Industrial-Scale Leadmaking with the QSL Continuous Oxygen Converter

Paul E. Queneau and Andreas Siegmund

INTRODUCTION

Consumption of lead in the Western world is approaching five million tonnes yearly, about two thirds of which is consumed in the manufacture of electric batteries. The remainder is used largely for protection from corrosion and incrustation, for sound insulation, and in glasses. Growth in lead consumption of 1.5-2.5% yearly is forecast, partly due to the increasing strength of economies in Asia. However, the production and use of lead presents well-known and serious health problems due to its toxic properties. Nevertheless, manufacturers can maintain lead’s position as a valuable industrial raw material by employing modern, efficient, and environmentally friendly technologies in its production, by developing wider use of applications, and by providing better safeguards in its use. Effective R&D to increase lead-battery efficiency is necessary in view of promising battery competition from other materials (e.g., Al, Li, Ni, Na, and Zn).  

Lead has a high recycling rate, yet approximately 55% of total production comes from primary lead smelters. More than 85% of this lead is still produced using Dwight-Lloyd sinter machines and blast furnace operations, which basically harks back to 1907 when the former was introduced. This old practice does not satisfy today’s requirements in respect to efficiency and environmental protection. Therefore, the QSL (Queneau-Schuhmann-Lurgi) continuous oxygen converter, which produces lead from both primary and secondary sources, is now used in three Lurgi-designed in-

DEVELOPMENT OF THE QSL CONVERTER

The novel QSL converter was conceived in the winter of 1972-1973 by two engineers working together in an academic environment: the design of a better pyrometallurgical process. The goal of Paul Queneau and Reinhardt Schuhmann was the development of a process for the continuous production of lead in which the pyrometallurgical reactor, the tarred oven, and the lead metal are contained in a single piece of equipment. The novel converter followed the “lead oxide pyrometallurgical” process developed in the INCO oxygen-flux smelting route and the copper oxide route. The top-blowing rotary converter was found to be essential for achieving a high efficiency in the process. The Sauerstieblend bottom-blowing converter was an essential component of the reactor. The production of copper oxide by direct distillation of copper metal was essential to the process. The novel converter was designed to meet the requirements of the demand for lead and to be as efficient as possible. The process was designed to be energy efficient and to minimize the environmental impact of the lead production process.

The QSL converter was designed to be a continuous process, which means that the lead production can be carried out continuously without interruption. This is achieved by the use of a single piece of equipment that contains all the necessary components for the production of lead. The process is designed to be as energy efficient as possible, with a high recovery of lead from the raw materials. The process is also designed to be environmentally friendly, with a minimal amount of emissions to the atmosphere.

The QSL converter has been successfully tested and has been in operation since 1973. The process has been shown to be highly efficient, with a recovery of lead of more than 99%. The process is also environmentally friendly, with minimal emissions to the atmosphere. The QSL converter is currently in operation in several countries around the world, and it is being used to produce lead for a wide range of applications.

To strengthen their cause, the oxygen converter inventors allied themselves with oxygen producers Canadian Air Liquide and employees Robert Lee and Guy Sward, forming QSLIP, Inc. (Queneau-Schuhmann-Oxygen Processes), led by faculty members of the University School of Engineering, Tromsø. It was initially aimed at co-combustion (rather than lead-making) because of the inventors’ greater industrial importance, and because of the inventors’ greater knowledge of the co-combustion.

The inventors’ thinking was summarized in the August 1974 issue of JCM, which illustrated the Q-S Continuous Oxygen Converter on the cover. The important economic advantages of the concept—a comparison to conventional furnace operations in copper, nickel, and lead production—are highlighted by its superior energy consumption, metal losses, and pollution. It is involved from the purging of the following key objectives: economic production of metal of low iron content, slag of low product-metal content, and gas containing high-sulfur dioxide content—light in one continuously operating, practical reactor. The resulting simple, flexible configuration embodying these primary considerations incorporates additional features for application to specific metal sulfide concentrates. The concept employed includes:

- Continuity, to minimize overall capital and operating costs.
- Autocatalysis, using oxygen, to minimize energy consumption.
- Producing a single off-gas of minimum volume and constant flow to minimize the costs of sulfur fixation and particulate matter removal.
- Bottom-blowing to achieve regulated, localized turbulent bubbling for optimal gas-liquid-solid contact with minimal eddy and splash.
- Securing true countercurrent flow in respect to metals (metal) and slag, with sequential staging of oxygen activity, temperature, and other controlling physicochemical conditions, and concurrent flow with respect to gas and slag.
- Employing an elongated, kiln-like vessel, sloped and stepped downward toward the metal discharge end, with blowcooling to promote positive metal (slag) flow and improved heat and mass transfer.

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industrial plants having a combined capacity of about 200,000 tonnes of lead bullion per year.

With the QSL converter, modern oxygen pyrometallurgy is used in the continuous, direct smelting of plumbiferous materials for energy-efficient, ecologically compatible, lead production. This converting process is incorporated in a single, closed, channel-type bath smelting unit. Autogenous roast-reaction smelting of lead sulfide concentrates is employed, followed by bottom-blown gaseous reduction of the ensuing lead oxide slag. Reduction is effected by mixer-settler, sequentially staged decrease in bath oxygen activity, and countercurrent flow of the lead produced. A wide variety of lead-bearing materials can be continuously converted into low-sulfur lead bullion, discard slag, and SO₂-rich off-gas.

The development of the flexible QSL converter from concept through Lurgi's pilot-scale validation during 1981-1986 is described in the sidebar "Development of the QSL Converter," and operation is outlined in the sidebar "Guidelines for QSL Converter Operation."

**QSL METALLGESSELLSCHAFT—GERMANY**

In 1988, Metallgesellschaft AG decided to replace its polluting conventional smelter in Stolberg, Germany, with QSL technology, so as to comply with the country's increasingly stringent environmental protection regulations. The new smelter started up in August 1990. It is designed for a 150,000 t/y throughput of lead-bearing materials, about two thirds of which are galena concentrates, and the remainder are secondaries (Table D). Figure 1 shows the simplicity of the overall QSL plant design. The plant was integrated into existing smelter facilities, permitting utilization of the feed preparation and wet-gas cleaning systems. The entire plant complex is monitored by a state-of-the-art control room and associated instrumentation. Operating experience since start-up led to several plant modifications. The converter is operating very satisfactorily, notably in regard to slag-reduction-zone performance and to service life of the submerged injectors. After an enlargement of the heat-transfer area in the waste-heat boiler, raw materials throughput is close to plant design capacity.

The plant is a custom smelter in which 20 different galena concentrates, high and low in lead, have been treated. The secondary raw materials consist of Pb/Ag residues from zinc plant operations, lead battery paste, and other lead-bearing materials such as lead scrap and lead glasses. During the past year, plant feed had an average ratio of concentrates to secondary materials of 49:51, at an average total feed rate of 30 t/h to the converter (Figure 2a). However, ratios of up to 40:60 have been achieved on a monthly basis. Composition of the plant feed is indicated in Figure 2b. The recirculated material consists of plant by-products (e.g., cluet, dress, and slag). Moisture content is high (13%) due to the large content of secondary materials. Feed silver content is collected in the lead bullion and recovered in a subsequent refining step. Converter slag is essentially iron silicate. The main slag-forming constituents—FeO, CaO, SiO₂, and Al₂O₃—are in the olivine percentage range. Slag basicity (CaO + MgO)/SiO₂—averages 0.8-1.0. Smelting-zone bath oxygen potential is controlled by solid-fuel addition, the amount of which is determined by the nature and amount of secondary materials in converter feed to obtain a 25-30% lead content as PbO in the 1,000-1,100°C discharge to the slag reduction zone. The latter zone's bath oxygen potential is submerged-injector-controlled so that little zinc is tumed, resulting in final slag zinc contents of up to 15%.

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**Table I. Design Capacity and Feed Materials of QSL Plants**

<table>
<thead>
<tr>
<th></th>
<th>Stolberg</th>
<th>Korea Zinc</th>
<th>CNIEC</th>
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<tbody>
<tr>
<td>Reactor Size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead Bullion Production Capacity</td>
<td>80,000 t/y</td>
<td>60,000 t/y</td>
<td>52,000 t/y</td>
</tr>
<tr>
<td>Total Length</td>
<td>33 m</td>
<td>41.1 m</td>
<td>30 m</td>
</tr>
<tr>
<td>Smelting Zone Length</td>
<td>12.5 m</td>
<td>14.4 m</td>
<td>10.5 m</td>
</tr>
<tr>
<td>Sulfur Reduction Zone Length</td>
<td>21.5 m</td>
<td>26.7 m</td>
<td>19.5 m</td>
</tr>
<tr>
<td>Sulfur Zone Dia.</td>
<td>3.6 m</td>
<td>4.2 m</td>
<td>3.3 m</td>
</tr>
<tr>
<td>Slag Reduction Zone Dia.</td>
<td>3.0 m</td>
<td>4.0 m</td>
<td>3.0 m</td>
</tr>
<tr>
<td>Daily Feed of Raw Materials (dry)</td>
<td>420 t/d</td>
<td>550 t/d</td>
<td>260 t/d</td>
</tr>
<tr>
<td>Feed Mixture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concentrates</td>
<td>63%</td>
<td>53%</td>
<td>100%</td>
</tr>
<tr>
<td>Residues</td>
<td>37%*</td>
<td>47%*</td>
<td></td>
</tr>
<tr>
<td>Raw Material Mixture Composition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pb</td>
<td>45%</td>
<td>35%</td>
<td>66%</td>
</tr>
<tr>
<td>Zn</td>
<td>5%</td>
<td>10%</td>
<td>5%</td>
</tr>
<tr>
<td>Cu</td>
<td>0.7%</td>
<td>0.6%</td>
<td>0.2%</td>
</tr>
<tr>
<td>As</td>
<td>0.3%</td>
<td>0.3%</td>
<td>0.05%</td>
</tr>
<tr>
<td>Sb</td>
<td>0.4%</td>
<td>0.3%</td>
<td>0.04%</td>
</tr>
<tr>
<td>Cd</td>
<td>0.05%</td>
<td>0.3%</td>
<td>0.04%</td>
</tr>
</tbody>
</table>

* Pb/Ag residues, ash, glasses, slag, refractory dust.
† Pb/Ag residues, Zn, residues, pasted from battery scrap, Au/Ag concentrates.
Lead contents in the 1,200–1,250°C discharge slag of well less than 2% are obtainable, but only when zinc is fused at low bath oxygen potential. A high-zinc content in recirculated flue dust is undesirable, because the latter can be a substantial proportion of total feed by weight (e.g., 20%). Slags containing more than 15% zinc are generally too viscous at converter temperatures. Normal plant lead recoveries exceed 98%, as indicated in the metallurgical balance of the Stolberg operation (Table II). Specific plant consumption figures for the past decade are shown in Table III.

The converter has a length of 33 m, a diameter of 3.5 m in the smelting zone, and of 3 m in the slag-reduction zone, with countercurrent lead-slag and gas-slag flow. It is refractory-lined with high-quality chrome-magnesite brick. A refractory underflow divider separates the smelting-zone liquid phase from the slag-reduction zone liquid phase. The smelting zone is equipped with three bottom-blowing nitrogen-water aerosol shroud-gas protected injectors through which tonnage oxygen is injected into the bath. The slag-reduction zone is equipped with six shroud-gas protected, bottom-blowing injectors. Five of these injectors blow tonnage oxygen and pulverized bituminous coal into the bath as reductant. The sixth is installed close to slag tap and blows tonnage oxygen and natural gas, easing settling of lead droplets in the slag. These slag reduction zone injectors operate in the essential sequenced mixer-settler configuration. A single system is employed for converter gas exhaust and treatment. Gas volume is about 25,000 Nm³/h and SO₂ content averages 10%. Excess heat in the off-gas is recovered in a waste heat boiler. The 47 bar steam generated, together with steam generated in the off-gas sulfuric acid plant, drives a turbo-generator unit. Electric energy so obtained amounts to about 3.5 MW. This more than covers the 5 MW power requirement of the QSL plant and amounts to 75% of the total plant requirement.

**GUIDELINES FOR QSL CONVERTER OPERATION**

Since the conclusion of Lurgi's QSL converter studies, continuing broad-based developmental work over the past decade has demonstrated the validity of the pilot plant-based conclusions and provided the following guide for QSL converter operation.

1. Molten lead concentrate, lead-bearing secondary and recycled materials, and flux are fed to the gentry sloped (0.6–1.0%) downward toward lead discharge), tilting, horizontal-kiln-like converter. The materials must be thoroughly mixed and large-tonnage blended to satisfy steady-state feed requirements. Lead-slag flow is countercurrent, and gas-slag flow should be concurrent, with lead recovered in the slag reduction zone joining the lead produced in the smelting zone. The lead is smelted in the first section of the converter: the oxygen-bottom-blow, strongly stirred smelting zone. It is characterized by a reaction activity defined by a Schultenmann number (log(P₉₀/P₅₀)) of about 2.9. Here, low-sulfur lead bullion is produced and discharged through a spout, and the PbO-rich slag remaining is passed to the oxygen and coal bottom-blow slag-reduction zone. In this section, both oxygen activity is progressively decreased to a Schultenmann number of about 0.2. At the point of slagging, the slag is cast before slag discharge. This sequentially staged bath oxygen activity as well as the compositional and temperature gradients are achieved by submerged oxygen and coal introduction through Seward-Lee injectors for staged heat and mass transfer in a series of regulated plume plumes. The independently and accurately controlled gas analysis injectors gas space sufficiently far apart—and their mass flow rates so regulated—as to form, with minimal splash, a longitudinal series of orderly reaction gas-slag bubble plumes of progressively decreasing oxygen activity and increasing temperature until slag discharge. These chemically active mixing regions are separated by passive lead settling pools. There is no intermixing of adjacent bubble plumes, thus providing a continuous mixer-settler, countercurrent lead-slag flow configuration in the slag reduction zone (Figures A & B).

The reactor is referred to Richter's modeling studies describing the fluid mechanics phenomenon of phase mixing and separation in this countercurrent reaction channel.**13**

Calm lead settling basins are located at both ends of the converter and between the two zones. The latter makes a refractory zone divider unnecessary. If, nevertheless, a refractory barrier of some kind is desired, it can be a wall with an underflow passageway, a maximal opening bridge arch, or an appropriately spaced suspended shallow baffle. The simplest reactor has no such barrier, a single gas off-take, and a single gas train (Figure C). A train includes gas leak exchange, dust recovery, and conventional sulfuric acid treatment of some or all of the dust for zinc and cadmium extraction, with lead returned as PbSO₄ cake to the converter. A wall is employed if separation of SO₂-rich and ZnO-bearing gaseous is desired. In this case, the converter has a gas off-take at each end and two gas trains (Figure D).

The mass flow rate of the sonic velocity gases simultaneously injected into the slag reduction zone should not exceed that needed for break-up of the jet into a well-developed turbulent bubble plume. The high gas velocity is necessary to prevent plugging the injectors by bath constituents. However, jetting of the hot reducing gas right through the bath due to excessive momentum is detrimental to gas utilization efficiency and to bath chemistry control. It is wasteful of costly inputs—heat transfer back to the slag is modest, and mass transfer is poor. Furthermore, such jetting can be the cause of unnecessary post-combustion difficulties and unwanted spattering and slopping. It is imperative that the bubble plumes maximize gas-liquid-solid interfacial contact area and mixing in their regions of the bath. The rate of heat and mass transfer is directly proportional to this area's magnitude, and reaction rate is inversely proportional to interfacial boundary layer thickness. The slag should be deep, so as to give the rapidly rising bubble time to accomplish their mission. Therefore, lead is not allowed to occupy essential working space, beyond that inevitably taken by the inherently ever-present shallow, continuous, underlying layer of previously produced lead. Furthermore, high lead levels reduce the service life of the injectors by interfering with the formation of the mandatory stable "mushroom" that protect their tips. The lead produced should flow steadily and continuously to the melting zone.

![Figure A. Flow circulation on one side of the injector in channel reactor water experiments.](image)

![Figure B. An idealized bubble plume in the reduction zone of the QSL oxygen converter: (a) injector (O₂ + coal) shroud and carrier gases; (b) jet; (c) bubble plume; (d) phase separation; and (e) mushroom.](image)
and of 4 m in the slag-reduction zone; an underflow wall separates the zones. The melting zone is presently equipped with four injectors, and the slag-reduction zone has seven. Off-gas to the waste-heat boiler from the melting zone has a volume of about 35,000 Nm³/h (including ingress air from the feed ports and the converter/vertical uptake transition) and has a 10–12% SO₂ content. Process gas generated in the slag-reduction zone is passed through a vertical uptake equipped with water-cooled membrane walls for heat exchange. It is then quenched with air and water to a temperature below 200°C and passed to a bag filter for dust removal.

Experience gained at the QSL plant in Stolberg was incorporated in the Korean plant design, and other improvements were also implemented. Converter feed was initially mainly galena concentrates. Good metallurgical results were soon obtained, and 15 different concentrates have now been treated. The converter operated at feed rates of 42–48 t/h, with 2–5% lead content in final slag. After optimization of process parameters, the proportion of secondary materials was increased (e.g., lead-silver residues from the zinc plant, oxide residues, and external sludge). Depending on prevailing slag-reduction-zone oxygen potential, much of feed arsenic content is reduced and partially dissolves in the secondary lead or is fused and collected with the zinc in the oxide dust. This is especially true when slag lead content is decreased below 5%. Feed rate to the reactor was increased after increasing the particle size of the coal used as a secondary material fuel in the melting zone, which led to less carry-over into the waste-heat boiler. Increased coal-utilization efficiency and decreased boiler burden permitted the higher converter feed rate.

Average 1994 feed rate was 47 t/h, with a ratio of concentrates to secondary materials of 68:32. The amount of fresh material in the feed was 60%, which is substantially higher than the 46% at Stolberg (Figure 2b). This is due to the lower average moisture content in feed material and the relatively lower flue dust production at higher feed rate. Current feed rate is 55–60 t/h, with a feed composition of 55% concentrates, 28% Pb/Ag residues, 6% oxide residues, and 11% miscellaneous lead-bearing materials (Figure 4). Final slags are similar in composition to those at Stolberg. Adjusted basicity is in the range 0.7–0.9, and lead content as PbO in the primary slag is 35–40%. The lead content of discharge slag is below 5%, corresponding to a total lead recovery of about 98%. Zinc input in converter charge is only partially fused (30–40%) in the slag-reduction zone. The slag discharged from the converter is scavenged in a simple, well-performing, top-blowed Aumelt slag fuming furnace, where the zinc and lead contents are decreased to 3–5% and less than one percent, respectively.

**QSL COMINCO—CANADA**

In December 1989, a QSL plant designed by Lurgi for 120,000 t/y lead output was started up at Trail, British Columbia. In compliance with Cominco’s request, the converter fuel requirement was to be met entirely by the direct
use of natural gas, although such use was contrary to both QSL and Cominco standard slag-reduction operations, which depend on solid fuel. After three months of failed attempts to successfully substitute slow-burning methane for bituminous coal, the converter was shut down and ultimately abandoned. It is being replaced by the Russian, coke-dependent Kivetz furnace.\textsuperscript{1,2,3}

**QSL CNIEC—CHINA**

In the summer of 1985, China Non-Ferrous Metals Import and Export Corporation (CNIEC) decided to build a QSL plant in remote Baiyin in the first commercial Lurgi QSL plant by installing a new lead smelter with a capacity of 52,000 t/y lead bullion. The design is primarily based on the treatment of galena concentrates. The QSL converter has a total length of 30 m, a diameter of 3.5 m in the smelting zone, and 3 m in the slag-reduction zone. Oxygen is blown into the smelting zone by three submerged injectors. Coal and oxygen are blown into the slag reduction zone by five submerged injectors. The overall concept is similar to the Stolberg plant (Figure 1) except for the energy-recovery unit. Total feed mixture consists of concentrates, fluxes, coal fines, recycled process flue dust, and some slag returned after zinc fuming in an electric furnace. The feed is proportioned, mixed, and agglomerated on a pelletizing disc before entering the reactor. The plant was started up at the end of 1990, but was shut down three months later due to process-related problems and mechanical problems—primarily in the oxygen plant. CNIEC modified and restarted the Baiyin plant in June 1995, after visiting the QSL plants in Stolberg and Onsan. Within six weeks of startup, very good metallurgical results were obtained at design capacity, and excellent operating performance continues.

**QSL VS. CONVENTIONAL TECHNOLOGY**

The capital cost of a 150,000 t/y QSL plant is about two-thirds that of a comparable conventional sinter machine.

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**Figure 3.** The QSL-Korea plant design.

**Figure 4.** The fresh-feed composition of QSL Korea Zinc (April 1995).

**Figure 5.** A comparison of energy consumption per tonne of raw material at Stolberg: (a) Conventional sinter machine—blast furnace—total: 5,183 MJ. (b) QSL converter—total: 3,853 MJ.
costs are also much lower in a QSL operation.

An outstanding value-added characteristic of the new practice is its manifest superiority over conventional leadmaking in respect to pollution. In 1970, German government authorities installed a network of monitoring stations in the Stolberg plant area to measure dust and heavy-metal precipitation. In the immediate vicinity (4 km²) of the plant, there are 24 examination facilities measuring plant emissions. Additionally, there are 48 more distant examination facilities, and another 13 beyond them. When the German government imposed the new "TA-Luft" legislation (technical instructions on air quality control) in 1986, Metallgesellschaft had only two alternatives in the following decade: either continue the Stolberg operation by introducing new technology or abandon the plant. Extensive modifications were, therefore, made in its conventional practice, but the "TA-Luft" heavy-metals emission standards still could not be met. Furthermore, planned reduction in SO₂ emissions proved impractical (e.g., an additional desulfurization facility for blast furnace off-gas treatment had to be rejected for cost reasons).

QSL technology was, therefore, adopted with resulting striking environmental change for the better, both inside and outside the plant. New practice emissions of dust are sharply lower over a wide spectrum. Emissions of lead, cadmium, and sulfur dioxide from the new converter facility have all been decreased by more than 90%. (Figure 7). The stringent clean air demands of TA-Luft are now being met, both close to and far from the plant's perimeter. For instance, the lead content in QSL dust emissions at the plant perimeter is 0.2 µg/m²—which is much lower than the corresponding German and U.S. control figures of 2.0 µg/m² and 1.5 µg/m², respectively.

**PAST TO FUTURE**

The solution to difficult energy and pollution problems around the world depends on better—not less—technology, an aphorism all rational environmentalists comprehend. In 1974, the inventors of the Q-S continuous oxygen converter publicized their belief in its superior capabilities for copper, nickel, and lead production in respect to energy consumption, metal loss, and pollution. "The dream of a better way" rejected in the United States as impossible is now a reality abroad. The QSL continuous oxygen converter meets the demand for economic, energy-saving, ecologically compatible lead production from both galena concentrates and, importantly, a great variety of secondary or recycled materials. Lurgi QSL plants have proven that their capital and operating costs—and injurious emissions—are all importantly lower than those of conventional sinter-mine blasterfurnace plants. Since the latter are superannuated, their obsolete design will not be copied in greenfield construction. Lurgi's modern lead converter can be retrofitted into these old-fashioned plants and, thereby, take

![Figure 6. Mass flow comparisons: (a) Conventional galena concentrate lead smelting—basis: 1,000 kg galena concentrates (65% Pb). (b) QSL galena concentrate and secondary lead smelting (Korea Zinc)—basis: 1,000 kg raw material (65% concentrates, 45% secondary materials) (46% Pb).](image-url)
maximum advantage of the existing infrastructure. In leadmaking, the future has arrived!

Many metallurgists find it difficult to believe that leadmaking—in overall terms—is more difficult than coppermaking. This misunderstanding is explainable by the marked dichotomy separating the two industries. Fruitful bridging of the chasm between their production technologies requires study: the chemical and physical properties of the two elements and their compounds at elevated temperatures are critically different. Better understanding of these facts will help clear the way for adoption of the continuous oxygen converting of mineral concentrates and secondary by the copper industry. The same conclusion applies to the pyrometallurgy of copper-nickel-cobalt sulfide concentrates. The great rewards attainable include improved metal recovery at lower cost and improved environmental protection. In the past half century, leadmaking brought up the rear of the oxygen pyrometallurgy parade. It is now a leader. Coppermaking and low-iron, copper-nickel-cobalt matte-making will surely follow—the future beckons! [11, 12, 13]

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