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CONTINUOUS CASTING IN THE COPPER INDUSTRY

door

Ir. P.F. Cuypers

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CONTINUOUS CASTING IN THE COPPER INDUSTRY

Preface

The Department of Industrial Engineering of the University of Technology and the Department of Economics of the Tilburg University started a co-operative project on the fabrication of copper and semi-products in the developing countries in 1983. The project was initiated in order to have an in depth case-study of resource based industrialization in developing countries.

The copper sector was selected because copper is a very important mineral export product of the developing countries and because a copper fabricating industry, producing semi-manufactures, can clearly be identified.

Particularly in the large copper exporting countries (Peru, Chile, Zambia, Zaire) copper ore goes through several stages of processing and is mainly being exported in the form of copper concentrates, blister and refined copper. Until the present time, however, these countries export very limited amounts of copper semi-manufactures. The objective of our research is to investigate if and under what conditions the copper exporting developing countries could produce and export certain copper semi-manufactures on a larger scale. The research is being limited to the primary fabrication of copper and copper alloy semis.

Four groups of products are distinguished: wire and wire rod; rods, bars and sections; plates, sheets and strips and tubes. The report at hand deals with the first group of products, more exactly continuous cast wire rod.

In order to determine the viability of export-oriented copper fabrication in developing countries, be it for regional or overseas markets, one has to investigate: the production processes and production costs in the industrialized countries, the import barriers in the major markets, marketing requirements and transport costs, and finally the feasibility of efficient production in developing countries. The general set-up of our research project has been to start with an investigation of existing international trade patterns and trade barriers (desk research) and of production and marketing of copper semis in Western Europe (through contacts with a number of companies). This research is presently still going on. For the second stage of the project it has been planned to investigate the feasibility of export-oriented copper fabrication in Zambia and in Peru. These two countries have been selected because they are major exporters of copper, but are at different levels of industrialization.

Thanks are due to Eric Kosters, who contributed to the technical part of the report, to Jan Vingerhoets of Tilburg University and Toon van de Ven of our own Faculty who scrutinized earlier drafts of the report.

Ad M.H. Sannen *
Pierre F. Cuypers *
Eindhoven, January 1987

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The coordinators of the project are: A. van de Ven of the Eindhoven University and Jan Vingerhoets of the Tilburg University.
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Chapter 1

INTRODUCTION

Developing countries (DC’s) which are exporting certain raw materials in large quantities would benefit more if these raw materials would be processed in the country itself and then exported. This is also true for copper, one of the most important non-ferrous metals.

Most copper exporting developing countries (Zambia, Zaire, Peru, Chile) already have to a certain extent a fully integrated primary copper industry, with besides mining and concentrating, also smelting and refining facilities. Exports of copper and copper-alloy semi-manufactures however are still very limited. Unctad (1982) estimates the share of semis imports in industrialized countries from the DC’s at not more than 1.9%.

The main objective of the paper at hand is: to analyze to what extent exports of copper semi-manufactures, more particularly continuous cast rod, can be substituted for refined copper exports from DC’s. Continuous cast rod (CCR) was chosen for three reasons:

a. because it is the intermediate form for the fabrication of copper wire, being the most important copper semi-fabricated product in the world. (around 50% of all semis)

b. because the continuous casting process applied for the production of CCR can be attached to refineries, thus enabling a direct conversion from refined copper to CCR. CCR may therefore in the future become an important refinery shape and consequently a new export item for copper producing DC’s.

c. because it is a standardized product in terms of shape, dimensions, composition and application all over the world.

Most of the existing studies in this field, trying to explain the limited share of the DC’s in the world market for copper semis or finished copper products, fall short of quantitative data. Their approach is usually limited to a listing of the problems with which potential exporters are confronted, and then come up with rather general recommendations of how to tackle those problems. This study arrives at more down to earth conclusions since it concentrates on one product only, and makes use of recent data about markets, patterns of trade, technological developments and production and transport costs simultaneously.

An introductory chapter, explaining briefly the significance of the continuous casting technology in the world copper industry, is followed by a description of the technical side of CCR production (chapter 3-6). The second part of the report (chapters 7 and 8) concentrates on production costs, markets, trade and possibilities for DC’s. In the final chapter the conclusions are presented.
Chapter 2

CONTINUOUS CASTING IN THE COPPER INDUSTRY: AN INTRODUCTION TO TECHNOLOGY AND MARKETS

The copper semi-fabricating sector may be divided into the following 2 subsectors:

a) Wire mills, producing continuous cast rod (CCR), hot rolled rod (HRR) and (or), drawn copper wire. The starting raw material is refined copper in the form of cathodes for CCR production or wirebars for HRR production. A simplified flow diagram of copper wire fabrication is shown in figure 1.

b) Brass mills, to be subdivided into:
- Rod mills, producing rods, bars and sections of copper and copper alloys;
- Rolling mills, producing plate, sheet and strip (flats) of copper and copper alloys;
- Tube mills, producing tubes and hollow bars of copper and copper alloys.

Flow diagrams of the production processes are shown in figure 2. Table 1 shows the relative consumption of these semis in the western world. It can be seen clearly that copper wire accounts for almost 50% of all semis consumption; the importance of CCR production, the raw material for 90% of all copper wire (10% is made from HRR) is herewith sufficiently indicated.

Continuous casting in the copper semis industry is not only limited to CCR production. It is also commonly applied in brass mills where it is used for the casting of copper and alloy billets and slabs. (See annex 1 and figure 2). The cast billet or slab is not rolled or drawn immediately after casting, as is the case with CCR, but first cut to a certain size suitable for further processing. The first step in the subsequent processing of the billets or slabs is preheating, to make rolling, extruding or piercing possible.

Unlike CCR, billets or slabs are no marketable shapes. Billets and slabs are usually cast in the brassmill itself, using direct scrap from customers, old scrap from dealers and some virgin metals for blending the desired alloys.

CCR production may be attached to a refinery or to a wire and cable manufacturer, but is also done in separate factories in which refineries and/or cablers may have a stake.

The world production capacity of CCR amounts presently (1984) to almost 8 million tpy. The growth of this capacity is shown in table 2 from which it can be seen that in the last five years there has been an impressive growth, also in Latin America and Asia. One of the results of this enormous growth however is a rather big surplus capacity which is estimated at 40%. Especially the last 2 years the growth in capacity therefore declined.
Fig. 1: Production flow of copper wire fabrication from wirebars (HRR) or cathodes (CCR).
source: Energy Audit Series, 1981
Figure 2 Production flows of brassmill products

Table 1 Relative consumption of copper and copper alloy semis in the western world in 1982 (in %).

<table>
<thead>
<tr>
<th>product</th>
<th>copper</th>
<th>copper alloy</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. wire</td>
<td>49</td>
<td>2</td>
<td>51</td>
</tr>
<tr>
<td>2. rods, bars, sections</td>
<td>2</td>
<td>17</td>
<td>19</td>
</tr>
<tr>
<td>3. plate, sheet, strip</td>
<td>7</td>
<td>11</td>
<td>18</td>
</tr>
<tr>
<td>4. tube</td>
<td>9</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>Total</td>
<td>67</td>
<td>33</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: Perlman and Davies, 1983.

Table 2 Growth of the CCR production capacity 1965-1982 (x 1000t).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>214</td>
<td>375</td>
<td>865</td>
<td>1251</td>
<td>1966</td>
</tr>
<tr>
<td>Western Europe</td>
<td>-</td>
<td>110</td>
<td>791</td>
<td>1804</td>
<td>2300</td>
</tr>
<tr>
<td>Japan</td>
<td>-</td>
<td>221</td>
<td>616</td>
<td>953</td>
<td>1350</td>
</tr>
<tr>
<td>South Africa</td>
<td>-</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>102</td>
</tr>
<tr>
<td>Socialist countries</td>
<td>-</td>
<td>33</td>
<td>65</td>
<td>365</td>
<td>365</td>
</tr>
<tr>
<td>Other</td>
<td>-</td>
<td>101</td>
<td>339</td>
<td>1036</td>
<td>1534*1)</td>
</tr>
<tr>
<td>Total</td>
<td>214</td>
<td>809</td>
<td>2508</td>
<td>4773</td>
<td>7110</td>
</tr>
</tbody>
</table>


Chapter 3
THE CONTINUOUS CASTING OF STEEL

In the production of ferrous and non-ferrous metals the melt has to be cast into various shapes. This can be done in two ways:

- in moulds;
- by continuous casting (CC).

In the first case the liquid metal is cast slag-free in casting moulds with a ladle. After the blocks have cooled down they are taken out of the mould, reheated and hot-rolled and cold rolled into delivery conditions. Figure 3 shows this casting technique.

![Casting in moulds](image)

Fig. 3. CASTING IN MOULDS

The other method is continuous casting. In 1857 Henry Bessemer designed a continuous casting production method for steel plate. The installation he used is shown in figure 4.

The liquid steel is cast between two rotating rolls. The metal solidifies and leaves the die in the shape of a plate. The quality of the steel plate proved to be not as good as expected, whereas the process couldn't be controlled with the state of technology in those days. Great efforts on behalf of research and development have led to the use of the continuous casting process on a large scale nowadays.

Figure 5 shows a schematic diagram of the process. The melt is cast in a bottomless cooled die. The speed of casting is equal to the speed.

![Schematic diagram of the Bessemer process](image)

Fig. 4: Schematic diagram of the Bessemer process.

- 8 -
of solidifying. The cast strand is secondarily cooled after it has left the die and if necessary cut into pieces by an automatic moving saw. The cutting cannot be done until the strand is completely solidified.

Figure 5.
Schematic diagram of the continuous casting process

The choice between CC or casting in moulds depends to a great extent on the scale of production. If a small output of discrete products is wanted, casting in moulds will be preferred. If a large quantity of integral products is required the continuous casting (CC) process will be used.
Figure 6. Production flow of steel semis
The production of steel semis by CC and by casting in moulds is shown in figure 6. The first casting machines, which came into operation in the fifties, were very tall. This was caused by the vertical casting technique and by the enormous demand for steel, so that the speed of casting had to be increased resulting in a longer (vertical) solidification trajectory. This led to very high investments in factory buildings.

The surface quality wasn’t as good as wanted until the seventies. Before then, further treatment was necessary to obtain a good surface quality. Nowadays the technological development ensures surface quality which satisfies the demands. Many of the new developments come from Japan. Ninety percent of the steel production is worked out there by the continuous-casting process. In the E.E.C. this percentage is about 50 percent against 30 percent in the United States. The share of the CC process grows and is expected to increase in the coming years. The increase of this share in Western-Germany is shown in figure 7. On a world scale, about 30% of all steel production (in 1982 the total steel production amounted to about 700 millions tons) was cast continuously in 1982. New technological developments like horizontal CC, making tall factory buildings superfluous, and energy saving measures will make the CC technology more and more cost efficient.

**Figure 7.**
Steel production and share of CC in Western Germany (1970-82).

source: Taschenbuch für die Stahlindustrie, 1985

Between the two methods of casting steel, in moulds or continuously, a difference exists in investments and production costs. These were compared by Giescking (1976) for three cases:  
1. billet production of 0.35 million ton/year;
2. blooms production of 1.5 million ton/year; 
3. slabs production of 5.0 million ton/year.

The investment for a CC installation appeared to be lower in all of the three cases. The differences in investments are shown in figure 8A. For the production costs as well, a CC installation performs better (see figure 8B and 8C). The costs represent the 1975 cost level in Western-Germany.

In all cases CC seems to be more economic. This can be explained by the lower efficiency, the smaller scale, the higher investment per tonne production and the bigger labour requirement for casting in moulds.

Other advantages of a CC-installation are:

---

**Investments steelproduction**

B: continuous casting  
A: casted in moulds

**Production costs steel-production**

**Production costs steel-production** related to capacity

Production 10^6 t.

Fig 8: Investment and production costs of steel production  
(Germany, 1975)  
A = casting in moulds  
B = continuous casting  
source: Gieseking (1976)
Better material-efficiency; less loss of material. Casting in moulds generates more scrap since the top and end of every rolled plate have to be cut off. The material-efficiency of casting in moulds is about 89 percent, against 94 percent with the CC-process;

Elimination of rolling-phase; cast shapes have to be reheated and subsequently rolled into plates, rods or profiles. This phase is superfluous for CC.

Energy-saving; the absence of a rolling-phase saves energy. Secondly: the better material-efficiency means also energy-saving. It has been calculated that the energy-saving comes to 1100 kJ/kg steel. This means saving of about 28 liters of heavy fuel oil per ton. [Archiv für das Eisenhüttenwesen, nr. 54 Jan. 1983]

Better quality of material; the CC process results in a homogeneous distribution of the different elements in the material caused by the relatively short solidification time and the absence of gravity-segregation. The difference in the distribution of elements is shown in figure 9.

The main disadvantage of the process is the decreased flexibility; large quantities of material are cast in one charge. This means increased standardization. Customers are thus confronted with a decreasing variety of shapes and qualities of materials.

![Fig. 9: Chemical composition of steel by different casting methods](image)
Chapter 4

THE CONTINUOUS CASTING OF COPPER WIRE ROD

4.1 Introduction

In the non-ferrous metals industry, CC was first established for metals like aluminium, zinc and lead, which all have a relatively low melting point compared with copper. In the 1960's CC was introduced in the copper industry. CC becomes attractive when big volumes of a standardized product have to be produced. This was the matter with copper wire in the 1950's. Conventionally copper wire was produced from wire bars, rectangular bars of about 1 m length and weighing approximately 80 kgs. Wirebars are cast from copper cathode, mostly in the refinery. In the wire mill, the wire bars are preheated and hot rolled into so called Hot Rolled Rod (HRR). The HRR's with a diameter of 6.3 to 8.0 mm are welded together to form continuous rod and then drawn to finer wire gauges. The production of copper wire according to this method is shown in figure 10. It accounts presently for about 10% of wire production, but is still decreasing. The weak spot of the HRR route is the welding of the HRR which leads to a relatively high occurrence of wire breaks during the subsequent drawing operations. With the advent of CCR this problem was overcome. The main advantages of the CCR technology are:

- Energysaving, since the casting and preheating of wirebars can be eliminated;
- Production of coils with a very high weight (up to 5 or 8 tonnes), and a continuous quality without welds;
- Increased production capacity;
- Decreased production costs;
- Simplified production scheduling;
- More compact production lines.

The raw material for CCR production is electro-refined cathode, which can be directly fed into a furnace for melting. A continuous casting system nearly always consists of the following parts:

- Melting furnace;
- Holding furnace;
- Casting machine;
- Cooling system;
- Burrs removing installation;
- Rolling mill;
- Pickling installation;
- Shear;
- Coiler.

The cathodes are melted in a melting furnace, (a shaft furnace or an induction furnace), and charged through a launder in a holding furnace. From this furnace the melt flows through a pouring furnace into the casting machine. The melt enters a cooled die and solidifies from the edge of the strand. If the strand is completely solid the burrs are removed and the strand is rolled in several passes to the demanded diameter. In most cases the rod is pickled for removing the oxygen layer and giving the rod a protective coating. At last the rod is coiled and cut. The ending diameter of the rod ranges from 6 to 28 mm according to the adjustment of the rolling mill. The production flow of copper wire according to the CCR route is shown in figure 11.
Figure 10: Production of copper wire according to the wirebar route (HRR)
(Source: Energy audit series no.12, the copper industry. London 1981)
Figure 11: Production of copper wire according to the CCR route.

(Source: Energy audit series no 12, the copper industry. London 1981)
Six production methods of CCR will be described in this chapter. These are:
1. Contirod (Krupp-Hazelett);
2. Southwire;
3. General Electric Dip Forming;
4. Outokumpu Upcast;
5. Continuus Properzi;
4.2 CCR production methods
4.2.1 CONTIROD (C)

Since 1973 a factory in Olen, Belgium, is in operation casting and rolling copper into wire rod. The process was developed by two institutions: Metallurgie Hoboken Overpelt (MHO) and Usines à Cuivre et Zinc de Liège. The plant produced rod with a diameter of 8 mm and had a capacity of 100,000 tons per year. In 1976 a second plant was installed with a capacity of 200,000 tpy. In 1978 MHO produced 230,000 Tons of CCR.

Presently, 17 plants are established all over the world with production capacities ranging between 60,000 and 225,000 tpy (see annex 2).

Copper cathodes are melted in a shaft furnace and charged into a holding furnace. Before the melt enters the casting machine the oxygen content is measured by an oxycell. The casting machine is of the Hazelett type with two steel belts placed above each other as shown in figure 12.

![Schematic diagram of Hazelett "conveyor-casting" machine](image)

**Fig. 12:** Schematic diagram of Hazelett "conveyor-casting" machine.
(1) ladle (2) cross-sections

The melt is cast between the two conveyor belts and then cooled down. The rectangular bar with a maximum surface of 9000 square mm is rolled in a Krupp rolling mill with 15 passes. The rod leaves the installation...
with a speed of 33 metres per second. Finally the rod is pickled and coiled. (see further: K. Mortier, 1983; Metall no. 11, nov. 1981 and no. 1, jan. ´82; Dompas J., 1974)

The process has some metallurgical advantages like:

+ a calm, non turbulent flow of the melt into the casting machine at relatively low temperature (1105-1100 °C). This results in a fine grain-structure and a good oxygen distribution;

+ a symmetrical, straight line solidification; no cracks;

+ a large cross section which makes a large capacity possible;

+ a small casting angle (+15%), when straightening the strand stresses and cracks are avoided;

+ an oxygen-free surface because of the pickling.

The specifications of the Krupp-Hazelett installation result in good properties of the product. The demands the customers make on
- good drawability;
- low recrystallisation temperature; and
- low wearing of drawing dies,
are satisfied by this production system.

4.2.2 SOUTHWIRE (SCR)

The Southwire process first went into operation in Carrollton, Georgia U.S.A., in 1965. At present about 30 Southwire plants are operating throughout the world (see annex 2) with annual production capacities ranging between 25,000 and 225,000 tonnes.

The installation consists of:
- a shaft furnace;
- a holding furnace;
- a casting unit;
- a milltrain with 13 passes;
- a pickling system;
- a coiler,
and a control chamber for the automatic controlling of the process. Figure 13 shows an overall view of the installation.

The copper cathodes are precisely weighed and then melted in a shaft furnace. Through a launder the melt flows into the holding furnace and then to the casting machine. The casting machine is shown in figure 14. The casting machine consists of a vertically positioned steel wheel, with a diameter of 2.5 mm, and a groove in the periphery of the rim. A steel belt closes the groove, thus forming a casting capacity. While the casting wheel rotates with a speed of 0.23 m/sec., the copper is cooled with water. Optimum uniform cast structure is ensured by automatically controlled coiling. The cast continuous strand passes the first roll
and then the edges are planed off to prevent cracks in the subsequent rolling process. When the rod has reached its final diameter it is pickled and waxed. The SCR is coiled in standard coil weights of 3.5, 4.0 and 5.0 ton.
Some latest technological advances incorporated in the SCR system are a computer controlled continuous melting furnace in line with improved launder design and an automatic metal control pouring system for casting (see E.H. Chiu).

4.2.3 GENERAL ELECTRIC DIP FORMING (GE)

In this process, developed by General Electric, a clean copper "seed" rod with a diameter of 9.6 mm is pushed through a container. The container is filled with molten copper with a depth of 5 m. The rod moves through the copper bath with a speed of 100 m/min. On emerging the rod is some 2.75 times its initial weight and has a diameter of about 16 mm. The rod is cooled to 850 °C and hot rolled in a protective atmosphere. Finally the rod is coiled. The casting principle is shown in figure 15.

The production capacity of the system ranges between 20,000 and 65,000 tpy. The rod has a low oxygen content and a uniform single-phase internal structure. At present some 17 G.E. plants are established all over the world (see annex 2).

4.2.4 OUTOKUMPU UPCAST (O)

The Finnish company Outokumpu began casting oxygen free copper rods in the 1940's. Vertical watercooled moulds were applied in the casting process. In the late 1960's quality requirements were becoming increasingly stringent, especially for surface conditions. Outokumpu decided to modernise its production system to give the product the demanded quality. Trials involving horizontal casting processes proved unsuccessful due to transverse cracking of the rod. In 1969 an upward casting system was developed and first applied in 1970.
In this casting process copper cathodes are melted in an induction furnace after which the molten copper is charged into a holding furnace. To prevent oxidation the melt is covered with graphite powder. A vertical, cooled die with underpressure sucks up the melt, where the copper solidifies. A schematic diagram is given in figure 16.

The diameter of the cast strand may vary between 8 to 25 mm. The withdrawal speed is limited and has a maximum of about 1.5 m/min. To maintain an economic output level, a caster may have a number of strands working simultaneously. Each strand can produce 1,000 tons per year. (See further: M. Rantanen, 1983).

The simple construction of the installation ensures economic production at a low output. At the moment 20 Outokumpu casters are installed all over the world, with annual production capacities varying between 3,000 to 30,000 tons (see annex 2). Especially semi-industrialized countries are attracted to this system because of its flexibility and low output levels.

Fig. 16: Outokumpu casting process

4.2.5 CONTINUOUS PROPERZI (PP)

The Properzi casting process was first developed for zinc and lead, and was later adapted to produce aluminium rod. In 1960 the company built its first copper rod caster. The capacity of this casting machine varies between 20,000 and 90,000 tpy. There are now 7 PP-casters established in various countries (see annex 2).

The Properzi installation consists of two wheels which are encircled by a steel belt. Figure 17 shows a schematic diagram of this installation. In the rim of the casting wheel a groove is made. The belt encloses the groove and thus the casting cavity is formed. The casting wheel has a diameter of 1.5 m. At the lower side of the wheel the casting cavity is cooled.
The cast bar is trimmed and a brushing unit removes any burrs left by the trimming process. The bar is then fed to the rolling-mill.

![Diagram of Properzi machine](image)

Fig. 17: Schematic diagram of Properzi machine.

4.2.6 LAMITREF PROCESS

Lamitref Koper B.V. in Hemiksem, Belgium is a company producing in continuous operation copper rod with a diameter range from 6.35 to 19.6 mm. As starting material copper wire-bars are used. The applied process is the "Hot Welding Continuous Copper Rod System" (HWCS). This system consists of:

- a continuous furnace in which wire-bars are heated to 950 degrees C;
- a five pass rolling mill which rolls the wire-bar to a bar of 43 mm diameter;
- an automatic butt-welding machine joining the bars together;
- a trimming installation to remove the burr arised by the welding;
- a 23 pass Properzi mill;
- a pickling system;
- a coiler, maximum weight 5 ton.

(For a more elaborate description see: N.Kemel, 1980.)

Basically the system works according the conventional HRR route, but with a major technological innovation regarding the welding. Experience learns that the weld has little influence on the rolling and drawing and on the quality of the rod. The advantages of the HWCS-system compared with the continuous casting process are:

+ 20% energy savings in wire rod production because melting of the wire bar is not required, only heating to rolling temperature is sufficient;
+ the production can be stopped at each moment;
+ scrap can easily be recycled by the company itself;
+ the process can also be used for alloys;
+ low investments compared to CCR.
One major problem is that the market for wire-bars is becoming unsure because of the dominance of continuous casting processes for wirerod production, where only cathodes are used. Wire bars tend to become in short supply and decrease in quality since they are made more and more from second or third quality cathodes in refineries.

The capacity of the installation depends on the speed of welding. This is now about 23 tonnes per hour, or an annual capacity of about 60,000 tpy. At least for 80% of the market the HWCS wire rod is equivalent to CCR. Only for the finest wire gauges (< 0.4 mm Ø) it is less appropriate. In the market segment of bigger wire gauges Lamitref is well able to compete, due to its lower capital costs.
An energy audit carried out by the BNF Metals Technology Centre in the U.K. analysed the two different routes for the production of copper wire, a wirebar (HRR) route and a continuous cast and roll (CCR) route. In both cases the end product was taken to be 1.4 mm wire. The wirebar route includes casting of wirebar, reheating and rolling to 6.3 mm wirerod, pickling, butt-welding, drawing to 1.4 mm wire and vacuum annealing (see figure 10).

The CCR route includes continuous casting and rolling to 8 mm wirerod with in-line pickling and drawing to 1.4 mm wire on a modern breakdown mill with in-line annealing. (see figure 11).

The total energy requirement of the two processes mentioned is determined by three categories of energy consumption:

- The fundamental quantity used is the Process Energy Requirement (PER) i.e. the sum of energy inputs to the process in the form of fuels and electricity. For the HRR and CCR routes the PER is respectively 9.55 and 7.0 GJ/tonne of wire produced.

- Secondly, non-process energy used for space heating and maintaining factory overheads is included.

  The proportion of non-process energy to process-energy was derived from annual consumptions and amounted to 30% in the making of wire and related products.

- Finally, energy is consumed when material is irretrievably lost in a process, i.e. cannot be recycled in the process itself. The sum of PER, non-process energy and metal-loss energy is called the total energy requirement of the process.

  The comparison of figures 10 and 11 learns that the CCR route saves more than 25% energy on wire production as compared to the HRR route. In CCR production the only heat consumed is in melting the cathodes prior to casting. In HRR production, energy is consumed first in melting the cathode for wirebar casting and later in the wiremill, heating the wirebar again for hot rolling. The additional energy consumption and other costs of wirebar casting is reflected in a premium over cathode. This premium however, does not reflect the full costs of conversion. This is due to two reasons:
wirebare is subsidized, to keep HKK competitive with CCR;
more and more scrap and lower grade cathode which does not
command the full price, is used for wirebars. (see Copper
Studies, October 1982).

As a result of the distortion of the wirebare premium fewer refineries
producing cathodes are willing to produce wirebars. Selling cathodes is
more profitable to them. This is one of the reasons why today about three
quarters of all wire is produced by the CCR route. The other advantages of
continuous casting, such as more consistent product, produced without
interruption, improved yield, simplified production scheduling and more
compact production lines, have already been described earlier in this text.

When only production of CCR is considered the PER amounts to 4GJ/tonne. The
melting of cathodes requires about 2.5 GJ/tonne, the casting, rolling and
pickling of the rod about 1.5 GJ/tonne of which 0.5 GJ is electricity (140
kWh). The other 3.5 GJ is delivered by the combustion of gas. With a
caloric value of 32 MJ/cubic metre about 110 cubic metres gas is needed to
produce 1 ton CCR.

In chapter 8 it will be shown that 40% of the costs of converting cathodes
into CCR are energy costs. It is therefore not surprising that research on
less energy intensive production methods is still going on.

In chapter 6 a new fabrication route will be described with which potential
energy savings of up to 50% can be made.

The PER measured in the BNF energy audit refers to a big rod mill, most
likely a Southwire or Contirod mill. Information from Outokumpu rod mills
showed much lower energy requirements per tonne output, viz. around 2.5
GJ/tonne (700 kWh). Since cathodes in the Outokumpu caster are melted in an
induction furnace all energy consumed is in the form of electricity. Due to
its small and simple equipment, the Outokumpu system is therefore more
energy efficient as compared to its bigger sisters.
In this chapter, three new developments in continuous casting technology will be briefly reviewed. These are:

- the horizontal continuous casting of billets and slabs;
- the horizontal continuous casting of strip and rod, and
- the continuous extrusion process for manufacturing copper wire and sections.

**a. The horizontal continuous casting of billets and slabs.**

It has already been mentioned in chapter 2 that horizontal casting (HC) combines the advantages of low investment and continuous process. The problem with HC has always been that, to achieve the same quality level from vertical machines, casting speed had to be low and that, in order to achieve the same productivity, additional strands had to be provided. Hence, the substantial savings in capital costs offered by HC are lost. *1)

The HC casting machine developed by the BNF Metals Technology Centre in the UK and marketed by a leading British supplier of continuous casting plants *2) seems to have overcome this problem. Some technical details of that process can be found in annex 3.

**b. The horizontal continuous casting of strip and rod.**

Again in the UK, a system has been developed for the continuous casting of copper rods, sections and narrow strips of high-conductivity materials *3) (see annex 8 for technical details). With this machine copperwire rod and special alloys and sections can be produced in moderate outputs that would be uneconomic from machines of the Southwire or Contirod type. The new, so-called "submerged-die" machines are capable of casting up to 8 strands simultaneously suggesting a combined output of 3 tons/hour of 19 mm dia rod.4)
The normal hourly capacity of South wire and Contirod systems is about 35 tons, that of General Electric and Outokumpu Systems varies between 1 and 10 tons, depending on the number of strands.

The advantages of this new moderate-output system are besides the convenience in operation and savings in capital costs, its flexibility in casting various alloys in a number of forms (rod, strip and sections) and in various production volumes depending on the number of strands in operation.

c. Continuous extrusion.

This new technology is established under the name CONFORM process and has been developed by the Springfields Nuclear Power Development Laboratories of the UK Atomic Energy Authority *1). The essential element of the process is an extrusion arrangement consisting of a continuous chamber which is provided by a wheel with a groove in its periphery (see fig. 18). Rotation of the wheel carries forward the feedstock, introduced into the groove and forces it to extrude through a die situated in or close to the abutment.

![Fig. 18: Conform continuous extrusion arrangement](Source: H.K.Slater)

The die face pressure together with high temperatures both generated by the frictional forces enable rod feed or metal feed in particulate form (i.e. powder, granules, chopped pieces or shot) to be consolidated and extruded as a fully dense product on a continuous basis.

The facility of the process to accept feed in particulate form is rather unique and creates the possibility of considerable savings in capital and operation costs, especially energy. The industry is now seriously considering the use of CONFORM as the primary process in a direct fabrication route from cathode to wire.

In figure 19 the conventional versus the CONFORM fabrication routes are schematically represented and in table 3 the corresponding total energy requirements for each route are listed.

In section 3.3 it has already been mentioned that considerable energy savings have been achieved by the transition from HKK to CKK. (Routes 2 and 5 in fig. 19). CKK or HKK directly extruded via the CONFORM process can produce wire in the annealed condition, thus removing the annealing operation and saving 21% on energy (routes 3 and 6). When cathode is granulated to provide feed material for direct extrusion to wire or strip, thus eliminating the energy intensive melting of cathodes, potential energy savings of 52% and 81% respectively are possible (route 7). The same energy savings may be related to the use of scrap as a source material.

Besides considerable savings in energy, the process has the advantage of achieving economies by its flexibility to change rapidly from one section to another.

A lot of research work still must be done on the materials of the die and of the wheel. Tools steels examined as potential die-material showed a tendency to creep under the influence of the temperature and pressure generated by the process. For extended performance, dies from ceramic materials should be considered. Products from various types of feed gave mechanical properties comparable to those of annealed material.

The temperature cycle of 225 - 450°C during each revolution of the wheel and the compressive stresses can lead to fatigue cracks on the periphery of the wheel and can cause premature failure.

![Diagram of copper wire and sections from cathode](image)

Fig. 19: Copper wire and sections from cathode (conventional vs CONFORM routes).
Source: H.K.Slater
Table 3. Energy requirements of fabrication routes for copper wire and sections.

<table>
<thead>
<tr>
<th>Product</th>
<th>Process route</th>
<th>no. (fig. 19)</th>
<th>Energy 1) (GJ/t)</th>
<th>Energy saving (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>wire</td>
<td>CCR and wiredrawing with Inline annealing</td>
<td>(4)</td>
<td>9.1</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>CCR and CONFORM</td>
<td>(6)</td>
<td>6.9</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Cathode granulation and CONFORM</td>
<td>(7)</td>
<td>4.4</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>strip</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Slabcasting hot and cold rolling, annealing</td>
<td>(1)</td>
<td>26.4</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>CCR rolling drawing and annealing</td>
<td>(4)</td>
<td>11.9</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>CCR and CONFORM</td>
<td>(6)</td>
<td>6.9</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td>Cathode granulation and CONFORM</td>
<td>(7)</td>
<td>4.4</td>
<td>83</td>
</tr>
</tbody>
</table>

1) includes 30% non-PER
Source: H.K. Slater
CHAPTER 7

MARKET STRUCTURE, INTERNATIONAL TRADE AND THE DEVELOPMENT
OF THE PRODUCTION CAPACITY OF CCR

7.1 THE WIRE AND CABLE MARKET

As has been pointed out earlier in this text, CCR is almost entirely being used as input in the wire and cable industry. Its importance is sufficiently illustrated by the fact that about 70% of the world consumption of refined copper comes from this industry. By further drawing of CCR, covering the drawn wires with various kinds of insulating materials, stranding and a number of other operations a very large range of wire and cable products is being produced in the industrialized world. These can be categorized as follows:

- wiring cables ca. 40%
- power cables " 20%
- winding wires " 15%
- telecommunication cables " 20%
- other cables " 5%

The wide variety in wire and cable products is illustrated in annex 4 with some examples. Below some remarks are made about their applications and the influence of substituting materials like aluminium or fiber optics on the categories mentioned above.

Wiring cables

These are used for distributing electrical power within domestic, commercial and industrial buildings, ships, aircraft, vehicles etc. The majority of these cables have small conductors and are insulated with rubber, PVC or polyethylene. The substitution of aluminium for copper in this market segment has occurred by means of copper-clad cable. These are cables with an aluminium core surrounded with a continuous metallurgically bonded cladding of copper. The copper cladding is necessary to obtain a stable contact resistance in terminations. Because of the lower conductivity of copper-clad conductors, a larger size is required, so that their application is limited to surface wiring where size increase causes few problems. Substitutions therefore, remains small (see also Metal Bulletin's special issue on copper, 1974).
**Power cables**

Such cables are used for distributing large amounts of power at high voltages. The cables usually have large conductors and insulation is either lapped impregnated paper, PVC or polyethylene. Since most of the cables are directly buried in the ground, metal sheaths or armour are usually provided for mechanical protection.

Aluminium has had a very great impact in the power cable market; the level of substitution is estimated at about 65% (MB Special Issue 1974).

**Winding wires**

These are solid metal conductors coated with insulating enamel. They are used for the winding of electric motors, transformers and a whole range of electrical apparatus and machines.

The impact of aluminium in this market is limited because of the larger size of aluminium wire, requiring more space in the electric motor or transformer, which is often not desired.

**Telecommunication cables**

These are mainly used on national telecommunication systems (trunk networks and local distribution networks).

The impact of fiber optics on this copper wire market segment will be enormous. It is estimated (Metall, Jan. 1983) that by the end of the century more than 90% of all networks will be replaced by optic fibres. The conversion however requires massive investments in cables and terminal equipment. Others therefore argue that substitution will go ahead much slower (MB, March 1980, p.43). Apart from optic fibres, aluminium offers a threat to copper in this market too, especially in those parts of the telephone networks where the increased diameters are of little consequence. Already by the early 1970's, 40% of the local secondary network installed had aluminium conductors (MB, 1974).

7.2 **Some major trends in the international trade and production of CCR and HRR**

Recent developments in international trade and worldwide production of CCR have been well described in two articles in "Copper Studies" (April 1982 and January 1984). A third article in "Copper Studies" (Oktober 1982) reviews the situation of HRR. The three articles together provide a good review of the worldwide trends in CCR and HRR production and trade.

Some of these trends will be highlighted here.

1. **Falling capacity of HRR, increase of CCR**
   
The world HRR capacity is shrinking very rapidly, with continuous casting capacity expanding more and more. From 1979 to 1981 non-socialist world production of HRR declined by almost 27%, from 2.27 to 1.66 million tons. CCR capacity however, increased from 5.0 to 7.81 million tons within 4 years (1980-1984), i.e. with more than 55%. It is expected that in the end only a few HRR mills will survive, processing wire bars made from clean scrap and off-grade cathode.
An exception in this sector is Lamitref koper of Belgium (see chapter 4), which managed to increase its market share of continuously rolled rod and possibly in the future will continue to do so.

The trend is:
- more and more good cathode being directed to CCK, of which world production will continue to increase;
- some good quality cathode being directed to wirebare and hence, rod, produced with the Lamitref "Hot welding system" and enjoying a growing market share;
- scrap and lower grade cathode supplying the production of wirebare and subsequently HRR, of which world production will further decline down to a level below 0.5 million tpy.

2. Trade growth in CCK

Due to the trends mentioned above international trade in wirebar is being replaced by trade in cathode and wirerod. Formerly, the users of rod, the wire mills, were also the operators of rod making capacity and dovetailed that capacity to their own output of wire and cable products. With the advent of continuous casting in the mid-1960's a new situation has emerged. A major portion of CCR capacity is now located at refineries without associated wire drawing interests (especially in Europe: MHO-Belgium, Norddeutsche Affinerie-Germany). CCK is therefore increasingly viewed as another refinery shape, rather than as a semi, and is, unlike HRR or CCK produced by wire mills, available to supply local or foreign markets. The increase in the international trade in CCK has therefore been equally strong as its increase in production. Trade rose from 225,000 tons in 1973 to almost 400,000 tons in 1977, an increase of 77% in four years.

3. Trade pattern

Western Europe accounts for the bulk of both exports (88%) and imports (78%) of CCK. Trade of CCR is therefore mainly within Europe which is encouraged by the absence of tariff barriers within the EEC. Tariffs on imports of wirerod hold back worldwide trade in the product.

Belgium is the leading exporter of CCR in the world; 47% of all world exports (mainly by MHO) are shipped almost entirely to nearby European markets within the tariff-free zone of the EEC.

Japan's involvement in international trade of CCK is solely as an exporter, but its export volumes are not very significant. Japanese CCR production is more linked to wire and cable making than is the case in Europe, so that the country is more important in the world market for wire and cable rather than for CCR.

Like Japan, the US is an absentee in wire rod trade too. The US have a large home market to serve, and because of the high degree of vertical integration between refineries and wire mills CCR capacity is well tailored to the needs of in-house wire drawing operations. Like Japan, the US export more wire and cable than CCR, mostly to Central and South America.

A number of developing countries in Asia and South America are striving to meet their own requirements for rod. This is the case with Taiwan, South-Korea, Malaysia (also supplying Singapore), Indonesia, the Philippines, Thailand and Turkey in Asia, and Mexico, Brazil and Argentina in South-America. Major importers of CCK and wire are still the Middle-East and North African countries,
which imported together in 1980 about 150,000 tons of CCR and wire. Nevertheless there is a general tendency that distant markets increasingly supply themselves. CCK is a product with a low value added, is quite awkward to ship and meets with import tariffs in many countries, so most exports will be shipped to countries that, in a sense, belong to the same market geographically and economically.

4. CIPEC-producers investing in Europe for CCR production
In 1975 Codelco of Chile went into partnership with Norddeutsche Affinerie and Hüttenwerken Kayser on a 40:40:20 basis to set up a CCR plant in Germany. The joint-venture Southwire plant (Deutsche Giessdraht in Emmerich) produces now 160,000 tpy high quality CCR, obtaining 60% of the cathode input from Chile. In 1980, the two state-controlled Zambian mining groups entered into partnership with Thomson-Brandt of France. A 130,000 tpy Contirod Plant (Société Continu Coulée de Cuivre, In Chauny) was established, thus securing a new outlet for Zambian copper in France. The question is whether this development of jointly owned CCR plants in Europe will proceed, now the great era of expansion in CCR capacity seems nearly over, and there is already an over-capacity in wire rod in Europe (see section 7.3). Perhaps CIPEC-producers will start negotiating participation in existing CCR plants by offering cathode discount. Setting up plants locally and then exporting the CCR is another possibility which will be discussed in chapter 8.

7.3 ESTIMATION OF THE FUTURE PRODUCTION CAPACITY OF CCR

The future production capacity of CCR, is determined by four factors:

1. The demand created by wire and cable fabricators;
2. The decline of HRR production;
3. The degree of utilization (expressed as a percentage of total rod capacity);
4. The advent of new production technologies for copper wire.

ad 1
Wire and cable fabrication determines, in terms of copper weight, almost 70% of refined copper consumption. This can be seen from annex 5 where figures of copperwire production and refined copper consumption are given. For the 1990's these figures will change, especially for the Developed Market Economies (DME). Due to substitution effects it is expected that in 1995 the telecommunication cables sector is largely replaced by optic fibres. This means a loss of copper demand of at least 10%. In the DC, substitution effects will not be so strong and moreover, market saturation will not yet be achieved. The growth in the demand for wire and cable will therefore be stronger in the DC's.

ad 2
The decline of HRR production until 1990 is estimated as follows (see table 4).
Table 4. Projection of HHR production capacity until 1990 (1000 t).

<table>
<thead>
<tr>
<th>area</th>
<th>1979 1)</th>
<th>1981 2)</th>
<th>1983 3)</th>
<th>1990 projection</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>870</td>
<td>647</td>
<td>135</td>
<td>40</td>
</tr>
<tr>
<td>Latin America</td>
<td>247</td>
<td>234</td>
<td>70</td>
<td>20</td>
</tr>
<tr>
<td>Japan</td>
<td>280</td>
<td>265</td>
<td>90</td>
<td>30</td>
</tr>
<tr>
<td>Other Asia</td>
<td>170</td>
<td>87</td>
<td>85</td>
<td>30</td>
</tr>
<tr>
<td>Western Europe</td>
<td>690</td>
<td>426</td>
<td>278</td>
<td>80</td>
</tr>
<tr>
<td>Other</td>
<td>15</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>2,276</td>
<td>1,658</td>
<td>653</td>
<td>200</td>
</tr>
</tbody>
</table>

notes:
1) Source: Copper studies, oct. 31, 1980
2) See annex 2
3) Estimated on the basis of, in annex 2 announced, close-downs.

The share of the DME in HHR world production in 1995 is estimated at 150,000 tons, that of the DC at 50,000 tons.

The capacity utilization rates at wirerod mills are given in table 5. It can be seen that the average degree of capacity utilization in the DME declined from roughly 70% in 1979 to 60% in 1982.

The era of great expansion of CCR production capacity in the DME seems now over. From 1982 to 1984 capacity grew only with 200,000 tons. A further decline is expected until the 1990's with an average growth per annum of about 50,000 tons. This growth will be mainly due to the gradual disappearing HRR mills.

Table 5. Capacity utilization rates at wirerod mills in Western Europe, USA and Japan 1979-1982 (%).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Western Europe</td>
<td>59.1</td>
<td>58.9</td>
<td>59.2</td>
<td>59.0</td>
</tr>
<tr>
<td>US</td>
<td>77.1</td>
<td>70.4</td>
<td>71.4</td>
<td>58.2</td>
</tr>
<tr>
<td>Japan</td>
<td>76.3</td>
<td>70.8</td>
<td>59.6</td>
<td>64.5</td>
</tr>
<tr>
<td>DME</td>
<td>70.8</td>
<td>66.7</td>
<td>63.4</td>
<td>60.6</td>
</tr>
</tbody>
</table>

Source: Copper Studies, jan. 84.

Presently most of the growth in capacity is occurring in the newly industrializing countries (NIC's) of South-East Asia and Latin America.

From the figures in table 6 the capacity utilization rate in the DC can be calculated. This rate should be equal to wire production (which reflects rod consumption) divided by total rod capacity and amounts to:

\[
\frac{812.8}{1,617.3} = 50\%
\]
The growth of production capacity in the DC is likely to continue. A doubling of capacity from 1.3 million tpy raw to 2.6 million type in 1990 is expected. After 1990 the growth may decline. By that time the DC will have increased their share of capacity from 18% in 1984 to 30% in 1990.

It is not impossible that after 1990 a net decline of CCR capacity will occur. This decline will be caused by the advent of new technologies for copper wire production, like the "Conform" extrusion process described in Chapter 6. The older wire and rod mills which were established before or around 1970 will have reached the end of their economic and technical lifetime in 1990 and may be the first to be replaced by the new technology.

The curves representing the expected growth of production capacity are shown in figure 20. Accounting to the estimates made, the world total CCK capacity will reach its peak of about 9 million tpy around 1990. 30% of this capacity will then be located in the DC's and 70% in the DME. If there is not a major breakthrough of successful new technologies for copper wire production, further growth of CCR production capacity in the 1990's of 9.5 million tpy or more can be expected. More likely however, the development of new technologies will lead to replacements of old CCR mills by rod or wire mills using new technologies, first in the DME.

Since 80% of the growth in world production capacity of CCR is expected to take place in the DC's (1.3 million tpy of 1.6 million tpy total), sellers of CCR production technology will have to concentrate more and more on the DC's. From annex 6 it can be seen that it is especially the Southwire process which is successful in capturing these markets; 43% of the CCR production capacity in the DC's is made up of Southwire plants. Although Outokumpu systems account only for about 12% of CCR production capacity in DC's, they are established in 8 of the 13 DC's producing CCR. The strong point of Outokumpu plants is their flexibility of production capacity which may range between 3,000 and 30,000 tpy. With this system it is easier to adjust the production capacity to the demand for CCR, than is the case with most of the other systems. It can be seen from annex 6 as well that the bulk of CCR overcapacity in the DC's is created by the "big ones": Southwire (in Korea and Taiwan) and Contirod (in Iran and Mexico).
If these firms do not develop systems of a more appropriate scale of production it can be expected that the Outokumpu, General-Electric and Properzi systems gain more ground in the DC's, let alone perhaps the bigger DC's like China and India.

In the DME the expansion possibilities of new big CCR mills has become quite limited. When it is realized that in Europe, both MHO in Belgium and Norddeutsche Affinerie have production lines which are not fully utilized, due to overcapacity, it can be imagined that a growth in demand will be met first by increasing production rate of the existing mills, or working under their maximum capacity. Possibilities for new CCR plants can be expected in the countries of the Eastern bloc, where consumption levels of refined copper still lay considerably behind the DME. (Contirod and Southwire production lines already operate in Poland, Bulgaria and Romania). It is not known however, whether the Eastern bloc have developed their own CCK production technology.

Fig. 20: Past en projected production capacity of CCR and HRR and new rod technology in the DME and DC.
N.B. Capacity utilisation is 60% in the DME and 50% in the DC.
To throw more light on the question as to what are the possibilities for the DC's to produce and export more CCR, two underlying questions have to be answered first:

a. Do copper exporting DC's have good reasons for replacing part of their refined copper exports by CCR?

b. What are the possibilities and benefits for DC's in general to produce CCR for the domestic or regional market?

To be able to answer the first question a calculation should be made of the costs a CCR producer in e.g. Zambia or Peru incurs if they want to export his product to Europe.

As an example will serve here a (not really existing) 150,000 tpy Southwire installation in Zambia attached to a refinery, and willing to export to Europe.

The second question will be answered by taking an existing Outokumpu wirerod mill in Zambia as an example which supplies the domestic and regional market (capacity 6,000 tpy).

8.1 PRODUCTION COSTS OF CCR IN EUROPE AND ZAMBIA

In both ferrous and non-ferrous semis the structure of prices is usually geared back to a basic price for the product, which is essentially a figure reflecting the cost of metal content and basic conversion costs. The basic conversion costs are reflected in the "premium" over metal cost. The consumer pays this relatively stable premium in addition to the metal price quotation on the day he purchases.

The current premium (1985) of CCR over the producer price of primary cathode is in Europe about $96 per tonne.

Related to a cathode price of $1,526 per tonne (average 1983/84) the premium rate for CCR is about 6.3%.

The conversion costs for CCR will now be compared on the basis of an example of an 150,000 tpy Southwire installation operating in Western Europe or in Zambia.
The Zambian plant is thought to produce mainly for the West-European market. A further comparison is made with a small Outokumpu plant in Zambia (6,000 tpy capacity) producing mainly for the regional market. Table 7 shows the basic figures used in the calculations.

Table 7. Details of CC rodplants in Europe and Zambia.

<table>
<thead>
<tr>
<th></th>
<th>SCR Europe a)</th>
<th>SCR Zambia b)</th>
<th>Outokumpu Zambia</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Nominal annual production volume</td>
<td>150,000 tonnes</td>
<td>150,000 tonnes</td>
<td>6,000 tonnes</td>
</tr>
<tr>
<td>2. Degree of capacity utilization</td>
<td>60%</td>
<td>50%</td>
<td>90%</td>
</tr>
<tr>
<td>3. Real annual output</td>
<td>90,000 tonnes</td>
<td>75,000 tonnes</td>
<td>5,500 tonnes</td>
</tr>
<tr>
<td>4. Total investment e)</td>
<td>$16 million</td>
<td>$20 million</td>
<td>$2.0 million</td>
</tr>
<tr>
<td>5. Total personnel f)</td>
<td>90 employees</td>
<td>135 employees</td>
<td>15 employees</td>
</tr>
<tr>
<td>6. Total annual costs per employee average g)</td>
<td>$20,000</td>
<td>$4,000</td>
<td>$4,000</td>
</tr>
<tr>
<td>7. Cathode price h)</td>
<td>$1,526</td>
<td>$1,348</td>
<td>$1,348</td>
</tr>
<tr>
<td>8. Interest rate</td>
<td>7%</td>
<td>7%</td>
<td>7%</td>
</tr>
<tr>
<td>9. Lifetime of the equipment</td>
<td>20 years</td>
<td>20 years</td>
<td>20 years</td>
</tr>
<tr>
<td>10. Average inventory of copper i)</td>
<td>4,000 tonnes</td>
<td>250 tonnes</td>
<td>20 tonnes</td>
</tr>
<tr>
<td>11. Energy requirement per tonne output j)</td>
<td>- natural gas mill 110 c.m.</td>
<td>- electricity 1000 kWh</td>
<td>- non process energy 30%</td>
</tr>
<tr>
<td>12. Energy prices h)</td>
<td>- natural gas 15 USc/m3</td>
<td>- electricity 1.5 USc/kWh</td>
<td>1.5 USc/kWh</td>
</tr>
<tr>
<td>13. Miscellaneous costs l) per tonne output</td>
<td>$6.0</td>
<td>$9.0</td>
<td>$9.0</td>
</tr>
</tbody>
</table>

USc = US dollarcent

a) Figures based on data from a European SCR mill
b) Hypothetical plant
c) Operating in Luanshya, Zambia (Metal Fabrications of Zambia)
d) In chapter 7 was shown that the average degree of capacity utilizations is 60% in the DME and 50% in the DC. The CC rod mill in Zambia is working at 90% capacity utilization.
e) Investments in Zambia for the same plant are higher due to additional investments in infrastructure, longer construction period etc.
f) It is assumed that in Zambia 50% more labour is required for the same output (lower efficiency)
g) Annual wage costs per employee in Zambia are estimated at 20% of those in western Europe.
h) The average 1983/1984 LME quotation is taken. The ex-refinery price in
Zambia equals this LMF price minus transport costs to Europe which amounted to $178 in 1984 (see Vingerhoets and Sannen, 1985).
i) In Europe an inventory of 2 weeks production is required. Zambia has sufficient with a one day stock.
j) See chapter 5. In Zambia only electricity will be used.
k) Western Europe and Zambian prices (1984) are taken.
l) These include: auxiliary materials, packing materials, quality control etc. and are assumed to be 50% more expensive in Zambia.

Table 8. Breakdown of production costs for the 3 CC rod plants of table 5.
(in $ per tonne output, for two degrees of capacity utilization).

<table>
<thead>
<tr>
<th>cost category</th>
<th>SCR Europe cap. ut. 60%</th>
<th>SCR Zamb. cap. ut. 50%</th>
<th>Outokumpu Zamb. cap. ut. 100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Wages</td>
<td>20.0</td>
<td>12.0</td>
<td>7.2</td>
</tr>
<tr>
<td>2. Financial costs a)</td>
<td>16.7</td>
<td>10.0</td>
<td>25.1</td>
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<tr>
<td>3. Inventory costs</td>
<td>4.7</td>
<td>2.8</td>
<td>0.3</td>
</tr>
<tr>
<td>4. Energy costs</td>
<td>31.2</td>
<td>31.2</td>
<td>19.5</td>
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<tr>
<td>5. Miscellaneous costs</td>
<td>6.0</td>
<td>6.0</td>
<td>9.0</td>
</tr>
</tbody>
</table>

Total: 78.6 62.0 61.1 44.8 68.0 64.2

Notes:
a) These costs include capital costs and depreciation calculated with the formula:

\[ R = P \left( \frac{(1+i)^n}{(1+i)^n-1} \right) \]

- \( R \) = annual financial costs
- \( P \) = total Investments
- \( n \) = lifetime of the plant in years
- \( i \) = interest rate

Table 8 shows the breakdown of the production costs. Southwire CCR produced in Zambia on the same scale as in Western Europe turns out to have about 28% lower production costs (at 100% capacity utilization). The low wages, low inventory costs and low electricity prices are the main reasons for this. The small Outokumpu mill clearly suffers from diseconomies of scale as compared to the SCR mill. Especially financial costs and wages are higher. Nevertheless production costs are only slightly above those in Western-Europe (at 100% capacity utilization).

Another advantage for a Zambian wire rod mill is the low cathode price. The transport costs of cathode (f.o.r. minestation to c.i.f. UK and world parts) presently amounts to about $178.0 per tonne, of which about $80.0 are overland transport costs to Dar-Es-Salaam and $98.0 are shipping costs (see Vingerhoets and Sannen, 1985).

A Zambian wire rod mill can buy its cathodes directly from the refinery at - 40 -
the LME price discounted with the transport costs for cathode to the UK (see table 7, note h). Especially for the Outokumpu mill this is an important advantage. Since this mill predominantly will have to concentrate on the domestic and regional market, transport costs can be kept relatively low. If it is estimated that transport to regional customers amounts on an average to about $100 per tonne, there is still a discount advantage of $78 per tonne. This means that the Outokumpu mill can also compete on more remote markets, like those of the Middel-East and South Asia. Metal Fabrication of Zambia Ltd (ZAMEFA), a company that brought on stream an Outokumpu wire rod mill in 1982 with a capacity of 6,000 tpy, presently exports about 40% of its production to South Asia (see Vingerhoets and Sannen, 1985).

A Southwire mill in Zambia would have to market the bulk of its output in Europe. Assuming that transport costs of CCR to Europe are 10% above those of cathodes, i.e. $196 per tonne, the total costs would be as follows:

<table>
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<tr>
<th>Description</th>
<th>Cost (per tonne)</th>
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</thead>
<tbody>
<tr>
<td>Cathodes (ex-refinery price)</td>
<td>$1,348</td>
</tr>
<tr>
<td>Production costs (50% cap. ut.)</td>
<td>$61</td>
</tr>
<tr>
<td>Transport (10% above cathode)</td>
<td>$196</td>
</tr>
<tr>
<td>Total (c.i.f. UK)</td>
<td>$1,605 ($79 above LME)</td>
</tr>
</tbody>
</table>

It is assumed that dutyfree imports in the EEC are possible under the Generalized System of reference (GSP). With the LME quotation of copper at $1,526 per tonne, the cost of delivery c.i.f. UK is $79 above LME. Since the current premium of CCR over cathode is about $96 per tonne, a minimal gross profit of $17 per tonne is possible.

If the degree of capacity utilization is higher, gross profit will accordingly increase to a maximum of $33 per tonne at 100% capacity utilization.

With production costs of the European producer at $78.6 per tonne (see table 8) above LME (at 60% capacity utilization) competition from Zambian CCR could be possible.

The costs comparison described above is shown graphically in figure 21. SCR Zambia and SCR Europe can compete on the European market as far as costs are concerned. For Outokumpu wire rod exports to Europe are not considered, only regional exports are taken into account.

![Figure 21 cost comparison of CCR produced in Zambia, exported to Europe or to neighbouring countries, and/or CCR produced in Europe for European customers.](image)

\[ P = \text{Production cost} \]
\[ T_O = \text{Overseas Transport costs (Zambia-UK)} \]
\[ T_R = \text{Regional Transport costs (average)} \]
8.2 OTHER FACTORS MORE IMPORTANT FOR PRODUCTION ALLOCATION

Like has been mentioned already in chapter 7 the joint venture wirerod plant of the Zambian mining group with Thomson-Brandt of France was not established in Zambia, but in Chauny, France. It is very likely that unless the comparable production costs disadvantages and risks related to production in Zambia have been decisive. For instance:

- CCR is quite awkward to ship. It is a product which is quite vulnerable for damages during overseas transport or due to uncarefull handling;
- Distant markets increasingly supply themselves. This is certainly the case with Western-Europe, so that market penetration would be difficult;
- A Zambian producer could not market its CCR with a significant price advantage in Europe. The costs of delivery c.i.f. UK are about equal to European production costs of CCR;
- There is already an installed overcapacity of 40% in Western Europe. This means that the market for CCR is saturated, which makes penetration difficult;
- The close relationship between producer and consumer of CCR which is common practice in Europe, could not exist when the plant is located in Zambia;
- Employment generation in CCR production is not very impressive; about 1 employee per 1000 tonnes output. The Zambian mining industry employs one person for every 10 tonnes output, so employment in the mining sector is 100 times as big as employment in CCR production. (see ZCCM annual report 1984);
- Zambian copper sells at a premium of about $ 15 per tonne above LME. This premium is not received when the copper is sold in the form of CCR, so that the gross profit of $ 17 per tonne on CCR exports is nullified;
- Zambian Consolidated Copper Mines (ZCCM) would probably be reluctant to sell a significant part of its production to a domestic fabricator, because foreign exchange earnings would drop accordingly. The mines need however big amounts of foreign exchange for equipment purchases, new investments etc.

It is assumed that the same reasoning can be followed for "Deutsche Giessdraht" in Emmerich, Western Germany which is a joint venture rod plant of "Norddeutsche Affinerie" (40%), "Hüttenwerke Kayser" (20%) and "Codelco" (40%) of Chile. It is therefore concluded that copper exporting DC's do not have many good reasons to replace a major part of their refined copper exports by CCR. Exports of small quantities however do seem possible, even
to more remote overseas markets. This is illustrated by the Outokumpu CC
rod mill in Zambia.

It can be expected that CC mills established in the DC's first of all cater
for the domestic and regional markets. They will not be established with
the purpose of mainly supplying remote overseas markets. If overseas
exports occur, the quantities will be small because there is no real
financial advantage. Supplying nearby markets is much more profitable.

This can be seen from the following example where the costs of delivery of
CCR to Zambia or the part of Dar-Es-Salaam (gateway to the region) are
compared for Zambian and European CCR.

CCR produced in Zambia and delivered to Zambian customers costs $1,426 per
tonne (cathode price $1.346 plus production costs $66). Delivered to
Dar-Es-Salaam by rail, the total costs increase with $86 per tonne on
transport costs to the port of Dar-Es-Salaam would cost $1,696 (cathode
price $1.526, production costs $62 and shipping $108). Delivery to
Zambian customers would increase costs with $88 overland transport costs
per tonne to $1,784 per tonne. In both cases there is a cost advantage for
the Zambian producers:

- CCR delivered to Dar-Es-Salaam,
  produced in Zambia costs $1,504 per tonne
  produced in Europe costs $1,696 per tonne
  Cost advantage Zambian producer $192 per tonne

- CCR delivered to Zambian customers,
  produced in Zambia costs $1,426 per tonne
  produced in Europe costs $1,784 per tonne
  Cost advantage Zambian producer $358 per tonne

For the non copper producing countries the economics of CCR production for
the domestic market is less demonstrable. This would depend upon their
distance from a refined copper supplier and the size of their wire and cable
market. If however the trend of distant markets increasingly supplying
themselves continues, new CCR plants can be expected to come on stream in
countries such as India, China, Egypt, Algeria, Iraq, Israel, Libya,
Marocco, Argentina, Chile and Peru. Thereby mostly replacing old HRR mills
or imports of wire and wire rod.

Some other factors related to the allocation of CCR production which may be
quite important have not yet been mentioned. These are, the availability of
know-how and skills in a country, the industrial environment and the
availability of capital for the necessary investments. Here it is assumed
that if a country is able to manage a copper mining industry it should be
equally able to run CCR production, even if it is high technology. More
problems could occur with the availability of capital, especially foreign
exchange, since many countries in Latin-America and Africa suffer from a
serious debt crisis.

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CHAPTER 9

CONCLUSIONS

The major conclusions from the analysis presented before are:

1. There is a variety of production technologies for CCR available. Any country or group of countries consuming more than 3000 tonnes per year on wire and cable products could theoretically establish a CCR mill.

2. The explosive growth of world production capacity of CCR seems nearly over. Especially in the DME growth is declining. The growth of world production capacity is now mainly taking place in the DC's.

3. In the 1990's the DC's will own one third of the CCR world production capacity.

4. Although production at competitive costs is possible in the DC's, no large scale exports of CCR from DC's to the DME's are expected. This is mainly due to the saturated markets in the DME's, the great distance from customers, the hazard of product damage during transport and the low employment operation of the technology.

5. Production of CCR for the local or regional market in the DC's can bring along considerable benefits, not only in DC's with big domestic markets but also in the DC's with smaller domestic markets for wire and cable products. This is especially here for copper producing DC's, which have the advantage of zero transport costs of refined copper, in addition to other advantages like low wages and, sometimes, cheap energy.

The conclusions drawn here seem to be supported by evidence from the DC's themselves. Fifteen of the twentyseven continuous casters in DC's were established since 1980, while before 1977 almost no CCR capacity in DC's existed.

The trend observed in Cooper Studies (dec., 1977) that unlike in many other industrial sectors, the further processing for export of copper in DC's seems to have ended at the refinery stage has indeed proved to be correct for the case of CCR. There are however good reasons to believe that in the 1990's as far as CCR is concerned, about one third of the world production will take place in DC's. What will lag behind is intercontinental trade in CCR, not production and also not regional trade. How the situation will develop for other semis will be analyzed in another study in this series.
there are increased possibilities in DC's to produce a wide variety of sections and alloys, tailored to the needs of a relatively small domestic market. It is high time that the odd situation of a country exporting refined copper, but having to import most of its copper and copper alloy semis requirement, comes to an end.
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- Pope b.v., Wire and cable manufacturers, Venlo, The Netherlands
- Lamitref Koper B.V., Hemiksem, Belgium
LOMA-MANN VERTICAL CONTINUOUS AND SEMI-CONTINUOUS CASTING

1. Molten copper alloy flows from a holding furnace and into a launder above the casting moulds. Rate of flow is controlled by needle valves.

2. The mould cavity is surrounded by a water jacket that chills the metal. Under-pouring eliminates internal porosity and inclusions. To avoid sticking, the entire mould assembly oscillates.

3. The smooth surface of the cast billets is gripped by pinch rolls that guide the billets and hold them for sawing by the circular cut-off saw. The saw cuts the metal while it moves downward at the same speed as the billets, maintaining the continuity of the system.

4. The vertical discharge basket tilts the cut billets into a horizontal position. Hydraulic cylinders eject them onto a roller conveyor, or any other type of handling device required.

Mould

The heart of the casting process is the mould. Molten metal is underpoured for smooth and splash-free entry into the mould. Flow rate is accurately controlled by valves regulated by the operator. To prevent sticking, and to obtain a superior surface finish, the mould is continuously vibrated in a sinusoidal pattern, with adjustable frequency and amplitude. Cool water is circulated through the mould to quench the metal. Water is also sprayed onto the cast billets or slabs as they descend below the mould, further cooling the cast shapes prior to sawing.

As the result of research and development work with BNF Metals Technology Centre to identify critical factors controlling the operation of the process, a set of mould hardware was developed to produce high-quality billets in a wide variety of alloys at speeds generally in excess of those obtained from normal commercial casting plants. Typical output speeds for 225 mm diameter billets in copper or free-machining brass are around 6 tonnes/hour strand. This technology has been successfully transferred to a number of commercial casting plants which have now been in operation for several years.

Source: Wellman Mechanical Engineering Ltd.
Non-ferrous brochures

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Molten aluminium or copper alloy can be cast into billets, slabs or into both of these shapes using a semi-continuous system. Multiple billets or slabs are made with each pour. One or more melting holding furnaces form the charge.

2. Water-cooled mould cavity speeds solidification of the metal for uniform internal structure. Lubricant is applied to give the shapes superior surface qualities as they are removed.

3. Strength of the castings is maintained by stainless steel guide columns built into the walls of the pit of the machine bank.

4. Billets or slabs are supported by a hydraulically controlled casting table that lowers them at a preset speed to match the metal poured into the moulds.

Illustration of BNF-Mann horizontal casting process. Key: 1 Melting and/or holding equipment; 2 Casting with vibrating moulds; 3 Withdrawal machine and accessories; 4 Flying saw; 5 Instrumentation and electrics; 6 Run out system.
### Country of Company

#### AFRICA

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#### WESTERN EUROPE

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### Planned and Existing CC Rod Mills by Country/Company (continued)

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*Source: CRU CC Rod Data Bank*

*Note: n.a. = not available
System: C = Contirod
GE = General Electric Dip-form
M = Metconrod
O = Outokumpu
OTH = Other
PP = Properzi
S = Secim
SCR = Southwire*
### Hot Rolling Mills in the Non-Socialist World, 1981

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October 1982 • COPPER STUDIES
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Source: CRU

n.a. = not available
MAPPLEBECK-MANN STRIP AND ROD CASTING

In association with John E. Mapplebeck Ltd (UK), Wellman offer systems capable of horizontal casting strip and rod in non-ferrous metals.

To retain its leading world-wide position, Wellman is participating in further research on narrow, intermediate and wide strip, to improve quality of production with the BNF Metals Technology Centre.

Mapplebeck have developed and now use three plants in their own works, producing high quality brass, phosphor bronze and nickel silver strip.

The composition of metal cast is monitored by the latest computer controlled direct reading emission spectrometer. The melting and holding furnaces are heated by electric induction with direct launder transfer between them.

The withdrawal-rolls pull the 150 mm-500 mm upwards wide strip from the holding furnace via the die/cooler unit.

Production rates can be as high as 500 Kg/hr at 200 mm wide, or 1000 Kg/hr plus at 450 mm wide and upwards.

In-line milling unit removes a thin layer from the strips to give 100% sound and oxide free surfaces which are so important in producing high quality strip to thin gauges.

Material produced by this casting system can be used for a wide variety of products in the telecommunication, ammunition, electrical and general engineering industries where the emphasis is on tight tolerances, and in the jewellery and electro plating trades where good surface finish is essential.

Source: Wellman non ferrous Brochure

Typical arrangement of a Mann strip casting and rolling line.
Wellman present the widest range of non-ferrous continuous casting equipment in the world.

BNF MANN
HORIZONTAL CASTING PROCESSES

To offer the latest and most advanced design available, Wellman have co-operated in a research and development project with the B N F Metals Technology Centre to produce the latest technology in this field.

B N F has a background of many years of research and development in the continuous casting of copper and its alloys, being equipped with full-scale plant. Its continuous casting machine designs are now extensively used commercially.

A new design of horizontal casting machine has been developed to achieve similar casting speeds to those obtained by vertical casting. This casting machine differs from the majority of commercial plants casting large billets in that, instead of attaching the moulds to a large holding furnace which is fed directly from the melting furnace, the mould is attached to a heated holding tundish of relatively small metal capacity, which is fed by a conventional downspout system. This arrangement has a number of advantages:

(i) Existing semi-continuous casting plant can be converted to continuous horizontal casting by removing the casting table and replacing it with the hot metal end of the new style casting machine.

(ii) The mould-tundish unit is easily removable and can be quickly replaced with a new pre-assembled unit thereby permitting a rapid die change, incorporating a change in the size of product if required.

(iii) The low overall weight of the mould-tundish unit permits the complete assembly to be reciprocated.

(iv) The low capacity of the holding unit means that an accidental break-out of the casting is a less significant event and permits the use of secondary cooling thereby enabling higher casting speeds to be attained. Additionally in free-machining leaded brasses (particularly the high leaded alloys for improved machinability), the formation of iron rich hard spots, which can cause excessive tool wear, is suppressed and the optimum lead particle size and distribution associated with high cooling rates can be achieved.

With this new horizontal machine it has been found possible to cast high quality billets both in respect of surface finish and internal soundness at speeds of the same order as those normally achieved on commercial vertical casting installations. The close control of cooling conditions in the mould system permits outputs to be obtained in parallel moulds, also enabling high quality products to be obtained at speeds below the maximum should it be necessary to reduce speed due to problems with the molten metal supply.

The machine lends itself, amongst others, to the:

(1) Copper industry for casting of piercing billets, say 88 mm diameter, 150-225 mm diameter billets and slabs, 500 x 88 mm diameter upwards.

(2) Copper alloy industry for casting of free machining brass, etc., 225-275 mm diameter billets and slabs.

(3) Zinc industry - casting slabs in zinc or zinc/copper/tin alloy.

(4) Aluminium alloy industry.

Main advantages...
- Concentric grain structure
- Casting speeds equivalent to vertical casting
- High quality billets
- Lower capital plant outlay through higher output

Single strand continuous casting plant producing copper billet.

Source: Wellman non-ferrous Brochures
Sources: Electric cables handbook Pope B.V., wire and cable brochures.

### Audiocables

<table>
<thead>
<tr>
<th>Microphone cable</th>
<th>Pick-up cable</th>
<th>Pick-up cable</th>
<th>Pick-up cord</th>
<th>Magnetophone cord</th>
</tr>
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<tbody>
<tr>
<td>1 x 0.20 mm²</td>
<td>1 conductor</td>
<td>2 individually screened</td>
<td>2 individually screened</td>
<td>4 individual screened (with copper or conductive PVC)</td>
</tr>
<tr>
<td>2 x 0.24 mm²</td>
<td>of 0.06 mm²</td>
<td>conductors of 0.06 mm²</td>
<td>conductors of 0.06 mm²</td>
<td>conductors of 0.06 mm²</td>
</tr>
<tr>
<td>2 x 0.20 mm²</td>
<td>- 0.15 mm²</td>
<td>- 0.15 mm²</td>
<td>- 0.15 mm²</td>
<td>- 0.15 mm²</td>
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<tr>
<td>overall screening</td>
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### Cables for Fixed Installation in Buildings

**PVC WIRING CABLES**

- 300/500 V and 450/750 V
- Main application: wiring in buildings

**PVC Insulated House Service Cables**

**CABLE DESIGNS**
Paper Insulated Distribution Cables

CABLE DESIGNS

Paper-insulated 4-core, 600/1000 V, steel tape armoured cable

Paper-insulated 3-core, 6.35/11 kV, belted, wire armoured cable

XLPE Insulated Distribution Cables

CABLE DESIGNS

XLPE insulated 4-core, 600/1000 V, armoured cable
ANNEX 5
Non-socialist world production of copper wire in 1000 tonnes and as percentage of refined consumption

<table>
<thead>
<tr>
<th>Region</th>
<th>Refined wire-production</th>
<th>as percentage of refined consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>1867</td>
<td>1269</td>
</tr>
<tr>
<td>Canada</td>
<td>209</td>
<td>145</td>
</tr>
<tr>
<td></td>
<td>2076</td>
<td>1414</td>
</tr>
<tr>
<td>Latin America</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>246</td>
<td>128</td>
</tr>
<tr>
<td>other</td>
<td>242</td>
<td>163</td>
</tr>
<tr>
<td></td>
<td>488</td>
<td>291</td>
</tr>
<tr>
<td>Europe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Austria</td>
<td>31</td>
<td>19</td>
</tr>
<tr>
<td>Benelux</td>
<td>322</td>
<td>306</td>
</tr>
<tr>
<td>France</td>
<td>433</td>
<td>360</td>
</tr>
<tr>
<td>W.Germany</td>
<td>747</td>
<td>482</td>
</tr>
<tr>
<td>Italy</td>
<td>388</td>
<td>265</td>
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<tr>
<td>Scandinavia</td>
<td>113</td>
<td>112</td>
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<td>Spain</td>
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<td>82</td>
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<td>Switzerland</td>
<td>14</td>
<td>47</td>
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<tr>
<td>UK</td>
<td>409</td>
<td>250</td>
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<tr>
<td>other</td>
<td>224</td>
<td>115</td>
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<tr>
<td></td>
<td>2809</td>
<td>2038</td>
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<tr>
<td>Australia</td>
<td>128</td>
<td>72</td>
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<tr>
<td>Asia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>1158</td>
<td>909</td>
</tr>
<tr>
<td>other</td>
<td>310</td>
<td>204</td>
</tr>
<tr>
<td></td>
<td>1468</td>
<td>1113</td>
</tr>
<tr>
<td>Africa</td>
<td>116</td>
<td>70</td>
</tr>
<tr>
<td>Total</td>
<td>7085</td>
<td>4998</td>
</tr>
</tbody>
</table>

Source: World Metal Statistics.

1) No figures published; assumption is 65% of refined consumption
Copper wire production and copper wire rod capacity in developing countries (x 1000 t) 1982/83

<table>
<thead>
<tr>
<th>Country</th>
<th>refined consumption&lt;sup&gt;1)&lt;/sup&gt; 1982</th>
<th>rated wire production&lt;sup&gt;2)&lt;/sup&gt; 1982</th>
<th>CCR production capacity&lt;sup&gt;3)&lt;/sup&gt; 1983</th>
<th>Total HRR (1981)</th>
<th>Total Rod</th>
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</thead>
<tbody>
<tr>
<td>Africa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Algeria</td>
<td>7.2</td>
<td>4.7</td>
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<tr>
<td>Egypt</td>
<td>8.1</td>
<td>5.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zaire</td>
<td>1.6</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Zambia</td>
<td>2.8</td>
<td>1.8</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Zimbabwe</td>
<td>6.0</td>
<td>3.9</td>
<td></td>
<td></td>
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<tr>
<td>Asia</td>
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<td></td>
<td></td>
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<td></td>
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<tr>
<td>India</td>
<td>83.2</td>
<td>54.1</td>
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<td>35.0</td>
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<tr>
<td>China</td>
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<td>270.0</td>
<td>36.3</td>
<td>36.3</td>
<td>36.3</td>
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<tr>
<td>Iran</td>
<td>3.4</td>
<td>2.2</td>
<td></td>
<td>6.0</td>
<td>3.0</td>
</tr>
<tr>
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<td>3.6</td>
<td>2.3</td>
<td>6.0</td>
<td>142.6</td>
<td>142.6</td>
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<tr>
<td>S. Korea</td>
<td>138.1</td>
<td>89.8</td>
<td>16.0</td>
<td>226.6</td>
<td>242.6</td>
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<td>Taiwan</td>
<td>73.9</td>
<td>48.0</td>
<td>10.0</td>
<td>200.0</td>
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<td>21.1</td>
<td>62.0</td>
<td>36.0</td>
<td>122.0</td>
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<tr>
<td>Indonesia</td>
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<td>27.0</td>
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<tr>
<td>Malaysia</td>
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<td>18.0</td>
<td>48.0</td>
<td>66.0</td>
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<td>Thailand</td>
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<td>24.0</td>
<td>24.0</td>
<td>1.0</td>
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<tr>
<td>South America</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Argentina</td>
<td>51.5</td>
<td>33.5</td>
<td>25.0</td>
<td>25.0</td>
<td>25.0</td>
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<tr>
<td>Brazil</td>
<td>249.3</td>
<td>161.9</td>
<td></td>
<td>148.5</td>
<td>148.5</td>
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<tr>
<td>Chile</td>
<td>32.8</td>
<td>21.3</td>
<td></td>
<td>100.0</td>
<td>248.5</td>
</tr>
<tr>
<td>Mexico</td>
<td>88.4</td>
<td>57.5</td>
<td>39.0</td>
<td>32.7</td>
<td>148.5</td>
</tr>
<tr>
<td>Peru</td>
<td>21.0</td>
<td>13.6</td>
<td></td>
<td>220.2</td>
<td>79.0</td>
</tr>
</tbody>
</table>

Total | 1,250.3 | 812.8 | 47.0 | 138.0 | 88.1 | 439.6 | 537.6 | 1295.3 | 322.0 | 1,617.3 |

Notes: 1) source: World Metal Statistics; 2) 65% of refined consumption; 3) P = Properzi, O = Outokumpu, GE = General Electric, C = Contirod, S = Southwire. Figures from: Copper Studies and annex II. 4) off stream