the bangles and bunches them after they are baked in the bangle-baking furnace (muffle furnace/*pakai bhatti*)
gulliwalla	worker who draws and carries the glass lump from pot furnace to other auxiliary furnaces
hil	silver and gold polish on bangles
jaali	wire mesh
judai	a process by which the two open ends of a bangle are joined
mistry	mason
muthia	a worker at the *belan bhatti* who uses an abrasive tool to cut off lengths of the bangle spiral at periodic intervals and/or removes the spiral from the belan

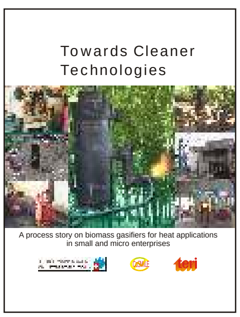
pakai bhatti	bangle-baking furnace or muffle furnace
pakaiya	worker who actually bakes the bangles in the bangle-baking furnace (muffle furnace/*pakai bhatti*)
palita	an ignited cloth, soaked in kerosene or diesel and wrapped around the end of a long mild steel rod
roti	flat bread
sabzi	cooked vegetable
sangh	federation
sedhai	a process by which the two open ends of a bangle are aligned
sekai bhatti	auxiliary furnace used for heating glass lumps to improve its plasticity for onward processing within factory premise
suhagin	married woman
tarkash	a bangle worker who draws a thin filament of glass from the glass lump and places it steadily on the rotating belan, so that the constant turning motion gives the filament a spiral shape
thekedar	contractor/middleman
tora	a bunch of 320 bangles tied with string

Other publications in the series



Towards Cleaner Technologies

A process story in small-scale foundries
(Published in 2006)
This book narrates, in a brief and simple manner, the process by which TERI and SDC developed and demonstrated an energy-efficient melting furnace and an effective pollution control system for the Indian foundry industry, and the measures being taken to spread these technologies. The book highlights the experiences of project staff and other stakeholders, and the challenges faced and tackled by them in the course of their work.



Towards Cleaner Technologies

A process story on biomass gasifiers for heat applications in small and micro enterprises
(Published in 2007)
This book describes, in a simple way, the process by which TERI and SDC developed clean, energy-efficient biomass gasifier systems for heat applications in small and micro enterprises. In particular, it highlights the experiences of project staff and other stakeholders, and the hurdles faced and overcome by them in the course of their work.

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The small-scale glass industries cluster located in Firozabad, near Agra, produces an estimated 50 million bangles each day. Traditionally, units in the cluster burned coal in low-efficiency furnaces, leading to high levels of emissions. Following the Supreme Court verdict in the famous Taj Trapezium case, the Firozabad units came under pressure to switch from coal to natural gas as fuel.

In 1994/95, SDC (Swiss Agency for Development and Cooperation) and TERI (The Energy and Resources Institute) entered into a partnership to find solutions to the energy and environmental problems of select SMiE (small and micro enterprise) sub-sectors through technology upgradation and human and institutional development. Four sub-sectors were selected for intervention: foundries, sericulture, glass industries, and brick manufacture.

This book narrates, in a brief and simple way, the process by which the partners developed and demonstrated two clean, energy-efficient technologies for the small-scale glass units in Firozabad: the gas-fired recuperative pot furnace, and the gas-fired muffle furnace. In particular, it highlights the experiences of project staff and other stakeholders, and the challenges faced and tackled by them in the course of their work.

This book is primarily intended as a guide for researchers, policy-makers, NGOs, donor organizations, academic institutions, and others involved in the small-scale sector, particularly in developing countries.