Executive Summary

Brick Kilns Performance Assessment & A Roadmap for Cleaner Brick Production in India

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A report prepared by

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Abstract

Introduction

India is the second largest producer of clay fired bricks, accountingfor more than 10 percent of global production.India is estimated to have more than 100,000 brick kilns, producing about 150-200 billion bricks annually, employing about 10 million workers and consuming about 25 million tons of coal annually. India's brick sector is characterized by traditionalfiring technologies; environmental pollution; reliance on manual labour and low mechanization rate; dominance of small-scale brick kilns with limited financial, technical and managerial capacity; dominance of single raw material (clay) and product (solid clay brick); and lack of institutional capacity for the development of the sector.

In a first of its kind detailed performance assessment,the principal investigating organizations -Greentech Knowledge Solutions Pvt. Ltd., Enzen Global Solutions Pvt Ltd, and University of Illinois,examinedthe energy, environmental and financial performance and brick maker input for five main brick firing technologies during 2011:

- Fixed Chimney Bull's Trench Kiln (FCBTK - India)
- Zig-zag (natural and forced draft - India)
- Vertical Shaft Brick Kiln (VSBK – India and Vietnam)
- Down-Draught Kiln (DDK- India)
- Tunnel kiln (Vietnam)

The study is one of two research components aimed at developing strategies for the introduction and promotion of cleaner walling materials in India.

Results

Energy performance

A large variation was observed in the energy performance of the monitored kilns. DDK (least efficient kiln) consumesfourtimes more energy compared to VSBK (most efficient kiln). The Vietnamese VSBK kiln had the lowest thermal energy requirement, followed by the Indian VSBK, zig-zag kilns and FCBTKs. The tunnel kiln, which incorporates a dryer, had higher energy use.

Environmental performance

- VSBK had the lowest emissions of Suspended Particulate Matter (SPM) followed by zig-zag kiln, tunnel kiln, FCBTK and down-draught kiln. VSBK also had the lowest Particulate Matter ($PM_{2.5}$) emissions.
- Of the gaseous pollutants measured,variations in the SO_2 concentration were observed, with lowest levels in the biomass-fueled DDK. This is because sulphur dioxide (SO_2) is dependent on sulphur in coal. Oxides of nitrogen (NO_x)emissions were generally below the detectable levels. The natural draught zig-zag kiln had the lowest carbon monoxide (CO) emissions. CO_2 emissions show similar ranking hierarchy as for energy.
- Both tunnel and VSBK had very low black carbon (BC) emissions, followed by zig-zags.FCBTKs and DDK had highest BC emissions.

Financial performance

Among cleaner kiln options, zig-zag kilns require lower investments and have shorter pay-back periods. Zig-zag kilns offer easy integration with the existing production process of FCBTKs.The tunnel kiln technology is suitable for large-scale production, requires large capital investment (10-20 times more compared to a zig-zag), and has long pay-back period. VSBK, being modular in nature, can be used for small- as well as medium-scale production but has problems of low productivity and poor fired brick quality with certain clays. It is suitable for firing only solid bricks and has a longer pay-back period compared to zig-zag kilns.

Production and selling price vary significantly by regions of the country; profitability of brick enterprises is higher in southern and western India.

Brick sector input

Major issues identified by brick makers that are likely to shape future growth of the brick-making industry include:

- Shortage of labour
- Increase in fuel cost
- Competition from other walling materials
- Multiple barriers to adopting semi-mechanized technologies

The way forward

The study recommends that the efforts to propagate cleaner brick kiln technologies over the next decade should focus on these specific technical measures:

- Adoption of cleaner kiln technologies (principally zig-zag and VSBK)
- Promotion of internal fuel in brick making by mechanizing the brick making process
- Promotion of mechanized coal stoking systems
- Diversifying products (e.g. production of hollow and perforated bricks)
- Promotion of modern renewable energy technologies in brick making

Implementation of these measures can result in annual coal savings of the order of 2.5 to 5.0 million tons/year in brick firing operation and associated CO_2emission reduction of the order of 4.5 to 9.0 million tons/year; significant reduction in air pollution (including SPM, black carbon, CO); improvement in profitability of brick enterprises; and improvement of working conditions for millions of workers employed in brick kilns.

Implementation of these measures requires a concerted effort by Government of India and brick industry. On the policy and regulatory front, Government of India may like to refer to the policies and regulations framed by some of the other developing countries in Asia. Among these of particular interest are: sustainable building material policy of Vietnam to promote resource-efficient brick production and the recent environment regulation of Bangladesh proposing a time-bound phasing out of FCBTK technology.

Next immediate stepsproposed toward achieving these recommendations include an environmental regulation to phase out older, inefficient technologies like FCBTKs, the predominant technology in use today and introduce newer cleaner brick firing technologies.; and undertaking an Indian brick development programme to support financing, technology transfer and skill development activities.

Executive Summary

I. Background

The growth in India's economy and population, coupled with urbanization, has resulted in an increasing demand for residential, commercial, industrial, and public buildings as well as other physical infrastructure. Building construction in India is estimated to grow at a rate of 6.6% per year between 2005 and 2030[1]. The building stock is expected to multiply five times during this period, resulting in a very large increased demand for building materials.

Solid fired clay bricks are one of the most widelyused building materials in the country.India is the second largest producer of clay fired bricks, accountingfor more than 10 percent of global production[2].India is estimated to have more than 100,000 brick kilns, producing about 150-200 billion bricks annually[3].

Brick making in India is characterised by the following features:

- Brick making is a small-scale, traditional industry[4]. Almost all brick kilns are located in the rural and peri-urban areas. It is common to find large brick making clusters located around the towns and cities, which are the large demand centres for bricks. Some of these clusters have up to several hundred kilns.
- The brick production process is based on manual labour, and brick kilns are estimated to employ around 10 million workers. Brick production is a seasonal vocation, as the brick kilns do not operate during rainy season. Most of the workers migrate with their families from backward and poor regions of the country. Families, including young children, work in harsh, low paying conditions. There is typically a lack of basic facilities,such as access to clean drinking water and sanitation.
- Bricksare fired to a temperature of 700 -1100 ^{o}C, requiring a large amount of fuel for the firing operation. Brick kilns are estimated to consume roughly25 million tonnes of coal per year, thus making it one of the highest industrial consumers of coal in the country.
- A rapid increase in the brick production and the clustering of brick kilns has given rise to environmental concerns:
    - Combustion of coal and other biomass fuels in brick kilns results in the emissions of particulate matter (PM), including black carbon (BC), sulphur dioxide (SO_2), oxides of nitrogen (NO_x), and carbon monoxide (CO). The emission of these pollutants hasan adverse effect on the health of workers and

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[1] McKinsey & Company, 2009. Environmental and Energy Sustainability: An Approach for India. McKinsey & Company, Mumbai, India.
[2] Maithel, Sameer, 2003. Energy Utilization in Brick Kilns. PhD Thesis. Energy Systems Engineering, Indian Institute of Technology, Bombay
[3] No agency in India keeps records of brick production. The numbers referenced here on brick kilns, total production and coal use are estimates that are often quoted by brick industry associations and experts.
[4] A traditional industry is defined as "an activity, which produces marketable products, using locally available raw material and skills and indigenous technology."

    - vegetation around the kilns. In recent years, higher cost and shortage of good quality bituminous coal has resulted in increased use of high-ash, high-sulphur coal, as well as use of industrial wastes and loose biomass fuels in brick kilns. All of these have resulted in new air emission challenges.
    - Use of large quantities of coal in brick kilns contributes significantly to emissions of carbon dioxide (CO_2).
    - Good quality agriculture top soil is used for brick production. Areas having large concentration of brick kilns suffer from land degradation.
- Apart from the environmental concerns, the industry faces other challenges, including:
    - Shortage of workers, resulting in an increase in wages and disruption of production.
    - Rapid increase in the fuel cost and limited availability of good quality coal.
    - Shortage of good quality clay in some regions and an inability of brick makers to adopt technologiesto utilize alternate raw material.
    - Increased competition from other walling materials, such as concrete blocks.
    - New demands resulting from trend towards high-rise construction.

Despite its significancein the construction sector, importance in livelihoods of the poor, being a large coal user and causing environmental and health impacts, the brick making sector has seen very few development interventions/programmes aimed at improving the industry. Initiatives that have been undertaken are listed in Table 1. The most significant government interventionswere the environmental regulations enacted in the1990's, which resulted in upgradation in the firing technology from moving chimney bull trench kilns to fixed chimney bull trench kilns.

Table 1. Development Programmes/Initiatives in the Indian Brick Industry

	Agency/ Programme	Type of Intervention	Impact
1970's	Central Building Research Institute, Government of India	**Technical**: Introduction of zig-zag firing technology and semi-mechanisation process	• Successful in seeding the technologies. • No large-scale adoption.
1990's	Central Pollution Control Board/ Ministry of Environment and Forest (MoEF)	**Regulation:** Air emission regulation for brick kilns	• Large-scale shift (around 30,000 kilns) from moving chimney Bull's Trench Kiln technology to more efficient and less polluting fixed chimney Bull's Trench Kiln technology.
1995-2004	Swiss Agency for Development and Cooperation	**Technical**: Introduction of Vertical Shaft Brick Kiln (VSBK) Technology	• Successful in seeding the technology. • No large-scale adoption.
2009-ongoing	United Nations Development Program - Global Environment Facility (UNDP-GEF)	**Technical**: Introduction of hollow bricks and other resource-efficient bricks.	• Not known

II. Objective

The objective of the study was to carry out a comprehensive assessment of brick making technologies to gain a deeper understanding of the energy utilization and emissions from current technologies as well as technologies that offer the promise of cleaner brick production.

To address theseobjectives, Greentech Knowledge Solutions Pvt. Ltd (GKS), Enzen Global Solutions Pvt Ltd (Enzen) and University of Illinois (U of I), with Entec AG (Entec), Hanoi Center for Environmental and Natural Resources Monitoring and Analysis (CENMA),and the Clean Air Task Force (CATF)conducted a detailed monitoring study from February to May 2011 examining five brick kiln technologies: two traditional brick kiln technologies widely prevalent in India – fixed chimney Bull's Trench Kiln (BTK) and Down Draught Kiln and three relatively newer technologies – Vertical Shaft Brick Kiln (VSBK), Zig-Zag Kilns, and Tunnel Kilns. Nine individual brick kilns were monitored for the following parameters:

- Energy performance: Specific Energy Consumption(SEC)
- Environment performance: Emission measurementsfor particulate matter (PM), black carbon (BC), and selected gaseous pollutants.
- Financial performance: Capital investment, cost of production, pay-back period.

The study also collected data on the current status of brick industry in the brick making clusters visited by the project team.

The assessment of the technologies and the industry were used to makerecommendations for strategies promotingcleaner brick production technologies.The results were also used as inputs in a parallel study[5] undertaken to assess multiple types of walling materials,including clay fired bricks.

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[5] For details please refer to the report "Strategies for Cleaner Walling Material in India" prepared by Enzen Global Solutions Pvt Ltd and Greentech Knowledge Solutions Pvt Ltd as a part of the project funded by Shakti Sustainable Energy Foundation in November 2011.

III. Methodology

Details of the monitored kilns are provided in Table 2. Of the nine kilns, seven are located in India, and two – tunnel kiln and a modified VSBK – in Vietnam, as neither is in operation in India.Both these kilns rely to a large extent on internal fuel[6] and were expected to have lower environmental footprint, especially in terms of emissions. The selection of Indian kilns was carried out to cover major kiln types and fuel combinations prevalent in the country.

Table 3 provides the list of technical parameters that were measured. In addition, fuel and clay samples were collected and analyzed from each of the monitored kilns. Business and process related information were collected through personal interviews with kiln owners.

Location of the monitored kilns is shown in Figure 1

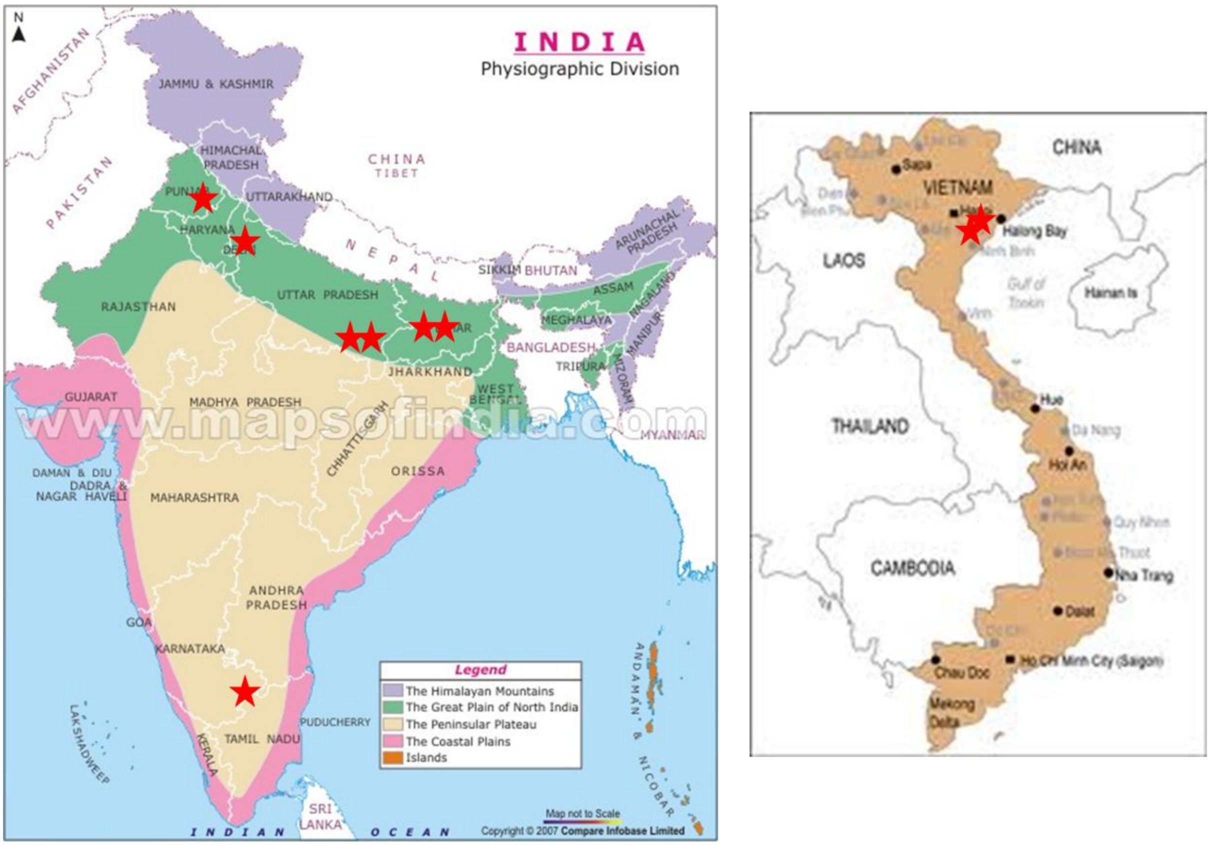

Figure 1: Location of Monitored Kilns in India & Vietnam

[6] The practice of internal fuel is widely prevalent in China – the largest producer of brick in the world, accounting for almost 50% of the production – and Vietnam. In this process, powdered coal is added during the brick forming operation and serves as a fuel during firing.

Table 2: Information on Monitored Brick Kilns

Type of kiln	Number of kilns monitored	Features of Monitored kilns			Remarks
		Place	Kiln size	Fuel used	
Fixed Chimney Bull's Trench Kiln (FCBTK)	3	Garh Mukteshwar (U.P)	Large	Coal (High volatile &high calorific value); rubber tyres; wood logs	➢ Accounts for more than 70% of total brick production in India. ➢ More than 30,000 FCBTKs currently operational in India. ➢ Emissions from a FCBTK are significantly affected by the fuel used and operating practice.
		Ludhiana (Punjab)	Large	Coal (High volatile & high calorific value)	
		Arah (Bihar)	Medium	Coal (Low volatile and medium calorific value)	
Zig-zag	2	Varanasi (Natural Draft)	Large	Coal (Two types) Biomass (Sawdust)	➢ Improved firing technology as compared to FCBTK in terms of environment emissions & energy consumption. ➢ Traditionally uses a fan for creating draft. ➢ Recently natural draft (using a chimney) has been successfully used in zig-zag kilns.
		Varanasi (Forced Draft)	Large	Coal (Mixture of two types of coal) Mixture of high volatile & high calorific value and low volatile & medium calorific value	
Vertical Shaft Brick Kiln (VSBK)	2	Arah (Bihar)	Small	Coal (Two types) ○ Steam coal ○ Coal Slurry (Internal)	➢ An estimated 100 VSBKs have been constructed in India. ➢ Considered most efficient kiln technology in terms of energy use. ➢ Improved VSBK technology is extensively used in Vietnam ➢ More than 300 VSBK enterprises in Vietnam.
		Hung Yen province (Vietnam)	Medium	Coal (Two types) ○ Coal powder (Internal) ○ Coal Slurry (Internal)	
Down-Draught Kiln (DDK)	1	Malur (Karnataka)	Small	Biomass ○ Fresh eucalyptus branches	➢ Improved version of a clamp kiln ➢ Popular in Malur cluster in Karnataka ➢ Malur cluster has roughly450 DDK .
Tunnel kiln	1	Nam Dinh province (Vietnam)	Large	Coal ○ Coal powder	➢ Tunnel kiln is the main technology for firing bricks in developed countries ,as well as several developing countries e.g. China, Vietnam ➢ India does not have a well-functioning tunnel kiln for clay brick firing; Vietnam has more than 500 operational tunnel kilns

Table 3: List of Technical Measurements

Process variable	Principle of measurement or analysis	Sample Location	Type *	Responsible organization
Fuel feeding rate	Weighing of fuel and time measurement	Fuel	P	GKSPL
Temperature of flue gas	Thermocouple	Stack/ flue duct	R	GKSPL/ Enzen
Temperature of bricks & surfaces	K-type Thermocouple/ Infrared thermometer	Inside the kiln/ outside surface of kiln	P	GKSPL
Stack flow**	Pitot tube	Stack	P	Enzen
O_2	Electrochemical	Stack/flue duct	R	GKSPL/CENMA
CO_2	Inferred from O_2	Stack/ flue duct	R	GKSPL/CENMA
	Infrared absorption	Diluted exhaust	R	Uof I
CO	Electrochemical	Stack/ flue duct	R	GKSPL/CENMA
	Electrochemical	Diluted exhaust	R	Uof I
SO_2	Barium-Thorin titrimetric method	Stack	I	Enzen/CENMA
NO_x	Gaseous sampling followed by colorimetry using phenoldisulfonic acid	Stack	I	Enzen
Suspended Particulate Matter (SPM)	Gravimetric	Stack	I	Enzen
HF	Electric potential methods using ion selective membrane electrode	Stack	R	CENMA
PM2.5	Gravimetric	Diluted exhaust	I	Uof I
Elemental and organic carbon	Thermal-optical analysis	Diluted exhaust	I	Uof I
Light absorption	Filter transmittance	Diluted exhaust	R	Uof I
Light scattering	Scattering sensor	Diluted exhaust	R	Uof I
Size-resolved carbon particles	Cascade impactor plus thermal-optical analysis	Diluted exhaust	I	Uof I

Notes:

* Average of single-point observations (P); Integrated sample (I) taken over many minutes; Real-time observations (R) averaged for presentation.
CENMA: Hanoi Centre for Environmental and Natural Resources Monitoring and Analysis, Vietnam.
GKSPL: Greentech Knowledge Solutions Pvt. Ltd. U of I: University of Illinois.
** For duct diameter smaller than 0.30 m, standard or modified hemispherical-nosed pitot tube was used, with a minimum diameter of 0.1 m. For low velocity (less than 3m/s) differential manometer was used.

IV. Energy & Environment Performance

Energy Performance

The Specific Energy Consumption (SEC) is the amount of thermal energy required to fire 1 kg of brick. Lower SEC signifies efficient operation of the kiln. The SEC for the monitored kilns are presented in Table 4.The improved VSBK kiln fromVietnam had the lowest SEC requirement at 0.54 MJ/kg of fired brick, followed by thezig-zag kilns (1.12 MJ/kg of fired brick) and FCBTKs (1.22 MJ/kg of fired brick). The tunnel kiln, which incorporates a dryer,had higher SEC of 1.47 MJ/kg of fired brick.The DDKhad the highest SEC (2.9 MJ/kg of fired brick), and it consumed 4-5 times more energy compared to a VSBK.

Table 4: SEC of the Monitored Kilns

Firing Technology	Process	SEC-Thermal energy (MJ/kg fired brick)*	Electricity/ mechanical powerused in the production process **
FCBTK	Manualmoulding& sun-drying	1.22	• None
Zig-zag	Manualmoulding& sun-drying	1.12	• None in case of natural draught • 36 lt diesel/day (SEC: 0.015 MJ of primary energy/kg of fired brick primary energy) for operating the fan in the forced draught kiln
VSBK	Indian VSBK: Manualmoulding& sun-drying Vietnam: Extruder moulding& shade-drying	0.95 0.54	• Indian VSBK: 10 lt diesel/day (SEC: 0.03 MJ of primary energy/kg of fired brick) for operating the conveyor (for 1-shaft operation). • Vietnamese VSBK: 15 kWh/1000 bricks (SEC: 0.1 MJ of primary energy/kg of fired brick) for operating the extruder, lifting of bricks, operation of unloading mechanism.
Down draft	Manual moulding& shade drying	2.9	• None
Tunnel– Vietnam – Internal Fuel	Extruder moulding, drying in shade and in a tunnel dryer.	1.47 ***	• 40 kWh/1000 bricks (SEC: 0.3 MJ of primary energy/kg of fired brick) for operating the extruder, tunnel dryer, tunnel kiln , etc.

Notes:

*The SEC values for FCBTK and zig-zag are simple average of the three FCBTKs and two zig-zag kilns respectively; for all the other kiln types, the data is for a single kiln.

**Energy/fuel used for producing heat for firing and drying process.

*** The kiln and the dryer are interconnected. The SEC also includes the energy required in the tunnel dryer.

Environment Performance

The environmental performance results are presented below.

Suspended Particulate Matter

Suspended Particulate Matter (SPM)is a term used for airborne particles ofdiameter less than 100 µm. The emission factor in terms of g/kg of fired brick for SPM is presented in Table 5. VSBK had the lowest SPM emission factor,followed by zig-zag kiln, tunnel kiln, FCBTK and DDK, respectively. Due to the addition of powdered fuel with the clay and steady-state combustion conditions, VSBK and tunnel kilnswere among the lowest emitters of SPM. Better combustion conditions resulted in lower SPM in properly operated zig-zag kilns compared to FCBTK

Particulate Matter ($PM_{2.5}$)

Emission norms in India do not address $PM_{2.5}$specifically, but it is frequently monitored because of its environmental and health effects. Fine particulate matter (diameters less than 2.5 µm) can penetrate more deeply into lungs than larger particles. It also has a longer atmospheric lifetime and a disproportionately greater effect on visibility and climate,relative to larger particles. VSBK technology had the lowest $PM_{2.5}$emissions, and DDKhad the highest $PM_{2.5}$emissions.

Gaseous Pollutants

Kilns were monitored for sulphur dioxide (SO_2), oxides of nitrogen ($NO_{x)}$ carbon monoxide (CO) emissions and carbon dioxide (CO_2). Table 5 provides the emission factors for various pollutants monitored in the study, normalized to grams of pollutant/kg of fired brick.

SO_2 emissions stem from the sulphur content of fuel,therefore significant variation in the SO_2 concentration were observed in the monitored kilns. SO_2 concentration was lowest in down draft kiln,which uses biomass fuel,with negligible sulphur content.

NO_x emissions were generally very low and below the detectable levels.

Emissions of carbon monoxide (CO) are an indication of incomplete combustion of fuel. Zig-zag kilns hadthe lowest CO emissions. Within the zig-zag technology, the monitored natural draught zig-zag kiln had much lower CO emissions as compared to the monitored forced draught zig-zag kiln. Good fuel-feeding and operating practices support this improvement.

CO_2 emissions are directly related to the SEC and carbon content of fuels being used in the kiln. Hence the CO_2 emissions show similar ranking hierarchy as for SEC.

Table 5: Emission Factors for the Monitored Kilns

Technology	Emission Factors (g/kg of fired brick)				
	SPM	PM2.5	SO_2	CO	CO_2
FCBTK	0.86	0.18	0.66	2.25	115
Zig-zag	0.26	0.13	0.32	1.47	103
VSBK	0.11	0.09	0.54	1.84	70
DDK	1.56	0.97	n.d	5.78	282
Tunnel	0.31	0.18	0.72	2.45	166

Notes:

The emission factors for FCBTK, zig-zag are VSBK are simple average of the three FCBTKs, two zig-zag kilns and two VSBK kilns respectively; for all the other kiln types, the data is for a single kiln.

n.d. = not detectable (measurement below detection limit

Black and Organic Carbon

Black carbon (BC) is a combustion product predominantly composed of strongly bonded graphitic-like carbon rings. This composition causes black carbon to be thermally stable at high temperatures and to strongly absorb visible light, causing warming. Organic carbon (OC) comprises all carbon species that are neither black nor carbonate carbon.

This study represents the first-ever measurements of BC from brick kilns, despite the fact that brick kiln upgrades have been targeted as a strategy to reduce BC. In November 2011, the United Nations Environmental Program in their assessment, *Near-term Climate Protection and Clean Air Benefits:Actions for Controlling Short-Lived Climate Forcers*,proposed replacing traditional brick kilns with more efficient ones, particularly VSBKs, as a measure to reduce BC.

Two methods were used in this study to measure light-absorbing carbon.

1. Thermo-optical analysis measured "elemental carbon" which is stable at high temperatures and is considereda synonym to BC. This analysis also measured OC.
2. Particle light absorption measured in units of square meters (m^2),together with scattering measurements, can be used to calculate affect of particles on visibility and radiative transfer. The single scattering albedo[7] is a measure of particle lightness, with pure BC having a value of about 0.22, polluted urban air about 0.7, and pure white particles 1.0

[7] Single scattering albedo – the ratio of scattering efficiency to total extinction efficiency (which is also termed "attenuance", a sum of scattering and absorption). Most often it is defined for small-particle scattering of electromagnetic waves. A single scattering albedo of unity implies that all particle extinction is due to scattering; conversely, a single scattering albedo of zero implies that all extinction is due to absorption. (http://en.wikipedia.org/wiki/Single_scattering_albedo)

Results of elemental and organic carbon measurements; absorption and single scattering albedo, are shown in Table 6.

Table 6: Results of Thermo-optical and Light Absorption/Scattering measurements

Technology	Elemental Carbon (g/kg fired brick)	Organic Carbon (g/kg fired brick)	Absorption (m^2/kg fired brick) *	Single Scattering Albedo *
FCBTK	0.13	0.01	0.22	0.67
Zig-zag	0.04	0.02	0.16	0.64 **
VSBK	0.002	0.06	0.06	0.77
DDK	0.29	0.09	1.13	3.5
Tunnel	n.d.	n.d.	n.d.	0.13

Notes:

The results for FCBTK, zig-zag are VSBK are simple average of the three FCBTKs, two zig-zag kilns and two VSBK kilns respectively; for all the other kiln types, the data is for a single kiln.

.n.d. = not detectable (measurement below detection limit)

*At red wavelength (660 nm)

** Excludes natural draught zig-zag kiln, where scattering measurements were spurious and may be affected by measurement error, as the readings are much higher than expected for the measured levels of particulate matter.

Both tunnel and VSBK had very low BC emissions, as indicated by low value of elemental carbon and high values for single scattering albedo. In the tunnel kiln, the BC emissions were below the detection level. The low BC emissionsin the tunnel and the VSBK can be attributed to the steady-state combustion conditions in these kilns and use of internal fuel.FCBTKs andDDKhad highest BC emissions. In both of these kilns, fuel feeding is intermittent, and combustion conditions show large variation with time. The results show that large BC emissions take place around fuel feeding intervals.Improved combustion conditions in zig-zag kilns, in the form of continuous feeding of fuel in small quantities and better mixing of fuel and air,lowered BC emissions compared to FCBTKs.

The BC emission factors of brick kilnsmay also be compared with other BC emitting sources. Figure2compares BC emission factors from this study, with emissions from other types of coal combustion and from mobile sources.

Emissions from coal combustion can vary widely depending on the quality of the combustion. The figure shows that well-operating power plants, with emission controls, have very low emissions BC, industrial stoker boilers have detectable emissions, and heating stoves – which have no control of emissions or airflow within the stove – have quite high emissions. (Heating stoves are not used in India.) The difference in emissions is not caused by the fuel, but rather is attributable to the management of the fuel-air mixing and proper handling of the exhaust products. Emissions of the kilns measured in this project fall between those of industrial boilers and heating stoves, as could be expected based on the combustion management.

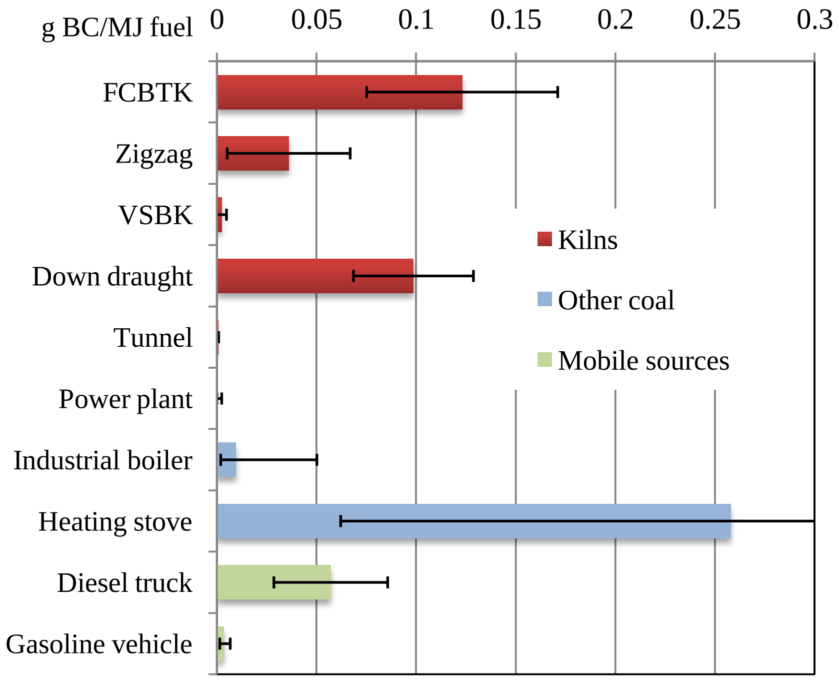

Figure 2: Comparison of BC Emitted from Kilns in this Study to Other Coal Sources and Mobile Sources[8].

V. Financial Performance & Quality of Fired Bricks

Capital Cost

A comparison of the financial performance of various technologies is presented in Table 7.FCBTK and zig-zag kilns require lower investments and have shorter pay-back periods. The tunnel kiln technology is suitable for large-scale production and requires large capital investment (10-20 times compared to other kiln types). VSBK, being modular in nature, can be used for small- as well as medium-scale production. It has a longer pay-back period compared to FCBTK and zig-zag kilns.

[8] Values presented for mobile sources are approximate emission rates for unregulated vehicles.

Table 7: Comparison of Kiln Technologies (Financial Performance)

Technology	Features	Approx. Capital Cost* (US $)	Production Capacity (million bricks/year)	Typical simple pay-back period under Indian conditions
FCBTK	• Chimney height 27 to 30 m; kiln circuit capacity 0.5 to 1 million bricks.	40,000 - 60,000	4-8	<2 years
Zig-zag	• Natural draft kiln with a chimney height of 30 m.	40,000 - 60,000	4-6	< 2 years
	• Kiln of 24-36 chambers; induced draft fan operated by a 15-20 hp motor; valve system in the flue ducts	60,000 - 80,000	4-6	< 2 years
VSBK	• Two-shaft Indian VSBK with a conveyor system for lifting the brick.	60,000	1.0 -1.5	2-3 years
	• Four-shaft Vietnamese VSBK: higher height; electrical lift; extruder for making internal fuel bricks; drying shade; hydraulic jack and fork-lift truck for unloading bricks	400,000	3.5-4.5	3-4 years
Tunnel	• Vietnamese tunnel kiln plant; daily production capacity: 40,000 to 50,000 bricks per day; tunnel kiln, tunnel dryer, drying shed, extruder for firing bricks	1-2 million	15-20	>3 years

Note: * excluding the cost of land; simple pay-back assuming 100% capacity utilization

Production Costand Selling Price

Data was collected on production cost and revenue. Typical production and selling price of bricks for different regions in the country are shown in Table 8. The profitability of brick enterprises is higher in southern and western India, due to higher selling price of bricks.

Table 8: Typical Production and Selling Price Data

Indo Gangetic Plains (Punjab, Haryana, UP, Bihar)	Production cost: Rs 2.00- 2.50 / brick	Selling Price: Rs 3.00 – 4.00/ brick
Southern and western India	Production cost: Rs 2.50 -3.50/ brick	Selling Price: Rs 4.50 – 8.00/ brick

Figure 3 shows the typical break-up of production cost for a FCBTK in Indo-Gangetic plains and illustrates that fuel is the largest cost component followed by operations (mainly manpower) cost. The production cost of natural draught zig-zag kiln is 15% lower than that of FCBTK.

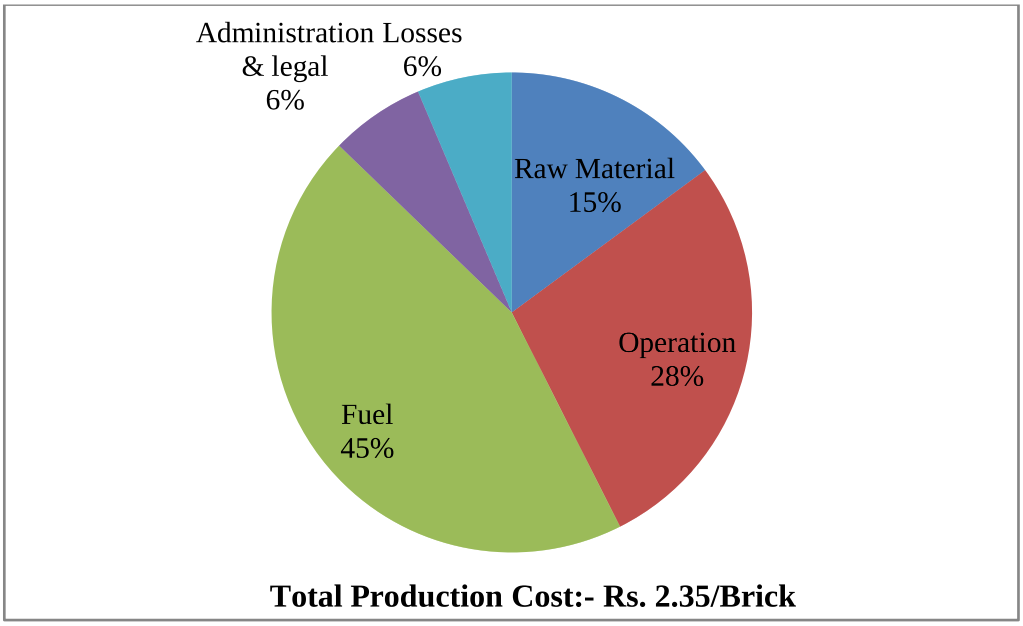

Figure 3: Average Production Cost Break-up Data for Monitored FCBTKs in Indo-Gangetic Region

Quality of Fired Bricks

The quality of fired brick depends both on the quality of green bricks as well as on the firing process.

The tunnel kiln is ranked best in terms of fired brick quality. Factors contributing to this improved quality include:

1. Fine control over the drying and firing process
2. The ability to achieve uniform temperature distribution in the firing zone,
3. Due to their large production capacity,they have mechanized brick production.

Both the VSBKs had problems with brick quality, and the quality was lower in the Indian VSBK. This is due to a variety of factors:

1. High static and dynamic load on the lower brick stacking in the shaft results in damage to the bricks.
2. Fast heating up and cooling down of bricks in the kiln can cause firing and cooling cracks in the bricks.
3. Some damage is also caused from excessive handling of bricks during lift-up to the kiln top and in the loading process

Due to the lower density and lower compressive strength of hand-moulded bricks, the problem in brick quality are more pronounced when hand-moulded bricks are fired in VSBK. From the experience of Vietnam, it was evident that the firing of machine-moulded bricks results in improvement in quality.

The FCBTK and zig-zag have slow heating and cooling rates and generally do not have problem of formation of firing and cooling cracks. The FCBTK does not have uniform temperature distribution in the firing zone and hence only 60-70% bricks are properly fired; the remaining production is either under- or over-fired. The zig-zag has more uniform temperature distribution, and hence 80-90% of the bricks are properly fired.

VI. Brick Sector Scenario

Input from prominent brick makers was sought via interviews during monitoring and two stakeholder workshops.The main objective of these interviews/interactions was to get better understanding of the current status of brick making and future trends.

Main findings are as follows:

Shortage of workers*:*The brick industry is facing a severe worker shortage, which resulted in a decrease in brick production of upto 30% in several important brick making clusters during 2011. The worker shortage was first noticed in 2007 with the first implementation phase of thMahatma Gandhi National Rural Employment Guarantee Act[9]. Most of the brick kiln owners want to reduce dependency on workers through semi-mechanisation[10]of the production process.

Rapid increase in the fuel cost: Fuel prices have risen 100-175% over the past five years. Management of fuel cost is an important consideration for brick makers, resulting in shifts to cheaper fuels. The majority of the brick makers do not have practical knowledge and skills to adopt energy conservation measures. There are no intermediaries to help brick makers implement energy conservation measures.

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[9] The Mahatma Gandhi National Rural Employment Guarantee Act (MNREGA) aims at enhancing the livelihood and security of people in rural areas by guaranteeing hundred days of wage-employment in a financial year to a rural household whose adult members volunteer to do unskilled manual work.

[10] Here semi-mechanization means use of machinery for moulding bricks using an extruder or a soft-mud moulding machine and partial mechanization of the material handling.

***Competition from other walling materials*:** Clay brick makers are facing competition from other walling materials. This is particularly true insouthern and western India.

Barriers in adoption of new technologies for semi-mechanization

- The majority (>90%) of brick kilns in the Indo-Gangetic plains are located on leased land. This is expected to be a large barrier in making investments in construction of new facilities andmachinery. A shift to new technologies would requireinvestment in land or renegotiating lease agreements. Due to high price of land around cities, brick enterprises are likely to relocate further away from towns and cities.
- Limited or no access to grid-electricity: Semi-mechanization of the brick production process requires electricity. Most of the existing brick kilns either do not have access to grid electricity or are located on rural electricity feeders, which are prone to power outages and poor power quality. This is a significant barrier in adopting new technologies. Adopting new technologies requires investmentsin captive power generation facilities by brick makers.
- Low profit margins for machine--moulded bricks: Machine-moulded bricks have a higher production cost and face stiff competition from lower-priced manually produced bricks.
- Financing: The capital investment in any robust and reliable semi-mechanization brick making package ranges from Rs 10-200 million. The majority of brick makers have no or limited access to bank credit.
- Lack of availability of off-the-shelf technology packagesand technology providers:Standard technology packages are not available. The know-how of the zig-zag firing is limited to a handful of brick makers. For VSBK technology there is only one active technology provider. The manufacturing of machinery for brick making is concentrated in a few small-scale enterprises. Recently some European brick-making machinery manufacturers have entered the market and are involved in field trials on India specific technology packages.
- Lack of availability of trained manpower**:**Operation of any new technology requires trained manpower, which is in short supply. The VSBK monitored during the study was operating at 50% of its rated capacity, mainly because of a workershortage. Similarly, the poor operation of the zig-zag forced draft kiln can be attributed to absence of trained manpower for its operation. Currently, there is no system in place to train manpower for the brick industry.

VII. A Road Map for Cleaner Brick Production in India

India's brick sector is characterized by traditionalfiring technologies, with high emissions; reliance on manual labour and low mechanization rate; dominance of small-scale brick kilns with limited financial, technical and managerial capacity; and dominance of single raw material (clay) and product (solid clay brick).

This report suggests that development of a cleaner brick production industry in India over the next tenyearsshould aim at:

Adoption of cleaner kiln technologies: The FCBTKs and DDKs should be replaced withzig-zag, VSBK or other cleaner kiln technologiesby 2020.

- Zig-zag kilns appear to be the logical replacement for FCBTKs, because of low capital investment, easy integration with the existing production process, and possibility of retrofitting FCBTKs into zig-zagfiring. The zig-zag kiln performance strongly depends on the kiln operation practices;also,zig-zag natural draught kiln appear to perform better than zig-zag forced draught kiln. These aspects need further study before finalizing recommendations and formulating a large-scale dissemination programme for zig-zag kilns.
- VSBK appears to have a limited market, mainly because of its inability to produce good quality bricks from all types of clays and low productivity under the Indian conditions. Incorporation of features of Vietnamese VSBKs into Indian VSBKs may help in improving the VSBK technology package. VSBK dissemination needs to be properly targeted.
- The tunnel kiln technology is capital intensive, and the current technological know-how and experience is limited in India. Adoption of tunnel kiln also requires extensive modifications in brick moulding, drying andmaterial handling. Widespread adoption of tunnel kiln technology is not foreseen in immediate future.

Promotion of internal fuel in brick making by mechanizing the brick making process; Internal fuel addition significantly reduces SPM and BCemissions. Cheaper fuels, such as, coal slurry, coal dust, charcoal dust, and sawdustcan be used as internal fuels and canhelp reduce fuel cost. Management of internal fuel addition is extremely difficult in the manual molding process. Semi-mechanization of mouldingneeds to be promoted to support use of internal fuels. Semi-mechanization of the brick moulding process would have other benefits, including an ability to use inferior clay resources and wastes, reduction in drudgery and better working conditions for workers, and potential to produce hollow and perforated bricks.

Promotion of mechanized coal stoking systems:High PM and BC emissions in FCBTKs occur during the period of fuel feeding. Continuous feeding of properly sized fuel, using a coal stoker in a FCBTK or a zig-zag kiln, can reduce the emissions significantly.

Diversifying products (e.g. hollow and perforated bricks):Hollow and perforated bricks require less clay and fuel as well as provide better thermal insulation of walls and hence needs to be promoted.

Promotion of modern renewable energy technologies in brick making:Apart from the CO_2 emissions caused by firing of coal in brick kilns, the current brick making practice has a very low carbon footprint. Any mechanization of the brick making process, as proposed above, would require use of electricity.Captive power generation using diesel fuel is expensive and has a high carbon footprint. Renewable electricity generation options using biomass gasifiers and solar PV need to be promoted. Semi-mechanization of the brick moulding process also requires artificial drying, which may increase the coal consumption in brick making. There is a need to develop more efficient drying systems based on use of modern solar thermal and biomass energy technologies.

To achieve these goals, recommendations to Government of India,include:

Modification in environmentalregulationsto phase-out FCBTKs:

Environmental regulationscan be amended to phase-out FCBTKsand replacethem with cleaner brick firing technologies. Any action on environmental regulations needs to be supported by complementary supporting actions, which may include:

- Preparation of standard zig-zagand other cleaner kiln technology knowledge packages (containing design, construction and operation guidelines).
- Training and certifying a cadre of technology providers in cleaner brick firing technologies.
- Educating/training brick kiln owners, supervisors and workers in cleaner brick firing technologies
- Supporting a modest R&D programme to consider improvements in zig-zag firing package, e.g. mechanical stoking of fuel; replacement of ash layer on the top of the kiln.
- Conducting environment monitoring of kilns to gain further understanding and guide the policy action.

Launching an Indian brick development programme

There is a strong case for a national programme for the development of the brick sector.The programme should address issues related to:

- *Planned relocation of brick industry clusters*: Identify sites for relocation of brick industry, based on factors such as clay resource mapping, mapping of waste sources appropriatefor brick making, access to electricity and distance from demand centers.
- *Technology transfer and dissemination*: Support for technology transfer/demonstration/field testing of semi-mechanized and cleaner firing technology packages.
- *Skill development*: Develop a cadre of local technology providers, who can also provide service and train supervisors and the workforce.
- *Financing*: Provide access to financing.
- *Advocate for policy change.* Work with appropriate partners to enact environmental policies to transform the industry.

Implementation of these measures can result in annual coal savings of the order of 2.5 to 5.0 million tons/year; significant reduction in air pollution; improvement in profitability of brick enterprises; and improvement of working conditions for millions of workers employed in brick kilns.