Towards sustainable production systems: *closingtheloops*

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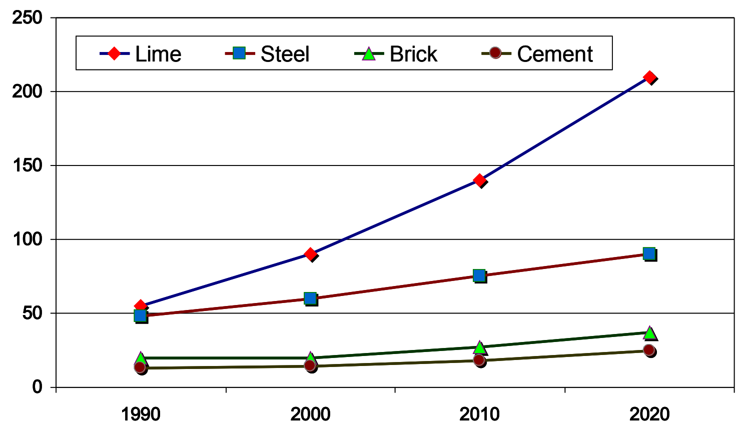
Abstract

The fast-growing Indian construction sector is that country's single largest contributor of CO2 *emissions. This sector is characterized by increasing shortages of conventional building materials, and by technologies that use resources and energy inefficiently.* A *response strategy has been devised to meet the growing demand for building materials while limiting emissions. To increase the supply of walling materials, Sustainable Production Systems have been defined. An eco-design case study is presented of TARAGRAM, an appropriate technology resource centre in central India whose production system closes the loops for the generation and sustainable utilization of water, biomass and energy resources.*

The construction sector in India is a major user of natural resources, energy, manpower and capital. It is also the single largest sector, responsible for 22 per cent of total emis*sions.* This sector is slated to grow continuously, with projected 4.6 percent annual economic growth resulting in increased affordability and a marked change in consumption patterns. There is also a trend towards increasing use of energy intensive building materials. Further, there is a backlog amounting to 18 million houses, with diminished availability of biomass materials (wood, thatch) and a saturating supply of conventional materials (stone, slate). It has been established that the major energy users in the building materials industry are the producers of cement, steel, bricks and lime, which together contribute 80 per cent of total emissions in the construction sector. Current demand for these four materials requires energy amounting to 743 PJ, with a corresponding 81 million tones of CO2 emis*sions.* In the specific case of cement, per capita consumption is expected to increase from the existing level of 60 kg to *210* kg by the year 2020. The latter figure is equivalent to current consumption in developed countries. The projected demand for these four building materials, for the period 1990-2020, is shown in ***Figure 1***.

Figure 1
Projected demand for building materials (1990-2020)



As these materials are largely material-intensive, their use puts increasing pressure on natural resources and on non-renewable energy resources. It is expected that, by the year 2020, their use will result in a three-fold increase in energy requirement. The corresponding emissions will escalate to 285 million tones of CO_2. These projections are based on current technology mixes prevalent in the respective manufacturing sectors. Besides putting immense pressure on natural resources, this trend will mean a 4.3 per cent per year increase in emissions and a doubling of emissions in per capita terms. Such a trend is clearly unsustainable.

Strategy for sustainable building technologies

The demand trends for walling and roofing show a transition to engineered and high-energy material alternatives: This is bound to give rise to a shortage in the materials required for building construction. The supply gap, evident in the case of burnt bricks for walling and stone and slate for roofing, is a natural consequence of the limited availability of natural resources such as clay and the conflicting requirements for limited energy resources. The normal response is to rely on improving energy efficiency within the basic material production sector. This response is seen in the cement and steel industries, which are acquiring new technology to achieve high standards of energy efficiency and environmental performance. The impact of technology measures alone on reducing emissions, within the context of the four major building materials, will be significant under the growth conditions projected for production of basic building materials. An assessment of the technology alternatives likely to be adopted has been made.

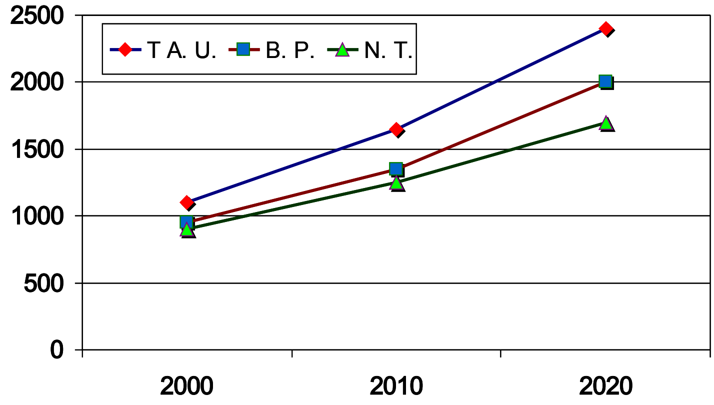
Technology alternatives

Three distinct scenarios have been developed by Development Alternatives in order to understand the impact of wide adoption of these technology options on net energy demand and resultant emissions.

1. The first scenario, Technology as Usual (TAU), is evaluated on the basis of the entire projected future demand being met with the current *mix* of technologies. The proportion of production using each existing technology is expected to remain unchanged.
2. The Best Practice (BP) technology option requires that all production capacity, both existing and new, conform to the Best Practice technology currently available.
3. The third option superimposes New Technology (NT) for all additional capacity, with the capacity of 1989-90 conforming to Best Practice technology.

Figure 2

Impact of technology on net energy demand for four building materials



In a situation where demand is expected to grow exponentially, the cumulative energy requirement for the four materials is expected to increase from 742 in 1989-1990 to 2363 PJ by 2020, under the TAU scenario. The introduction of BP has a net positive impact, reducing energy consumption by 17 per cent to *2000* PJ in the year 2020. On the basis that all new installed capacity conforms to the new technology available, the total energy saving possible is 563 PJ, equivalent to 25 percent of the total energy that would be consumed using present technologies. These projections reflect the energy savings possible through technology intervention alone, with the projected demand for building materials fully met. Clearly this is not enough.

The reduction of emissions and a positive impact on resource efficiency can become significantly greater through promotion of low-energy building material alternatives and options which rely on highly efficient use of energy-intensive materials like cement and steel. There is evidence from various parts of India that new walling materials, timber substitutes, and roofing alternatives can be adopted within a reasonable time frame and on a wide scale. For walling, stone cement blocks have been widely accepted in areas where brick production burnt is no longer economically feasible or the cost of transportation has become excessive. Ferro-cement and micro-concrete roofing tiles have in recent years achieved wide acceptance, especially in areas where stone crusher waste is locally available.

Any strategy for improving housing through sustainable building technologies will need, on one hand, to augment the supply of building materials to meet demand and, on the other, to integrate ecological design concerns into the delivery process. The sustainability of such a strategy will require consideration of factors such as local availability, decentralized production systems, resource efficiency and materials movement. This in turn requires integration of a Sustainable Production System for building materials with techno-economic packages for efficient delivery. The key elements of the strategy are illustrated below. Two i of the main processes discussed are:

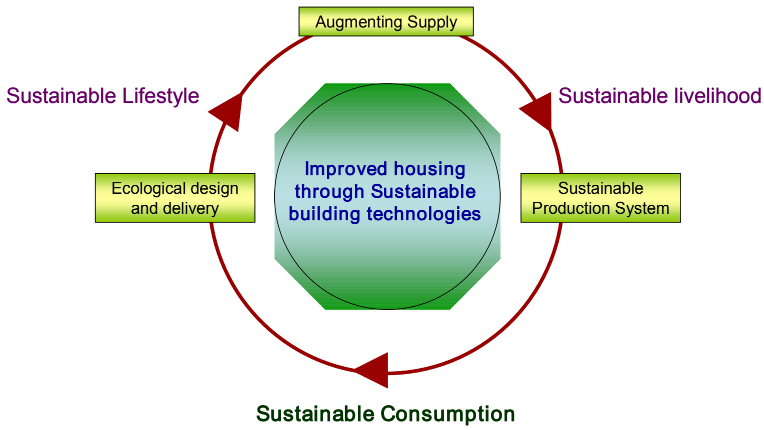
- augmentation of supply: a case study concerning walling;
- TARAGRAM: a study in eco-design.

Augmentation of supply: a case study concerning walling

There is dear evidence of a leveling off in the supply of conventional building materials such as burnt bricks and slate. On the basis of a projected demand for 45.31 billion bricks in 1990, the projected demand for 2020 is 89.1 billion. According to the projections of the Planning Commission for the VIII plan period (1992-97), later verified by the Building Material and Technology Promotion Council, brick production is likely to reach the saturation point at about 46.5 billion. This is attributed to the limited availability of day of requisite quality, coupled with restricted availability of fuel and increasing environmental concerns regarding the operation of brick kilns. Thus a strategy for reducing emissions can only be seen in the context of fulfilling demand through assuring supply.

Figure – 3

Elements of a strategy for improved housing



The effective augmentation of supply can only take place while incorporating efficient utilization of resources. For walling, burnt brick production is the dominant factor and can only be sustained through major improvements in technology. Use of Best Practice technology results in a 10 per cent increase in energy efficiency. The newly introduced Vertical Shaft Brick Kiln (VSBK) technology is likely to improve energy efficiency up to 30 per cent. The shortfall in supply is likely to be satisfied by stone-cement and concrete blocks. A series of technology measures have been incorporated in order to develop different scenarios for walling, characterized as follows:

- Using Technology as Usual, all brick production would be carried out with the existing mix of technologies.
- Best Practice technology would be adopted for all brick production, (limited to 46.5 billion per year).
- The supply of walling material in the period 2000-2020 would be augmented by stone-cement

and concrete blocks.

- Twenty-five per cent replacement of brick production up to 2020 would be achieved through the introduction of new technology (e.g. VSBK).
- Twenty-five per cent replacements of bricks up to 2020 would be achieved through use of low-energy alternatives (e.g. compressed earth blocks, fly ash products).

The impact of each of these measures has been evaluated in terms of energy requirements, energy savings possible, and resource Utilization. The adoption of Best Practice for 46.5 million bricks results in a saving of3.3 million tones of coal by 2000. Substitution by concrete blocks further limits the energy requirement, resulting in a saving of 14 PJ in the year 2000, growing to a saving of 40 PJ by 2020. A partial replacement of existing brick kilns by VSBK technology brings down the energy requirement even further. The maximum saving that can be achieved while fulfilling the demand requirements is 4.4 million tones of coal for walling purposes alone in 2000, growing to 7 million tones by 2020.

The choice of technology clearly needs to be region-specific, taking account of building practices, raw materials and environmental imperatives. In addition to energy efficiency, Sustainable Production Systems need:

- full accounting of resources, especially proper energy pricing; and
- decentralized production of building materials.

Energy pricing

The manufacture and distribution of cement entails significant transportation costs for finished goods and energy costs for manufacturing. As the use of cement and cement products grows, energy pricing will have to be increasingly rationalized.

The fuel cost per metre of walling in the case of concrete blocks is Rs.11/ -, for a net energy consumption of 164 MJ in terms of primary energy used. In the case of burnt bricks, the cost of fuel is considerably higher at Rs. 40/- per square metre, mainly due to the cost of coal. The corresponding energy for walling from burnt bricks is 495 MJ.

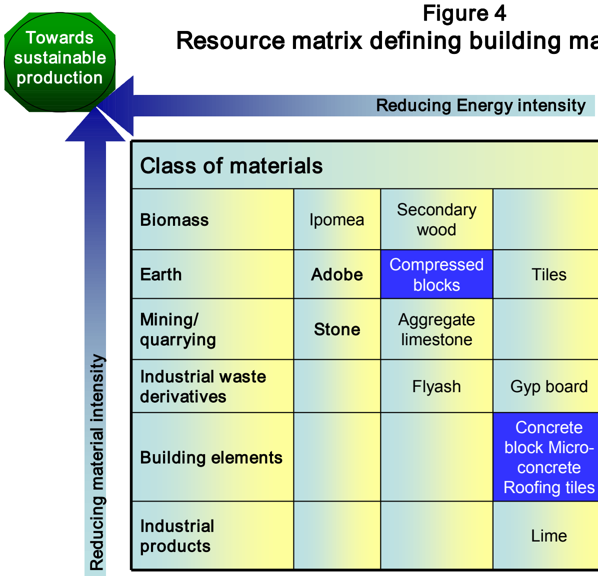
An analysis of fuel costs per unit of energy using Best Practice in cement and brick manufacture provides some valuable insights. The cost per unit input energy being paid by the large cement industry for high-quality coal, electricity and diesel appears to be only 80 per cent of the price for equivalent fuel estimated in brick manufacture. A policy that prices fuel equally for both materials without taking account of transportation costs would result in an increase in fuel costs for the cement industry from Rs. 470/- to 560/- per tone. This factor is even more important in view of the long distances over which cement is presently transported because of highly subsidized transportation costs. Though the suggested pricing is only indicative, the whole issue of energy costs, particularly in relation to electricity and diesel, needs to be examined in greater detail. Moreover, these costs are assuming greater importance in view of the current trend to provide large electricity generation capacities using diesel generating sets.

Decentralized production

From the previous section, it has become evident that energy efficiency up to 25 per cent could be achieved through improved production processes. However, the augmentation of supply can be achieved through wide use of cement-based blocks and judicious substitution of natural materials with industrial waste and low-energy derivatives. With these measures, the total energy requirement can be reduced 50 per cent compared with the requirement for present production and usage, while still meeting demand. Some of these low-energy alternatives are compressed earth blocks, manually compressed using cement and lime as stabilizers, and fly ash-lime blocks produced through mechanical compaction. A wide variety of stone-concrete blocks can be produced using a cement matrix with different grading of stones and stone crusher waste. Each of these materials can be produced by decentralized workshops located near the source of materials. In the case of concrete blocks and micro-concrete roofing tiles, there is ample evidence of the economic viability of decentralized production and marketing systems.

Sustainable Production is achievable by simultaneous reductions in material and energy intensity. Different building material options can be located within a Resource Matrix (*Figure 4*) which defines the path to be followed in regard to emerging building products and technologies. Some of these options are described in the next section.

Figure 4
Resource matrix defining building material options



Class of materials					
Biomass	Ipomea	Secondary wood			
Earth	**Adobe**	Compressed blocks	Tiles	Brciks	
Mining/ quarrying	**Stone**	Aggregate limestone			Coke
Industrial waste derivatives		Flyash	Gyp board	**Autoclave blocks**	
Building elements			Concrete block Micro-concrete Roofing tiles	Ferrocement	
Industrial products			Lime	Cement	Steel sections Aluminium

TARAGRAM: a study in eco-design

Eco-design

Any sustainable society must be based on design processes and production systems that are sensitive to ecosystem limits. Energy and material flows must be minimized and, to the extent possible, local resource flows given preference over long distance ones. The construction sector is responsible for the built environment, including shelter and infrastructure. It draws heavily on the resources of the earth and can cause extensive damage to the natural environment. The design and construction of human settlements and industrial units must therefore take special care to integrate the satisfaction of human needs with concerns for resource efficiency and economic viability.

TARAGRAM is the appropriate technology resource centre of Development Alternatives, located in Orchha in central India. (TARA, which stands for "Technology and Action for Rural Advancement", is the brand name of the products of Development Alternatives. *Gram* in Hindi means village.) The mission of TARA GRAM is to develop techniques and institutions that can regenerate the resource base and make it available for utilization in an efficient, equitable and environmentally sound manner. TARAGRAM serves as a model to bring together social, environmental and technological knowledge to generate sustainable livelihoods through decentralized production systems. Such livelihoods are needed in large numbers throughout the developing world to improve material standards while maintaining the physical resource base.

TARAgram manufactures products using local raw materials. At present, these include paper, building materials and energy; new ones are being added continually. In addition to serving as a demonstration facility for such livelihood technologies, TARAGRAM provides on the job and course-based training for personnel from micro-enterprises that wish to set up similar plants.

The captive power plant converts renewable biomass fuels (including mainly local agro-wastes and unusable weeds) into 80 k W of electricity using a highly efficient gasifier and diesel generating set *(Figure 5)*. The power plant will shortly be working at its full-rated capacity of 100 kW. A pyrolysis unit also generates excellent charcoal from local biomass. These fuel conversion technologies have been developed by various research institutions in India and are optimized for local conditions. The electricity generated supplies the needs of the entire campus, including the manufacturing plants, training establishment, artisans' village, and other facilities for community interaction such as an open air theatre.

Figure 5
100 kW gasifier at TARAgram

The handmade paper unit, a micro-enterprise based on front-line technology designed by Development Alternatives, employs more than 70 people, mostly women who earlier had no source of income. Its raw materials include cotton rags from nearby urban markets and textile mills, used paper, and waste biomass. The paper unit occupies more-than 500 square metres of covered and open areas for pulping, lifting, drying and finishing. The layout and placement of work stations have been carefully designed to simplify and reduce movement of materials, energy and people, leading to considerable savings in piping, wiring and human effort.

Indeed, the basic design principles of the entire village seek to maximize the functionality of the production facility and minimize the use of external energy and the movement of raw materials, water, finished goods, and people.

Figure 6
Building production from waste: stone-cement blocks, ferrocement channels

The design and materials for the building were also chosen to maximize the use of local skills and building forms. The structure therefore uses a series of arches built with hand-moulded stone-concrete blocks *(Figure 6)*. Where the building is not exposed to water, the walls are made of compressed earth blocks. In dry areas, the roofs covered with Tara micro-concrete roofing tiles (TARACrete) and supported by steel trusses made from locally available used boiler tubes. The roofing tiles are coloured green to blend with the foliage. To maintain the high standards of cleanliness needed for paper finishing, the roof is made of ferrocement channels.

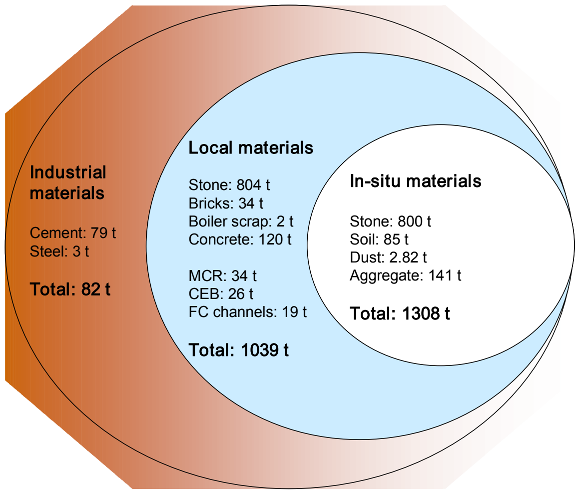
The materials used for construction are largely of low to medium energy intensity. Energy intensity can be classified as follows:

- low energy intensity: on-site materials and recycled materials - up to 5 km radius;
- medium energy intensity: local materials - up to 50 km radius;
- high energy intensity: industrial products - up to 500 km radius.

Wherever possible, we have used waste and recycled materials available locally. Use of industrial building products has been minimized.

Resource utilization for the construction of TARAGRAM is shown in *Figure 7*. The entire TARAGRAM complex averages 0.12 tones of cement and 4.5 kg of steel per square metre of construction, compared with conventional building technologies which consume 0.21 tones of cement and 14.5 kg of steel for a building with the same performance.

Figure 7
Material procurement by distance at TARAgram



Water management

Being a production facility, TARAGRAM needs assured water throughout the year. In fact, its requirement is approximately 100,000 litres of fresh water per day. Designing the site for sustainable water management therefore assumed prime importance. Th6 initial site work was entirely devoted to water conservation structures, including gully plugs and drainage channels.

To ensure adequate ground water recharging, a checkdam has been constructed on a stream that borders the site. The reservoir thus created retains water throughout the year and ensures adequate charging into an open well, which is the main source of water for TARAGRAM operations.

The geo-hydrological formations fortunately ensure that the water is potable. Because of the recharge caused by the checkdam, and in contrast to most other places in the area, water is available throughout the year.

Within the paper manufacturing process, great care has been taken to recycle the water as much as possible. While the total water requirements of the paper production unit are 115,200 litres of water per day, recycling and selective grading of more than 50 per cent of the water reduces the requirement for fresh water to less than 55,000 litres. Finally, the water leaving the paper production process is passed through settling tanks to reduce total dissolved solids. The treated water is directed to the building material section for a second reuse. A small quantity of the treated water is also used for watering the site and for horticulture. The water discharged from other production processes is allowed to percolate through the gully plugs provided on-site, to effectively close the loop.

Energy requirements

The energy requirements of TARA GRAM are primarily electrical energy for motors and pumps; heat energy for assured drying of paper and water heating; and cooking energy for site requirements. Several alternatives were explored for setting up a power-generating utility based on self-sufficiency and the use of renewable resources. As a result, the 100 kW power plants use a biomass gasifier based on technology developed by the Indian Institute of Sciences of Ban galore together with a commercially available diesel generating set. The gas generated replaces as much as 90 per cent of the diesel fuel needed for producing electricity. Even though wood-based gasifiers have been operational for some time in India, their effectiveness for non-wood biomass fuels has not been established. The biomass-based gasifier, designed specifically for TARAGRAM, relies on the use of Ipomea, a biomass waste available along most of the water bodies and stagnant streams in the region. An initial assessment of local availability has established renewable resources of Ipomea of approximately 500 tones per year, more than sufficient for the one tone per day required for the power plant. There is no conflict involved in the use of this material, since it has no other uses. Environmentally, since it is pyrolized in the gasifier and not burnt in the open, the emission of toxic fumes is avoided. This unit has been commissioned and is working efficiently. The collection and preparation of the Ipomea has also led to the setting up of small household enterprises.

The waste heat from the exhaust system and the cooling water will be utilized for drying paper and biomass products. A heat exchanger system with forced convection is being set up to extract approximately 60 kW of heat equivalent for drying operations. The cooking energy requirements are met through waste char, which is produced during regular maintenance and cleaning of the gasifier-system. It is proposed to tap part of the producer gas and use it directly for thermal applications. This system will be set up only after safety aspects have been duly established.

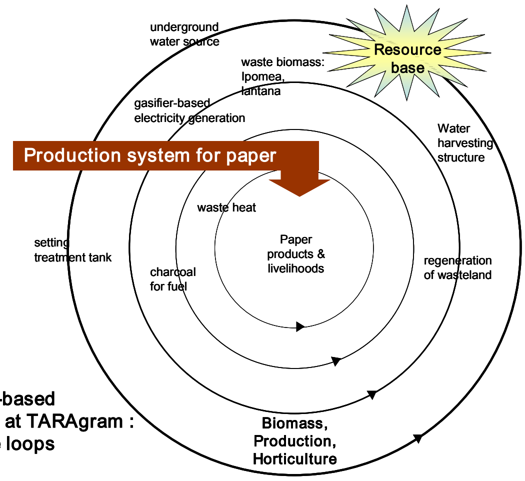


Figure 8

Livelihood-based production at TARAgram : closing the loops

The design of the production system is based on inputs of biomass and recycling of wastes. The biomass can be effectively regenerated by efficient management of land and water resources. Closing of the loops for water, biomass and materials is shown in *Figure 8*. The net outputs of this system are sustainable livelihoods, handmade recycled paper and appropriate building materials. The scope of TARA GRAM is being extended to integrate other resources that can be made available with long-term renewability, by using local skills and through technology development. The project will aim to demonstrate the economic viability of Sustainable Production Systems, while ensuring maximization of products into the local economy.

Conclusion

Increasing the supply of building materials in India is achievable through a multi-pronged strategy which integrates energy efficiency, in relation to existing building materials and processes, with sustainable production systems for building material alternatives. The process can only be completed by ensuring eco-sensitive design and delivery processes which take user concerns into account and lead to the creation of sustainable livelihoods. The demand for housing can be met, while limiting energy and emissions to up to 50 per cent of the level that would be likely using conventional processes. This strategy would need a regional focus to take into account resource issues, livelihood requirements, and macroeconomic trends. A regional model for integrating these concerns has been evolved. It will be evaluated for its impacts on resources and livelihoods.

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