The future of the red metal—A developing country perspective from India

Amit Kapur

Center for Industrial Ecology, School of Forestry and Environmental Studies, Yale University, 205 Prospect Street, New Haven, CT 06511, USA

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Abstract

Three plausible scenarios—Tech World, Green World, and Trend World, for copper use in India during the 21st century are presented. The scenario framework is based upon the Intergovernmental Panel on Climate Change scenarios for greenhouse gas emissions and the scenario model is based upon the intensity of use hypothesis. Irrespective of the scenario, India’s intensity of copper use will continue to increase until 2050, with rapid growth occurring between 2020 and 2050. By 2100, copper use in India could range between 9 and 17 Tg Cu/year, showing a multiple increase from the present level of 0.3 Tg Cu/year. Three sectors—housing, power, and transport are expected to be the major drivers of copper use. Currently, copper production from secondary copper meets approximately 40% of the contemporary demand. However, the Government of India needs to promote the recycling industry in the country to make it more organized and market driven such that it can provide an important feedstock of resources to meet India’s burgeoning demand for materials.

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Keywords: Red metal; Copper use; Indian economy; Scenario analysis; Substance flow analysis

1. Introduction

India is primarily an agrarian economy with more than 70% of the population still living in the rural areas. However, the decade of the 1990s was a revolutionary era in the
Table 1

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Total recoverable reserves (Tg)</th>
<th>Apparent rate of use a (Gg/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>2527</td>
<td>600</td>
</tr>
<tr>
<td>Chromium</td>
<td>97</td>
<td>600</td>
</tr>
<tr>
<td>Copper b</td>
<td>98</td>
<td>200</td>
</tr>
<tr>
<td>Iron</td>
<td>13435</td>
<td>36000</td>
</tr>
<tr>
<td>Lead b</td>
<td>35</td>
<td>100</td>
</tr>
<tr>
<td>Manganese</td>
<td>191</td>
<td>-</td>
</tr>
<tr>
<td>Silver b</td>
<td>0.004</td>
<td>3</td>
</tr>
<tr>
<td>Tin b</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>Zinc b</td>
<td>10</td>
<td>20</td>
</tr>
</tbody>
</table>


* Values refer to the year 1998.

* Metal content.

Indian economy when a highly closed and regulated economy was opened to globalization through a series of economic and liberalization reforms. India with over 1 billion people is now the world’s fourth largest economy (expressed in purchasing power parity dollars) and is still growing at rates higher than those of other developing countries being next only to China. India is a rapidly developing country with a vision to become a developed nation by 2020 (Kalam and Rajan, 2002). The country is perceived to become a global player in the world economy in this century. The boom of the information technology (IT) sector has further propelled the Indian economy by providing a competitive edge over other countries in this field. With a large pool of inexpensive and highly skilled manpower, India is emerging as the back office of the world both for providing IT services and for research and development activities in various science and technology fields. However, the transformation will require exponential growth in basic infrastructure sectors, such as housing, energy, telecommunications, etc. The tremendous growth potential in these sectors implies a huge demand for basic materials, such as steel, copper, aluminum, zinc, etc. The reserves estimates and apparent rates of use of major metals in India are shown in Table 1. Going forward, it is likely that the gap between demand–supply of these metals from domestic sources will continue to increase, so India would have to rely increasingly on imports of different ores and minerals (Roonwal and Wilson, 1998; Indian Bureau of Mines, 2001; Indiastat, 2004).

This paper presents a set of future scenarios of material use in India, with copper as the example. India is an appropriate representative example to present the developing country perspective to analyze the question: Is it reasonable to expect developing countries to leapfrog and dematerialize given their contemporary socio-economic profile? It is expected that the strongest growth in demand for copper products will take place in countries, such as China and India, that currently have relatively low levels of per capita copper use, but have a large potential for rapid industrialization and infrastructure development. The impact of such strong growth in developing countries can be significant and may
influence the structure and prospects of the global copper industry in the long term. In addition, various other factors, such as the lackadaisical nature of governments in these countries towards environmental policy and regulation, use of relatively inefficient and environmentally damaging technology by small and medium enterprises, a huge informal network of recycling, and existing technological gaps in various sectors can also influence material use patterns. This study builds on the previous work on future scenarios for copper use at the global and regional level (Kapur, 2005).

2. The Indian Copper Industry—an overview

For over 3 decades, there was only one primary producer of copper in India, M/s Hindustan Copper Limited (HCL), a Government of India owned enterprise with an installed capacity of 47.5 Gg Cu/year of cathode copper. There were approximately ten copper mines under HCL’s operations; but on account of high operating costs and decline in ore grades, HCL’s profitability and production output was significantly affected over the last decade. As a result, the Government of India plans to privatize it through the disinvestments route. With the liberalization reforms in the 1990s, the Government of India allowed private companies to set up copper smelters in the country. Thereafter, over the last 5 years, two private players, M/s Sterlite Industries Limited and M/s Hindalco Industries Limited (the copper business division is known as Birla Copper) emerged, each with installed capacity of 150 Gg Cu/year of cathode copper. Both Sterlite and Birla Copper import copper ore/concentrates from mines owned by them in either Australia or Africa. This type of business model provides a certain degree of stability in terms of supply and price of copper ore/concentrate to their smelting facilities in India. With a six-fold increase in cathode copper production, India’s import of cathode copper has declined significantly, resulting in a savings of valuable foreign exchange for the country (e.g., in the year 2000, India imported 180 Gg of copper ore and concentrate, and 30 Gg of cathode copper, as compared to the 1994–1998 period when on an average India imported 34 Gg of copper ore and concentrates and 130 Gg of cathode copper) (ICSG, 2002). Countries in Asia accounted for 44% of global refined copper usage of 15 Tg in 2002. However, India’s share is approximately 5% of Asia’s demand or 3% of overall global copper demand.

The fabrication and manufacturing of copper and copper alloys semi-products are dominated by copper wire and strip, followed by copper flat products, engineering and sanitary castings, and metal artwares. The domestic production, import, and export statistics of copper and copper alloy semi-products for the year 2001–2002 are given in Table 2. The total copper usage in the country is approximately 450 Gg Cu/year. Compared to its domestic production, the net import–export rate of semi-products is significantly lower. The largest exports of copper and copper alloy semi-products are metal artwares, which include handicrafts and utensils.

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1. When copper ores are subjected to sequential processes of concentration, smelting, and electrolytic refining, the end product is known as cathode copper.
2. Fabrication processes transform cathode copper into semi-finished products, such as ingots, strips, and bars, which are also known as semis.
Table 2
Domestic production, import and export of copper, and copper alloy semi-products for the year 2001–2002

<table>
<thead>
<tr>
<th>Copper and copper alloy semi-products</th>
<th>Domestic production</th>
<th>Import</th>
<th>Export</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wires and strips</td>
<td>240</td>
<td>25</td>
<td>3</td>
</tr>
<tr>
<td>Flat products</td>
<td>85</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Tubes and sections</td>
<td>32</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Metal artwares</td>
<td>40</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Engineering and sanitary castings</td>
<td>50</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Metal powders and chemicals</td>
<td>15</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Total</td>
<td>462</td>
<td>42</td>
<td>51</td>
</tr>
</tbody>
</table>

All figures are net copper content expressed in Gg Cu/year. Source: ICSG (2003).

3. Contemporary copper cycle—India

The Stocks and Flows Project at the Center for Industrial Ecology, Yale University, is addressing the anthropogenic budgets of materials used in the technological society, their current generation and processing rates, use patterns, spatial distributions, and recycling streams. Contemporary copper cycles have been estimated at different levels—city, country, regional, and global. The concepts of substance flow analysis (SFA) were employed to develop the contemporary copper cycle at each level. SFA is an important tool of Industrial Ecology based upon the law of conservation of mass that monitors the flow of specific substances in order to identify environmental problems and propose remedial/prevention strategies. Country-level statistics on production (P), imports (I), and exports (E) (hereafter designated PIE data) of copper concentrate, blister copper, and cathode copper are published annually by the World Bureau of Metal Statistics (WBMS) and the International Copper Study Group (ICSG). In addition, the PIE data for copper and copper alloy semi-products are also published. The data for each process and its corresponding flow were collated for all the countries, and mass balance estimates were determined by the following equation:

\[
\text{Net copper flow} = \sum \text{production} + \sum \text{import} - \sum \text{export} + \text{change in stocks}
\]

To avoid possible double accounting of trade flows, the net import or export rate of copper was determined by taking difference between imports and exports. The net addition or depletion of copper stock in a reservoir was determined using Eq. (1). Copper flow estimates for mine tailings and smelter slag were determined empirically using Gordon (2002) approach. The waste management flows were determined as per Bertram et al. (2002).

The “best estimate” contemporary copper cycle (ca. 2001) of India is shown in Fig. 1(a) (modified from the original cycle illustrated in Graedel et al., 2004). Overall, India is a net importer of copper. It imports more copper ores and concentrates rather than cathode copper. The sectoral distribution of copper end uses is shown in Fig. 2. The electrical and electronics sector account for more than 50% of contemporary copper use. As per the accounting of statistics in India, the use of building wire and cables is included in this sector, instead of the building and construction sector. The net import–export rate of copper-containing finished products is shown in Table 3. The import of copper-containing finished products
Fig. 1. (a) "Best-estimate" contemporary copper cycle of India (ca. 2001). All units in Gg Cu/year (modified from the original cycle illustrated in Graedel et al., 2004). (b) "Best-estimate" contemporary copper cycle of India (ca. 2001) with confidence ratings. All units in Gg Cu/year (modified from the original cycle illustrated in Graedel et al., 2004).
Fig. 2. Sectoral copper end uses in India (1995–1996) (data source: ICSG, 1997).

Table 3
Trade of finished products in India (ca. 2001)

<table>
<thead>
<tr>
<th>Product</th>
<th>Trade volume a (Gg/year)</th>
<th>Copper concentration (%)</th>
<th>Copper flow (Gg Cu/year)</th>
<th>Direction of trade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicles b</td>
<td>73</td>
<td>1–1.5 d</td>
<td>1.0</td>
<td>Net export</td>
</tr>
<tr>
<td>Insulated wire c</td>
<td>–</td>
<td>60</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Metalworking machinery d</td>
<td>20</td>
<td>14.5 c</td>
<td>2.9</td>
<td>Net import</td>
</tr>
<tr>
<td>Industrial machinery</td>
<td>56</td>
<td>2</td>
<td>1.1</td>
<td>Net import</td>
</tr>
<tr>
<td>Ships and boats</td>
<td>157</td>
<td>0.5 d</td>
<td>0.8</td>
<td>Net import</td>
</tr>
<tr>
<td>Electronic products e</td>
<td>34</td>
<td>2–4.6 k</td>
<td>1.1</td>
<td>Net import</td>
</tr>
<tr>
<td>Aircraft</td>
<td>1</td>
<td>28</td>
<td>0.02</td>
<td>Net import</td>
</tr>
</tbody>
</table>

Total product (export–import) 195 4.9 Net import

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2 Includes passenger cars, motor vehicles for the transport of goods, road tractors, motor buses, motor cycles, and other cycles.
3 Keoleian et al. (1997).
4 Informed estimate.
5 Includes insulated electric wire, cable, bar, and strip.
6 Average value from physical measurement.
7 Includes agricultural machinery and parts, tractors for non-road use, civil engineering equipment, textile and leather machinery and parts, paper and pulp mill machinery and parts, printing and booking machinery and parts, food processing machinery and parts, and other machinery and equipment.
9 Includes data processing equipment, television receivers, radio broadcast receivers, telecommunication equipment, and household equipment.
10 Von Arx (1997).
12 WEKA (1999).
is significantly lower as compared to copper ore and concentrate imports. Metalworking and industrial machinery account for most of the imports of copper-containing finished products, whereas vehicles and automotive components are the biggest exports. Some of the interesting observations from the cycle are:

- There is net addition of 240 Gg Cu/year as “in-use” stock of copper.
- Approximately 90 Gg Cu/year of copper is lost to the environment.
- India generates 220 Gg Cu/year of copper discards, approximately 75% of which consists of wastes from electrical and electronics equipment as illustrated in Table 4.
- There exist no data on utilization of new scrap in the fabrication and manufacturing processes.
- Gaps to provide the mathematical closure of mass balance (as shown by dotted boxes in Fig. 1) for each of the reservoirs are significant with respect to the flows entering and exiting the reservoirs.

With a fast growing economy and an exponential increase in apparent refined copper use as shown in Fig. 3, the net addition of “in-use” stock of 240 Gg Cu/year seems comparatively lower as compared to that of China which adds five more times of in-use copper stock every year. A total of 334 Gg Cu/year is unaccounted for in the contemporary copper cycle of India. Most probably, this unaccounted for copper represents additional utilization of old and new scrap during copper production, fabrication, and manufacturing. There is a lack of reliable and documented data on the utilization of old and new scrap. As a general rule, the data quality and reliability decreases from left to right in Fig. 1. To assign confidence ratings to copper flows we utilize Moss and Schneider (2000) approach and the confidence scale developed by Graedel et al. (2004) for contemporary regional level copper cycles. The contemporary copper cycle of India with confidence ratings is shown in Fig. 1(b). All copper flows pertaining to waste management reservoir have a very low confidence rating, whereas copper production flows are more reliable.

### Table 4

<table>
<thead>
<tr>
<th>Waste category</th>
<th>Per capita generation (kg/capita-year)</th>
<th>Copper content (%)</th>
<th>Copper content (Gg Cu/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Municipal solid waste</td>
<td>29</td>
<td>0.04</td>
<td>12</td>
</tr>
<tr>
<td>Construction and demolition waste</td>
<td>29</td>
<td>0.04</td>
<td>12</td>
</tr>
<tr>
<td>Hazardous waste</td>
<td>39</td>
<td>0.02</td>
<td>8</td>
</tr>
<tr>
<td>Industrial waste</td>
<td>203</td>
<td>0.01</td>
<td>20</td>
</tr>
<tr>
<td>End of life vehicles</td>
<td>0.5</td>
<td>0.7</td>
<td>4</td>
</tr>
<tr>
<td>Waste from electronics and electrical equipment</td>
<td>1.3</td>
<td>13</td>
<td>169</td>
</tr>
</tbody>
</table>

* Kapur et al. (2003).
  1 Bertman et al. (2002).
  2 The municipal authorities in India usually include C&D waste in the MSW streams. The value reported for MSW generation was equally split into C&D and MSW streams.
  3 The weight of an average car is estimated to be 1000 kg, and for buses and trucks a weight of 12,000 kg is assumed (ARGET, 2000).
  4 WEEE waste generation rate adjusted after accounting for disposal in the MSW waste stream.
4. Scenario analysis

Scenario building is a creative art that involves generating innovative ideas about the future, ideas well supported by the contemporary state of scientific knowledge. The futurist usually first portrays the script (the “storyline”) for the future, and thereafter, wherever possible, makes an attempt to quantify the scenario driving forces and the plausibility of the end result. In certain cases, the futurist builds scenarios by drawing upon the intellectual knowledge base of subject experts or individuals who have a well-informed opinion of the system(s) under consideration. Scenarios can either be extrapolative or normative. Extrapolative scenarios utilize historical and contemporary trends to describe the future, whereas normative scenarios propose the alternative future state of the system and trace back the scenario to the present to suggest measures on how to achieve the desired future (IPCC, 2000). The development of scenarios begins with extensive understanding and analysis of the present and the past of the system under consideration. This is followed by the identification of the key variables of the system, formulation of the underlying assumptions for scenario analysis, and development of the methodological framework.

The Intergovernmental Panel on Climate Change (IPCC) in its Special Report on Emission Scenarios (SRES) has developed a family of four scenarios – A1, A2, B1, and B2 – that describe future worlds that are generally more affluent than those of the present (IPCC, 2000). The critical scenario driver(s) for each scenario range from very rapid economic growth and technological change to high levels of environmental protection, from low to high global populations, and from the high to low greenhouse gas (GHG) emissions. The interrelationship between the SRES scenarios and the present study is the common set of scenario driving forces, i.e., demographics and economics. This set of driving forces and associated data variables is an essential component of any scenario building exercise. IPCC’s SRES report has done a very comprehensive review of the literature and of available...
knowledge concerning how these variables are likely to interact and behave in the future, and has built on this information to correspondingly develop quantitative projections up to year 2100. The present study draws upon the qualitative description of the SRES scenarios and utilizes the quantitative projections for GDP and population in developing scenarios for future rates of copper use.

As part of this study, the following three scenarios for future rates of copper use have been developed:

- Tech World;
- Green World;
- Trend World.

The name of each scenario refers to the dominant driving force influencing the future. The ‘Tech World’ scenario assumes that rapid technological change and high economic growth determine the future material flows. The basis for the ‘Green World’ scenario is a vision of a world that is increasingly environmentally sensitive. The ‘Trend World’ scenario is a “business-as-usual” scenario, in which the system in the future represents a picture of things continuing to happen in the same way that they are happening now. Kapur (2005) provides the detailed narrative storylines for each of the scenarios and their interpretation in greater depth from the point of view of intensity of material and copper use.

4.1. Methodology

The methodology to develop the scenarios is based upon the earlier work on scenarios for copper use for different world regions—OECD90, ASIA, REF, and ALM (Kapur, 2005). Non-linear regression analysis of historical time series data of intensity of copper use and GDP per capita for developed countries, such as Japan and United States, reveals an inverted-U relationship between intensity of copper use and GDP per capita (Kapur, 2005). A similar trend was observed for other OECD90 countries as well, such as United Kingdom, France, South Korea, etc. The inverted-U trend can be explained in terms of the changes in the product composition of income and material composition of products (Radetzki and Tilton, 1990). The product composition of income refers to the structural changes in the economy, as one moves from a low, resource intensive agricultural base to a high, resource intensive manufacturing base, leading to a peak in intensity of resource use and thereafter to a decline as the economy base shifts to the service sector which is also low resource intensive. The material composition of products refers to the changes in intensity of use due to material substitution and technological change. The intensity of resource use is considered an important indicator that captures the changes in patterns of overall resource use in relation to a country’s economic growth. Technological innovations in resource production (e.g., mining from continuously declining ore grades in United States) and use are also indirectly reflected in the intensity of use curve. A physical indicator, such as resource use per capita, could also be potentially used to make scenarios for resource use. The per capita copper use trends in the OECD90 region indicate a uniform increasing trend different from the intensity of copper use curve where one can observe a declining trend (Kapur, 2005). Therefore, the physical indicator does not signify the changes in product composition of income and material composition of products. The United Nations has the intensity of use...
indicator in its list of plausible indicators of sustainable development (Friends of the Chair, 2002). Therefore, the inverted-U hypothesis was assumed to hold for developing countries, such as India, as well. However, the developing countries may not observe peak intensity of use values at similar income level as the countries in the OECD90 region and their rate of decline of intensity of use might be greater or lower than the OECD90 countries. This will depend upon how fast they are growing and how rapid is the diffusion of technological change from developed to developing regions in different scenarios.

The time scale chosen for the scenario analysis is the period 2000–2100. Three copper scenarios are developed, termed Tech World, Green World, and Trend World. Their baseline data and theme of the scenario storyline are similar to IPCC’s A1, B1, and B2 scenarios, respectively. (A “copper A2” is thought to be less likely and hence has not been developed.) As per the IPCC data, all GDP per capita values are in constant 1990 US dollars, based upon the market exchange rate. The dependent parameter estimated in this work, the intensity of copper use, was based upon apparent refined copper use, which for a country or a region is defined as the sum of refined copper from domestic production, plus imports, minus exports, and change in stocks. The term “use” here refers to the copper that enters the fabrication and manufacturing system of a country’s economy. The historical data for apparent refined copper use were collected from various editions of metal statistics bulletins and yearbooks published by WBMS, ICSG, and the United States Geological Survey (USGS). The data sources were inconsistent in reporting whether apparent refined copper use data included both primary and secondary copper production.

4.2. Scenario quantification

The rate of copper use for a given country or region in a particular scenario is governed by the following equation:

\[ Cu_{use,c,s,t} = P_{c,s,t} \times (GDP \ per \ capita)^{c,s,t} \times I_{c,s,t} \]  

where \( P \) is the population and \( I \) is the intensity of use; \( s \), scenario; \( c \), country; \( t \), time.

The future projections for population and GDP per capita in Eq. (2) over the time period 2000–2100 for each of the countries in different world regions under different scenarios have been provided by IPCC (CIESIN, 2002a,b). The objective of the scenario quantification process is to project the most plausible trajectory for intensity of copper use or the term \( I \) in Eq. (1) for a given country within the theme of the scenario storylines. Kapur (2005) describes the mathematical equations governing the intensity of use trajectory. The intensity of use trajectory can be broken down into three critical stages—the incline phase during which the intensity of use is increasing; the turning point thereafter, where the intensity of use begins to decline; and the final stabilization phase at high-income levels during which the intensity of use declines very slowly and approaches a stable value. The determination of the turning point was done after the analysis of the present rates of growth of intensities of copper use and the historical evidence from the other regions and/or countries where the intensity of copper use curve has experienced the turning point. The estimation of the end point of the stabilization phase is not as straightforward as the determination of the turning point. The end point can be determined mathematically using regression analysis.
techniques, or the futurist using his or her subjective judgment could fix the end point at a discrete value. The following qualitative considerations were also taken into account while quantifying the intensity of use trajectory for India, different from the intensity of use trajectories developed for regions by Kapur (2005):

- structural composition of the country’s economy;
- availability of human intellectual capital;
- potential for infrastructure growth;
- environmental regulations.

India, compared to other countries in Asia, such as China, South Korea, and Taiwan, is not the manufacturing center of the world, although the manufacturing sector in India is able to meet the demand of its own rapidly growing domestic market. The share of the service sector in the Indian economy is growing, primarily driven by the IT boom and the availability of skilled, English-speaking labor. Despite this, there exists huge potential for infrastructure growth in sectors of housing, power, and telecommunications. The growth of the service sector depends largely on whether appropriate infrastructure exists to support the system. Environmental policy and regulations in India as like other Asian countries are primarily “command and control” driven. The focus is on compliance rather than on promoting voluntary efforts on behalf of all stakeholders to protect natural resources and improve ambient environmental quality.

Moving towards a services economy would thrust India towards lower intensity of material use. India will move closer to its peak intensity of copper use when its basic infrastructure needs would have been met. The income level at which it would reach peak intensity of copper use and its actual value would depend on at what rate its economy grows. The Tech World is a high economic growth scenario, therefore, there will be more demand for copper in sectors, such as energy, infrastructure, and basic services. This would lead to a high peak intensity of use followed by rapid decline due to advances in technical knowledge. The Green World is also a high economic growth, but lower than the Tech World and economic growth is achieved through enhanced productivity in resource use, environmental protection, and uniform distribution of income. This would lead to a lower peak intensity of use as compared to Tech World at a slightly lower income level. In the Trend World, the intensity of material use continues to grow at rates equal to contemporary levels, attains peak intensity of use in the medium term, and thereafter, declines slowly. The rate of decline of intensity of material use is slower as compared to the Tech World and Green World scenarios. In Trend World, copper use continues to grow in its conventional end uses. Substitution of copper through technological leapfrogging to a less copper intensive system is primarily limited. Overall the scenarios for copper use in India will broadly follow the scenarios for ASIA described in terms of huge demand for copper in the next several decades (Kapur, 2005).

4.3. Results and discussion

4.3.1. Intensity of copper use trends

The intensity of copper use trends for the three scenarios is shown in Fig. 4. Also shown in the figure are historical trends for the intensity of copper use until the year 2000. The intensity of copper use and GDP per capita values corresponding to the years 2000,
Fig. 4. Intensity of copper use trends in India for three different development scenarios.

2020, 2050, and 2100 are illustrated in Table 5. The Tech World and Green World are converging scenarios at extremely high-income levels. Irrespective of the scenario, India’s intensity of copper use will continue to increase until 2050, with rapid growth occurring between 2020 and 2050. The reason for this increase is that a significant portion of India’s population is still unable to afford permanent housing and basic infrastructure services, such as telephone and electricity connections. In Tech World and Green World scenarios, India experiences a high economic growth; as a result, intensity of copper use peak is higher as compared to that in the Trend World scenario. In the Green World scenario, the rate of decline in the intensity of copper use is rapid as compared to that in the Tech World scenario. In a Green World scenario, market oriented environmental regulations enhance recovery, reuse, and recycling of copper. Both in Tech World and Green World scenarios, India also benefits from technological leapfrogging in sectors, such as telecommunications, transport, and electronics; but the diffusion of new technologies is more rapid in the Green World scenario.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>2000</th>
<th>2020</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tech World</td>
<td>(557, 0.5)</td>
<td>(1514, 0.6)</td>
<td>(5966, 1.0)</td>
<td>(58960, 0.3)</td>
</tr>
<tr>
<td>Green World</td>
<td>(557, 0.5)</td>
<td>(1464, 0.6)</td>
<td>(5047, 0.9)</td>
<td>(32094, 0.3)</td>
</tr>
<tr>
<td>Trend World</td>
<td>(557, 0.5)</td>
<td>(823, 0.5)</td>
<td>(3787, 0.8)</td>
<td>(10410, 0.8)</td>
</tr>
</tbody>
</table>

The first value in each pair is GDP per capita expressed in US 1990 $ and the second value is the intensity of copper use expressed in g/US$. 

The GDP per capita and intensity of copper use trends (2000–2100) are shown in Table 5. The Tech World and Green World are converging scenarios at extremely high-income levels. Irrespective of the scenario, India’s intensity of copper use will continue to increase until 2050, with rapid growth occurring between 2020 and 2050. The reason for this increase is that a significant portion of India’s population is still unable to afford permanent housing and basic infrastructure services, such as telephone and electricity connections. In Tech World and Green World scenarios, India experiences a high economic growth; as a result, intensity of copper use peak is higher as compared to that in the Trend World scenario. In the Green World scenario, the rate of decline in the intensity of copper use is rapid as compared to that in the Tech World scenario. In a Green World scenario, market oriented environmental regulations enhance recovery, reuse, and recycling of copper. Both in Tech World and Green World scenarios, India also benefits from technological leapfrogging in sectors, such as telecommunications, transport, and electronics; but the diffusion of new technologies is more rapid in the Green World scenario.
4.3.2. Copper use trends

The copper use trends are shown in Fig. 5 for the three scenarios. Their values for the years 2000, 2020, 2050, and 2100 are illustrated in Table 6. By 2100, copper use in India could range between 9 and 17 Tg Cu/year, showing an exponential increase from the present level of 0.3 Tg Cu/year. The Tech World and Trend World both depict a continuously increasing trend in rate of copper use. However, in a Green World, rate of copper use will slow down after 2050. Comparatively, in Asia, the copper use in 2100 is expected to be in the range 13–55 Tg Cu/year and the global range of corresponding values is 30–130 Cu Tg/year (Kapur, 2005). Therefore, India would account for a significant share of copper use in Asia. Although over the last few years the Indian economy has been growing at a rate next only to that of China, its rate of copper use is significantly lower. In the year 2000, China’s refined copper use was approximately 2 Tg Cu/year (ICSG, 2002). A list of projections for copper use in India based upon literature review is given in Table 7. The projections do not portray a similar trend and are divided in their opinion whether copper growth in India will be robust or slow.

Table 6
Copper use trends (2000–2100)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>2000</th>
<th>2020</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tech World</td>
<td>0.3</td>
<td>1</td>
<td>9</td>
<td>17</td>
</tr>
<tr>
<td>Green World</td>
<td>0.3</td>
<td>1</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>Trend World</td>
<td>0.3</td>
<td>0.5</td>
<td>4</td>
<td>14</td>
</tr>
</tbody>
</table>

All values are expressed in Tg Cu/year.
Table 7
Copper use projections for India based upon literature review

<table>
<thead>
<tr>
<th>Copper use projection (Tg Cu/year)</th>
<th>Year</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5–0.9</td>
<td>2008</td>
<td>IIM (1999)</td>
</tr>
<tr>
<td>0.6–1.7</td>
<td>2013</td>
<td>IIM (1999)</td>
</tr>
<tr>
<td>0.4–0.8</td>
<td>2007</td>
<td>Viswanathan (1998)</td>
</tr>
<tr>
<td>0.5</td>
<td>2007</td>
<td>Planning Commission (2002b)</td>
</tr>
<tr>
<td>0.2</td>
<td>2010</td>
<td>Dorian et al. (1990)</td>
</tr>
<tr>
<td>0.6</td>
<td>2012</td>
<td><a href="http://www.indiastat.com">http://www.indiastat.com</a> (as accessed on 01/17/04)</td>
</tr>
<tr>
<td>0.7</td>
<td>2006</td>
<td>ICSG (1997)</td>
</tr>
<tr>
<td>1.2</td>
<td>2010</td>
<td>Cayci and Sezer (1994)</td>
</tr>
<tr>
<td>2.1</td>
<td>2020</td>
<td>Cayci and Sezer (1994)</td>
</tr>
<tr>
<td>3.3</td>
<td>2030</td>
<td>Cayci and Sezer (1994)</td>
</tr>
</tbody>
</table>

4.3.3. Per capita copper use trends

The per capita copper use trends are shown in Fig. 6 for the three scenarios. Their values for the years 2000, 2020, 2050, and 2100 are illustrated in Table 8. Irrespective of the scenarios, India’s per capita copper use will increase rapidly from the year 2020. By the year 2100, per capita copper use in India will be in the range 8–15 kg Cu/(capita-year). Compared to India, the overall per capita copper use in Asia will be in the range 4–18 kg Cu/(capita-year) (Kapur, 2005). The present level of per capita copper use of 0.3 kg Cu/(capita-year) in India is one of the lowest in the world (T. Grover, personal communication, 2003). This can be attributed to a couple of factors. The Government of India, in the seventies, on account

Fig. 6. Per capita copper use trends in India (2000–2100) for three different development scenarios.
of foreign exchange limitations, issued a policy directive that prohibited the manufacture and use of copper cables for house wiring, and as a result, aluminum captured the copper market in India in one of its dominant uses (Viswanathan, 2003). A lot of building codes and by-laws written thereafter promoted the use of aluminum over copper (N. Shukla, personal communication, 2003). The policy directive was withdrawn in 1993 and slowly the reverse substitution of aluminum with copper for house wiring use is occurring in India.

4.4. Future sectoral drivers and non-drivers

4.4.1. Housing

It is estimated that housing shortage in India is close to 40 million units and housing demand is growing at 2 million units every year (ADB, 2004a,b). Although the housing shortage is primarily for low-income households, a new trend is emerging in urban centers where usually private single floor households are being torn down and multi-floor apartment complexes are being built in their place to meet the demand. As a result, the gross built up area for the residential category has nearly doubled to 19.2 million km² over the 1997–2002 time period (Anon., 2003). The Government of India through its different agencies is primarily responsible for low-income housing and still continues to use aluminum for house wiring, whereas all private construction in the country prefers to use copper (M.A. Narsimhan, personal communication, 2003). With the withdrawal of the policy directive for not using copper for house wiring, it is expected that new housing units constructed by the government and its agencies in the future will also use copper.

4.4.2. Telecommunication

India’s telecommunication sector has witnessed a revolution in terms of the unprecedented exponential growth over the last 5 years. The number of telephone lines added to the basic services network over the last 5 years has been one and half times more than what was added over the last 50 years (Gupta, 2003). For an average Indian citizen in an urban area, possessing a mobile phone is easily affordable now. The number of telephones (both fixed and mobile) per 100 people or tele-density has grown approximately four times to 4.9 telephones per 100 people since 1995–96 (MoCIT, 2003). More than 80% of villages in India have direct access to telecom facilities (MoCIT, 2003), although there is only one connection per village and the connection is usually through satellite. By 2010, it is anticipated that the tele-density will be 18 telephones per 100 people and India will possess more than 200 million telephones, with the share of mobile phones growing very rapidly as shown in Fig. 7. The use of copper for telecom cables in India has been declining on account of the substitution of jelly filled telecom copper cables by optical fibre cables.

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Table 8
Per capita copper use trends (2000–2100)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>2000</th>
<th>2020</th>
<th>2050</th>
<th>2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tech World</td>
<td>0.3</td>
<td>1</td>
<td>6.3</td>
<td>15.3</td>
</tr>
<tr>
<td>Green World</td>
<td>0.3</td>
<td>0.9</td>
<td>4.5</td>
<td>8.3</td>
</tr>
<tr>
<td>Trend World</td>
<td>0.3</td>
<td>0.4</td>
<td>2.9</td>
<td>8.0</td>
</tr>
</tbody>
</table>

All values are expressed in kg Cu/(capita-year).

---
Fig. 7. Trends in number of telephones (fixed and mobile) in India (data source: MoCIT, 2001, 2002). and the rapid diffusion of mobile and wireless technologies. These trends are expected to continue (Viswanathan, 2003; M.A. Narsimhan, personal communication, 2003).

4.4.3. Power

The growth in India’s power sector has not been able to match the increase in demand. In 2002, India was faced with base load energy and peak energy deficits of 7.5% and 12.6%, respectively (Planning Commission, 2002a). The Government of India proposes to double the generation capacity from the present level of 100 GW by the end of 2012 (Narsimhan, 2002). To achieve this ambitious target, the Government of India started the Accelerated Power Development Program in the year 2000 with an objective to strengthen the sub-transmission and distribution network, as most of the power distribution networks in India are highly inefficient. Power delivery losses are more than 50% and the failure rate of distribution transformers is over 25% every year (Narsimhan, 2002; Patankar, 2001). It is expected that the Government of India, state governments, and power utilities in the future would prefer copper coil distribution transformers over aluminum, as energy savings from using copper outweigh the relatively lower capital costs of aluminum distribution transformers over the long term operational cycle of the transformer (Narsimhan, personal communication, 2003). With the growth in the power sector, as well as in distribution transformers, copper use is expected to grow in the power and control cables market, especially in the control cables where copper use in India is dominant (ICSG, 2003).

4.4.4. Transport

India is fast emerging as a world manufacturing hub for compact cars and a supplier of variety of automotive components (Chatterjee, 2004). Suzuki of Japan was the first foreign player to set up a vehicle manufacturing facility to cater to the Indian market in
the early 1980s. Presently there are more than a dozen foreign and domestic players with their manufacturing or assembling facilities in India. The Indian consumer never before had access to such a variety of automobiles in terms of price, size, and features. In the year 2000, India produced 5 million vehicles and exported approximately 3% of its production, as shown in Fig. 8. Over the last 2 years, the export of vehicles has nearly doubled. Out of the 50 million registered vehicles, two wheelers (scooters, mopeds, and motorcycles) accounted for 70% of the total as shown in Fig. 9. The burgeoning domestic market has further potential for growth, as the vehicle ownership rate in India of six vehicles per 1000 people is relatively low and vehicle-financing schemes have become common over the years. The number of registered vehicles in India is expected to be 100 million by 2010 and will further double by 2020 (K. Deb, personal communication, 2004). In addition, the proposed shift by the automotive industry globally to move to a 42 V system will increase the copper requirement per vehicle (Murugan, 2003). Thus, the transport sector, after housing and power, will be one of the other important drivers that will influence growth of copper use in India.

4.4.5. Electronics and consumer durables

The trends in possession of electronics and consumer durable items, such as televisions, cassette/radio players, washing machines, refrigerators, vacuum cleaners, personal computers, etc., in Indian households over the last 25 years is shown in Fig. 10. There is an approximately eight-fold increase, primarily driven by the growth in the use of television, especially since the Asian Games in New Delhi in 1984 when broadcasting in color was first introduced in India. The growth in the use of televisions further gained momentum
Fig. 9. Registered motor vehicle in India by category in the year 2000 (data source: http://www.indiastat.com (as accessed on 12/14/03)).

Fig. 10. Trends in possession of electronic and consumer durable items in Indian households (1977–2002) (data source: http://www.euromonitor.com (as accessed on 02/10/04)).
with the introduction of cable television in India during the first Gulf War in 1991. The new media provided immense opportunities to the electronics and consumer durables industry to market their products aggressively to the Indian consumer and be able to influence their purchasing behavior. Further, with the entry of foreign players from South Korea, Japan, Europe, and the U.S.A. in the 1990s, the intense competition in the industry meant that high quality products were now in the price range of the Indian consumer. The industry is expected to continue its exponential growth for the next 10–15 years as well. The future growth will be driven by an increase in use of personal computers, residential air conditioners, microwave ovens, digital disc players, and cameras. In terms of implications for copper use, except for air conditioners, most of the products are either imported or assembled in India. As a result, this sector is not expected to drive copper use in India.

5. Copper recycling in India

The copper industry in India, which utilizes different types of old copper scrap, is highly unorganized and is mainly dominated by small and medium enterprises in handicrafts, utensils, artware, and wire bar manufacturing. Most of the industries are not registered with the government on account of environmental concerns and tax liabilities. The main areas of copper recycling in India are (ICSG, 2003):

- Post consumer copper discards, mainly collected from households by individual scrap merchants.
- New scrap from fabrication and manufacturing units without a melting facility. Such units include cable and wire manufacturing, forging, and redrawing units. The scrap is either sold in the scrap market or returned to the raw material supplier.
- Import of old scrap by either scrap traders or individual units. Imported scrap is usually either melted and/or refined.
- Recovery of copper wires from post consumer insulated cables and wires.
- Recovery of copper from mixed old scrap either sold or auctioned by Indian Railways.
- Recovery of copper and copper alloys from copper ash, brass ash, and dross.

The copper recycling activity in India involves a variety of people—from the roadside scavenger to the scrap merchant who imports and/or buys scrap based upon domestic demand and copper scrap prices on the London Metal Exchange. None of the entities in the recycling hierarchy are supported by any specific policies by the Government of India to encourage recycling (Bhatkar, 2002). All the recycling activities are driven by the economics of copper scrap, although copper scrap prices in the Indian domestic market are usually higher than the international prices (ICSG, 2003). Copper scrap in India is a highly volatile commodity as no scrap merchant stockpiles. Rather, copper is traded on a cash-before-delivery basis. Another constraint to copper recycling in India is that the Government of India through its environmental regulations on hazardous wastes restricts import of certain types of copper and copper alloy scrap which might contain lead and cadmium above permissible limits.

The generation rates of different types of copper scrap are given in Table 9. Old copper scrap accounts for nearly 60% of the total generation. Copper and copper alloy scrap generated from large-scale ship breaking activities in India account for nearly one-third of
Table 9
Generation rates of different types of copper scrap in India

<table>
<thead>
<tr>
<th>Scrap type</th>
<th>Generation rate (Gg Cu/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Old scrap</strong></td>
<td></td>
</tr>
<tr>
<td>Copper cables</td>
<td>10</td>
</tr>
<tr>
<td>Radiators and brass utensils</td>
<td>4</td>
</tr>
<tr>
<td>Ship breaking</td>
<td>19</td>
</tr>
<tr>
<td>Winding wire</td>
<td>10</td>
</tr>
<tr>
<td>Cartridge brass of spent bullets</td>
<td>14</td>
</tr>
<tr>
<td>Mixed railway scrap</td>
<td>5</td>
</tr>
<tr>
<td><strong>Sub total</strong></td>
<td><strong>62</strong></td>
</tr>
<tr>
<td><strong>New scrap</strong></td>
<td></td>
</tr>
<tr>
<td>Wires and cables</td>
<td>12</td>
</tr>
<tr>
<td>Forgings, reworking, fabrication, and machinery</td>
<td>24</td>
</tr>
<tr>
<td>Copper ash, dross, etc.</td>
<td>5</td>
</tr>
<tr>
<td><strong>Sub total</strong></td>
<td><strong>41</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>103</strong></td>
</tr>
</tbody>
</table>

All figures are in net copper content expressed in Gg Cu/year. Source: ICSG (2003).

Old scrap generation. Old copper cables, mainly discarded by power utilities and Indian railways, discarded defense artillery, and winding wire from worn-out motors are other significant sources of old scrap. The new scrap is generated from wire and cable manufacturers, fabricating, forging, and redrawing units. The biggest user of copper and copper alloy scrap in India is in the manufacture of brass products by small-scale handicrafts and utensil making units (IIM, 1999). Taking into account both the import of 90 Gg Cu/year of copper scrap in the year 2001–2002 and the domestic generation, the utilization of different types of copper scrap meets approximately 40% of the total copper demand in the country. However, with the growing demand for copper in housing, power, and transport sectors and the requirements for high quality and pure refined copper in these sectors, a higher rate of recovery of copper scrap would have little influence on bridging virgin copper supply and demand deficit in India.

6. Policy implications

A developed India will achieve overall economic growth in terms of reducing the number of people living below the poverty line and, as a result, improve the quality of life of its citizens with easy and affordable access to basic infrastructure services of housing, water supply, sanitation, and power, and also better healthcare for all. Over the last decade, India has initiated a lot of efforts in this regard, but a lot remains to be done. To realize its dream, India’s demand for basic materials, such as steel, aluminium, copper, paper, plastics, timber, petroleum, and cement, will increase substantially over the next 20–30 years. Therefore, it is not expected that the Indian economy would begin to “dematerialize” in the short to medium term. Given India’s strength of human capital in terms of skilled scientists and engineers, India will not lag behind if opportunities for technological leapfrogging are available, either...
created through research and development within India or through technology transfer from
developed countries. India can derive maximum benefit from technological leapfrogging on
account of the sheer volume of her domestic market. The rapidly increasing use of mobile
phones and wireless local loop technologies across India is a perfect example in this regard.
Plausible sets of scenarios for copper for India have been presented. Given the magnitude
of the increase in copper use in India and India not being self-sufficient in copper resources,
certain macro implications for policy can be drawn. Not only copper, India also imports
large quantities of antimony, molybdenum, tin, tungsten, and platinum group of metals
(Planning Commission, 2002b). India, unlike developed countries, such as United States,
cannot afford to build strategic stockpiles of resources critical for the growth of the economy.
India needs to prepare a policy document on what will be its material requirements over the
next 20–30 years and how the country anticipates to meet the demand either through imports
or technological changes vis-`a-vis its own resources. Such a document will lay out a list
of critical resources for the Government of India to take priority action. Also the Government
of India needs to review the ongoing privatization of the minerals sector in the country. A
certain degree of privatization is definitely beneficial as it brings in the desired investment
for new mineral exploration and development and also the best of the technology in the
field. The Indian market is not yet mature enough to adjust to the dynamics of the market
forces. The government still needs to retain its executive powers, as is evident from the last
quarter of 2003 when Indian exports of finished steel to China started to affect the domestic
demand–supply scenario and the government intervened to stabilize the prices. Specifically
for copper, the long-term viability of business model of the two primary private producers of
copper in India needs further investigation. The Government of India also needs to promote
its metals recycling sector by streamlining its policies, taxes, and duties on imports and
processing of scrap. An organized and market driven recycling industry in India can provide
an important feedstock of resources to meet India’s burgeoning demand for materials.
The future of copper in India is as bright as the metal. Three sectors – housing, power,
and transport – are expected to be the major drivers for copper. Reverse substitution of
aluminum with copper is occurring in India after the withdrawal of the policy directive
against the use of copper for house wiring. Although the share of the service sector, driven
by the information technology revolution, is rising in India’s gross domestic product, the
intensity of copper use will continue to increase until 2050. By 2050, it is expected that India
will be a developed nation, having provided basic infrastructure services to all its citizens.

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