Chapter 7

Energy Use in the Copper Industry

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All aspects of copper production require energy, whether in the form of electricity, explosives, or hydrocarbon fuels (diesel, gasoline, natural gas, fuel oil, coal, coke), or as the energy equivalent of materials consumed (e. g., chemicals and steel grinding media). In 1977, the primary copper industry purchased 121 **trillion** Btu of energy, or around 85 million Btu per short ton of cathode copper produced. [1]This compares to around 15 million Btu/ton for iron mining and steel production, 24 million Btu/ton for lead production, and 64 million Btu/ton for zinc,

Mining uses about 20 percent of the total energy requirement; milling around 40 **percent; and smelting, converting, and refining the remaining** 40 **percent.** Actual requirements vary widely depending on the mine characteristics and type of smelter, however. Table **7-1 shows one estimate of energy requirements** in Btu equivalents for a hypothetical copper operation. It is interesting to note that pollution control equals a large percentage of the energy demand for smelting. In countries where pollution control is not required or is less stringent than in the United States, smelter energy demand could be as much as fifty percent lower. The significance of this difference would depend on the comparative energy costs, and the importance of energy for the total operating cost (see ch. 9).

A number of technological changes have reduced energy use in recent years. For example, automatic truck dispatching makes more efficient use of haulage and decreases diesel consumption. In-pit crushing and conveying can eliminate the need for truck haulage altogether, substituting electricity for diesel fuel. Computer control of other processes improves operating efficiency by maintaining operations as close to the ideal as possible. Changing from reverberatory to flash furnaces cuts total smelting and refining energy requirements by one-third. The use of leaching and solvent extraction eliminates smelting and converting altogether, Further conservation is possible, however.

This chapter reviews the energy requirements for the various stages of copper production, in-

[1] Michigan Technological University, *Effects of Increasing Costs on the Future Relation between Open Pit and Underground Mining,* report prepared for the U, S. Bureau of Mines, December 1982, vol. 1.

Table 7-1 **.—Energy Requirements for Copper Production**

Operation	10' Btu/ton	Total	Percent of total
Open-pit mining:		20.13	19-25
Drilling	0.61		
Blasting	3.90		
Loading	1.85		
Hauling	13.14		
Ancillary.	0.64		
Milling:		42.73	40-52
Comminution	0.16		
Beneficiation	42.57		
Smelting: [a].		6.2-22.7	8-21
Electric furnace	22.68		
INCO flash	6.27		
Outokumpu flash	9.20		
Mitsubishi reactor . . .	12.21		
Noranda reactor	10.41		
Converting:		0.9-6.5	1-6
Electric furnace	6.50		
INCO flash.	0.94		
Outokumpu flash	2.13		
Mitsubishi reactor[b] . .	3.02		
Noranda reactor[b]. . . .	1.77		
Gas cleaning:		6.3-8.2	8
Electric furnace	7.73		
INCO flash.	7.76		
Outokumpu flash	8.16		
Mitsubishi reactor . . .	6.25		
Noranda reactor	7,36		
Electrorefining:.		5.6-6.3	6-7
Electric furnace	5.61		
INCO flash.	6.29		
Outokumpu flash	6.29		
Mitsubishi reactor . . .	6.29		
Noranda reactor	6.29		
Total		81.9 -106.5	

[a]Includes roasting and heat recovery, and all materials
[b]Includes slag cleaning.

SOURCE: Charles H. Pitt and Milton E. Wadsworth, *An Assessment of* Energy *Requirements in Proven and New Copper Processes* report prepared for the U.S. Department of Energy, contract no EM-78 -S-07.1 743, December 1980.

Table 7-2.—Hypothetical Copper Operation for Analyzing Energy Use

Vertical depth below rim.	750'
Dynamic slope angle of sidewalls. . . .	30°
Average slope of haul roads in pit . . .	6 %
Surface haul to dumps	2,500 (6% grade)
Surface haul to primary crushers	2,500 (level)
Overburden/ore body stripping ratio . .	1.25
Mill head value of ore	0.55 % Cu
Value of flotation concentrate	25 % Cu
Value of flotation tails.	0.069 % Cu
Recovery factor ore to concentrate. . .	87.455 %
Recovery factor concentrate to cathode copper.	98.67%
Recovery factor ore to cathode	86.29%
Primary cathode copper produced per year.	100,000 tons

SOURCE Charles H. Pitt and Milton E. Wadsworth, *An Assessment of Energy Requirements in Proven and New Copper* Processes, University of Utah, report prepared for the U.S. Department of Energy, contract no EM-78-S-07-1743, December 1980, p. 25

eluding the type and amount of energy used, the variables that affect energy demand, and possible means of reducing demand. In each case, the estimates of energy demand are based on the hypothetical operation described in table 7-2.[2]

[2]Unless otherwise noted, the material in this chapter is drawn from Charles H. Pitt and Milton E. Wadsworth, *An Assessment of Energy Requirements in Proven and New Copper Processes,* report prepared for the U.S. Department of Energy, contract no, EM-78-S-07-1 743, December 1980.

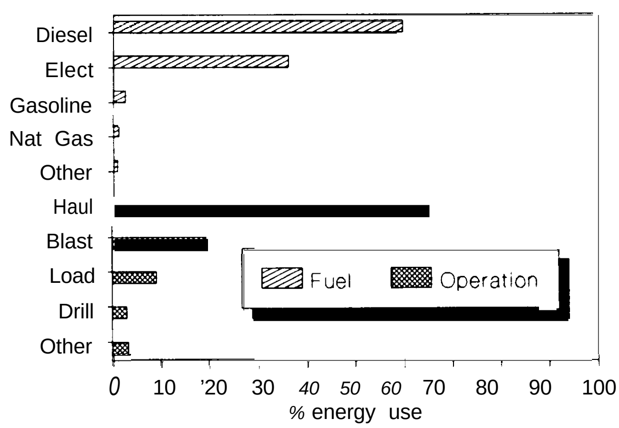
MINING

The hypothetical open-pit mine described in table 7-2 uses an average of 20 million Btu of energy per ton of cathode copper produced, or about 21 percent of the energy consumed in producing copper (see figure 7-1). Approximately 59.7 percent of the energy is in the form of diesel or light fuel, **36.1** percent electricity, 2.4 percent gasoline, 1.0 percent natural gas, and 0.7 percent in some other form.[3] Hauling operations account for around 65 percent of the total energy consumed in open-pit mining, assuming conventional rock hauling by diesel-fueled dump trucks.[4] Blasting is the next largest use–about 19 percent —in the form of explosive energy. Electricity for shovel loaders and for drilling account for 9 percent and 3 percent, respectively. Finally, ancillary operations use around 3 percent of the total energy used in open-pit mining; these include auxiliary mobile equipment that consumes diesel fuel, gasoline, and lube oil; electrical pumping for pit dewatering; reclamation equipment such as scrapers, dozers, and graders, which use diesel and lube oil; and electrical sprinklers for revegetat ion.

[3]L. L. Gaines, *Energy and Material Flows in the Copper Industry,* Argonne National Laboratory, prepared for U.S. Department of Energy, December 1980.

[4]This estimate also includes the lube oil used by the trucks.

Figure 7-l. -Open-pit Mine Energy Use



Underground mines use electricity for generating compressed air, pumping, lighting, 'ventilation, and hauling miners and materials. They also use diesel fuel for surface hauling of ore to the mill. Approximately 155 pounds of explosives are used for every short ton of copper produced in underground mines. [5]

The average grade of the ore mined, the ratio of overlying dirt and rock (overburden) to the ore body (stripping ratio), and the depth of the pit

[5]Gaines, supra note 3.

below the surface rim all affect the amount and form of energy used in open-pit mining (and processing). There is a trade-off between energy conservation and resource recovery. The cut-off grade[6] used in mining determines: 1) how much ore and waste have to be transported, 2) how much ore is milled or waste is available for dump leaching operations, and 3) from the ore that is milled, how much copper is recovered and what volume of tailings is produced (see table 7-3).

The stripping ratio also affects where and in what form energy is consumed, because it determines how much material is handled as waste. In general, as the stripping ratio increases, the amount of mine energy per ton of cathode copper also increases. Similarly, as the pit depth below the surface rim increases, the vertical and horizontal distances that the waste rock and ore must be hauled also increases. This increase is reflected in greater energy use, primarily for hauling.

Much of the energy consumed in conventional hauling is used to move the heavy dump trucks, which are empty 50 percent of the time. Many mines today are replacing trucks with conveyer belt systems that run primarily on electricity. Truck haulage costs are around 4 times those of belt haulage costs.[7] One mine realized an energy savings of 30 percent with the partial use of conveyer systems.[8] Conveyers will not be feasible at all mines. **Because rock hauling accounts for such a large portion of the energy consumed in mining, however, it is one area where further research and development may result in large savings.**

optimization of the use of explosives for fragmentation versus increased crushing or grinding energy also can minimize energy use and lead to savings.[9]

Photo credit: Jacques LeGross

Hauling accounts for around 65 percent of the total energy used in open pit mining.

[6] As disusscd in ch 5, the cut-off grade is the mineral value that must be present in the ore for it to be mined and processed economically. Material below that grade is left in situ or discarded as waste.

[7] Assuming diesel fuel cost of 30 cents per liter and electricity at 5 cents per kWh.

[8] Robert J.M. Wyllie, "In-Pit Crushing Still Gaining Ground in Open Pit Mines," *Engineering and Mining Journal,* June 1987, pp. 76-80.

[9] See the discussion of comminution in ch. 6.

Table 7-3.—Effect of Varying Cut-off Grade[a]

Cut-off grade (% Cu)	Millhead grade (% Cu)	Tons milled (x 10’)	Million Btu/ton cathode copper produced			
			Mining	Concentrating	Refining	Total
0.00	0.45	26.600	17.4	53.7	35.2	106.3
0.22	0.50	23.515	18.3	47.5	35.2	101.0
0.29	0.55	21.070	20.1	42.6	35.2	97.9
0.34	0.60	19.086	22.2	38.6	35,2	95.9
0.40	0.65	17,444	24.7	35.2	35.2	95.1
0.45	0.70	16.061	28.1	32.4	35.2	95.8

[a] It should be noted that the possible recovery of metal by means of dump leaching is not included in this table.

SOURCE: Charles H. Pitt and Milton E. Wadsworth. An *Assessment of Energy Requlrernents in Proven and New Copper Processes,* report prepared for the US Department of Energy, contract no. EM-78-S-07-1743. December 1980

MINERAL PROCESSING

Grinding and concentration together consume about 45 percent of the energy used in the production of cathode copper. Assuming an ore grade of 0.55 percent and a recovery rate of **87.5** percent copper in the concentrate, concentrating 1 ton of copper ore requires over 200 billion Btu, or approximately 42 million Btu/ton of cathode copper.[10] Grinding accounts for roughly 60 percent of the total energy consumed in processing, and crushing 12 percent. Pumping new and recycled water, operating the flotation equipment, and regrinding and filtering account for the remainder.

[10]This includes the electrical energy to operate the equipment as well as the energy equivalent for the flotation chemicals, grinding media, and liners.

Crushing and grinding also consume a considerable amount of steel. The energy equivalent of these materials is sometimes included in energy analyses, and is about **6.4** million Btu. Similarly, flotation chemicals consumed have an energy equivalent of about 3.18 million Btu.

Two basic parameters affect the energy demand of processing mills: the amount of grinding needed to liberate the metal from the ore, and the hardness of the ore. The finer the grind, and the harder the ore, the higher the energy requirements. Hardness also dictates how much steel or other grinding media is consumed during ore processing.

present crushing and grinding processes are extremely inefficient in their use of energy. Only

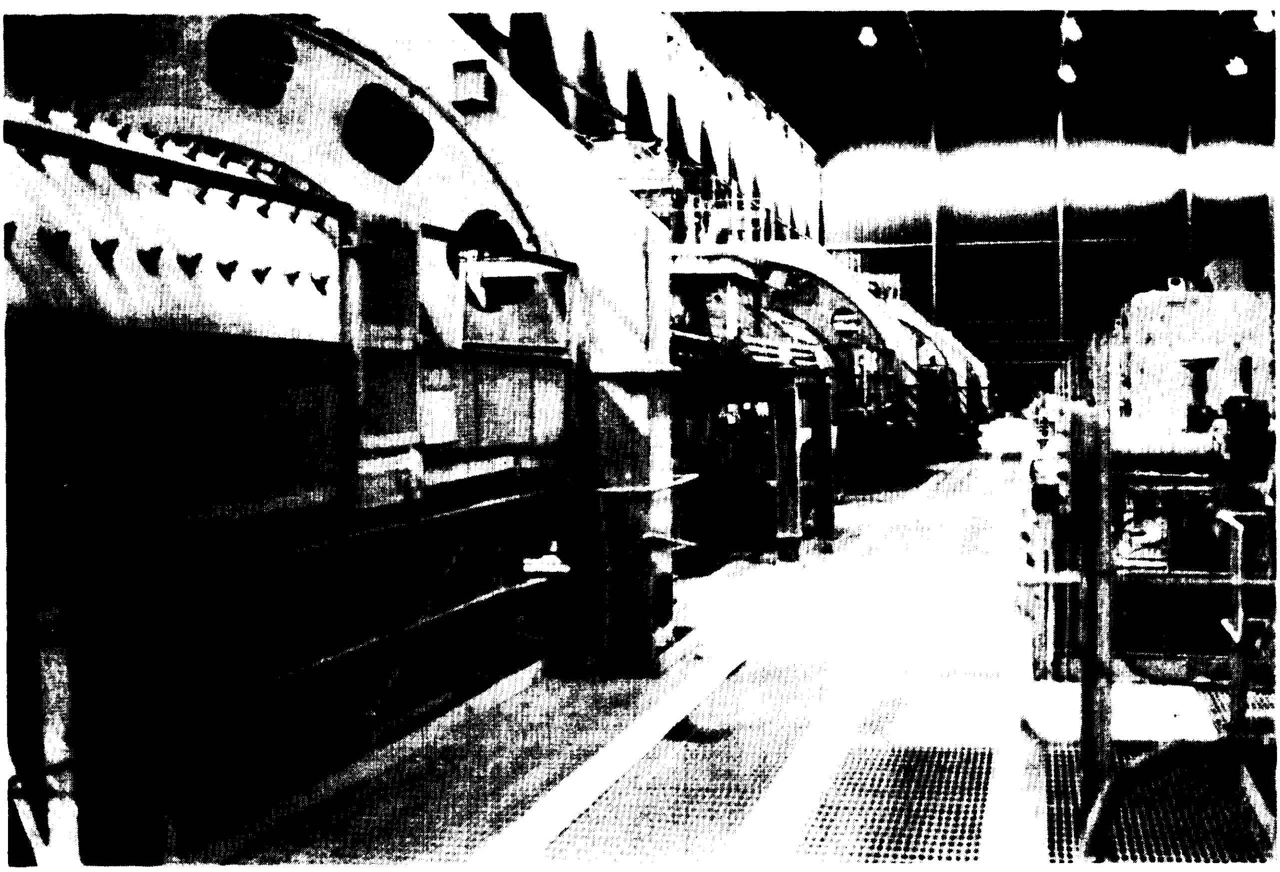


Photo credit: Jenifer Robison

Grinding accounts for approximately 60 percent of the energy used in milling.

1 to 2 percent of the energy input is used to create new surfaces on the mineral particles. Methods that could improve energy efficiency include installing automated controls (to optimize the throughput at a fixed energy input), using alternative types of grinding mills, and allocating energy among blasting, crushing, grinding and regrind ing.

Controlling the size and content of ore entering the plant can improve energy efficiency 5 to 10 percent. Additional improvements could be realized with better classification devices to avoid regrinding fine material. Development of integrated control strategies for the entire comminutier-dbeneficiation plant ultimately will lead to savings in both energy use and operating costs,

In some cases, steel grinding media can be replaced by pebbles or pieces of the ore itself **(autogenous grinding). Pebble** and autogenous grinding save materials costs, but are inefficient in direct energy use compared to conventional tumbling mills. The trade-off between materials conservation and energy efficiency is determined by the characteristics of the ore being processed and the difference between the prices of steel and energy. Therefore, the merits of autogenous or pebble grinding must be evaluated on a site-specific basis. Alternative grinding devices such as attrition mills which might have higher grinding efficiencies need additional research.

PYROMETALLURGICAL PROCESSES[11]

Energy requirements vary widely for the different pyrometallurgical processes. Table 7-4 compares the energy requirements for seven smelter types, including the energy equivalents of the materials consumed by each process. Flash furnaces make the most efficient use of the thermal energy released during the oxidation of sulfides; they generate sufficient heat to provide a large proportion of the thermal energy for heating and melting the furnace charge.[12] Although electric furnaces use electrical energy efficiently because of the low heat loss through the effluent gas, they make limited use of the heat produced during oxidation of the sulfide minerals, and their energy costs are high because of the high price of electricity.

Continuous smelting processes theoretically would be more energy efficient than conventional smelting and converting because heat loss in transferring the matte to the converter would be eliminated. The potential for heat loss in fugitive emissions also would be reduced. As noted in chapter 6, however, neither the Noranda nor the Mitsubishi process has yet proven truly continuous in practice. A genuine one-step process **could result in a savings of 10 to 20 percent of the energy used in smelting and converting.**

Although replacing an existing furnace is an expensive proposition, it is the surest way to cut energy consumption and control emissions. Most domestic smelters replaced their furnaces in the last 10 to 15 years, however. Thus, today's smelting energy conservation techniques rely on incremental improvements in fuel use, and on reducing heat loss.

Increasing the oxygen content of the air in the furnace is one way of improving fuel efficiency. oxygen enrichment results in more complete oxidation, and thus a more efficient transfer of heat from the gas to the charge. This lowers the fuel requirements for reverberatory, Noranda, and flash furnace smelters (see table 7-5). Because of the higher thermal efficiency, less heat is lost through the stack gases. Oxygen enrichment also reduces the amount of nitrogen in the combustion air; nitrogen is capable of carrying off about 20 percent of the heat input to a furnace.[13]

[11] pyrometallurgical recovery of copper Is its extraction from ores and concentrates through processes employing chemical react tons at elevated tern perat u res (see c h. 6).

[12] Chemical reactions that produce more heat than they consume are termed "exothermic"; smelt ing processes that are exothermic and do not req u ire addit 10 na I energy once the fu mace has been heated are called "autogenous."

[13] Gaines, supra note 3.

Table 7.4.—Energy Requirements for Pyrometallurgical Processes (million Btu/ton)

Process	Reverb- wet charge	Reverb- dry charge	Electric furnace	INCO flash	Outokumpu flash	Noranda reactor	Mitsubishi reactor
Materials handling	0.73	0.73		0.73	0.57	0.79	0.66
Dry or roast.		0.66	2.67	1.86	1.23	0.80	1.29
Smelting:							
Fuel	25.01	14.50			0.80	3.72	6.46
Electricity	0.64	0.64	19.03	0.05		1.26	1.58
Surplus steam	–10.00	–4,35			–3.43	– 1.82	–8.00
Converting:							
Electricity	1.63	1.26	2.92	0.94	0.64	0.37	1,42
Fuel	0.54	0.32	3.58			0.09	0.25
Slag Cleaning					1.49	1.31	1,35
Gas cleaning:							
Hot gas	4.03	2.83	0.78	0.59	0.42	0.69	0.86
Cold gas	0.25	0.40	2.21	0.31	0.21		0.32
Fugitive emissions	3,57	3.57		3.57	3.57	3.57	0.89
Acid plant	2.27	3.87	4.74	3.19	3.86	3.10	4,08
Water	0.10	0.10		0.10	0.10		0.10
Anode furnace	5.82	5.82	5.10	5.82	5.82	5.82	5.82
Materials:							
Miscellaneous					0.04	0.65	0.63
Oxygen				3.53	3.04	3.17	1.29
Electrodes			0.86				0.16
Fluxes	0.04	0.03	0.12	0.02	0.01	0,02	0.06
Water	0.08	0.08		0.08	0.08		0.08
Anode furnace	0.47	0.47	0.51	0.47	0.47	0.47	0,47
Total	35.18	30.93	42.52	21,26	18.92	24.01	19.77

SOURCE: Charles H Pitt and Milton E. *Wadsworth, An Assessment of Energy Requirements in Proven and New Copper Processes,* report prepared for the US Department of Energy, contract no EM-78-S-07-1743, December 1980.

Table 7-5.— Reduction in Fuel Consumption Due to Oxygen Enrichment

Process	Oxygen enrichment	Reduction in fuel consumption
Reverberatory.	27%	20%
Outokumpu flash	30-75%	autogenous[a]
INCO flash	95.99 %	autogenous[a]
Noranda	36%	34%
Mitsubishi	58.3%	84%

[a]Autogenous means that no additional fuel is required to maintain the melt. The furnace uses the heat evolved from the exothermic oxidation of the metal sulfides to melt the charge, Therefore, fuel is only required initially to start the oxidation reactions

SOURCE Charles H. Pitt and Milton E. Wadsworth, *An Assessment of Energy Requirements in Proven and New Copper Processes,* report prepared for the U S Department of Energy, contract EM 78-S-07.1743, Dec. 31, 1980

Waste heat is recovered from both flash and reverberatory furnaces and used to preheat the combustion air and/or to generate electrical power (cogeneration) to drive the blowers in the acid plant and blow air in the converters. Waste heat also can be used to dry the furnace charge before smelting, because moisture can carry off the heat in the furnace and increase fuel requirements. Drying also helps to homogenize the charge. Dryers usually are fueled with natural gas or oil and require from 1 to 3 million Btu/ton of cathode copper; using waste heat could save 0.7 million Btu/ton.

Roasting also dries the charge, and reduces the fuel requirements and effluent gas volume of the furnace. Like flash smelting, roasting can be an autogenous process that uses the exothermic heat generated by oxidation to continue the roast, so it does not require additional fuel.

Air Quality Control

Sulfur dioxide emission controls account for 6 to 11 million Btu/ton of cathode copper (see table 7-4). The hot gases from the roaster, smelting furnace and converter are cleaned separately to recover copper metal entrained in the dust. The gas streams are then combined and cold gas cleaning is employed to remove dust that might foul the acid plant. Methods and energy requirements for controlling fugitive emissions vary based on the type of furnace and the building enclosure, especially in the area of the converter aisle. The Mitsubishi reactor uses the least energy for controlling fugitive emissions because the molten matte transfer area is enclosed. Energy requirements for acid plants are a function of the gas volume and sulfur dioxide concentration (see ch. 8).

HYDROMETALLURGICAL PROCESSING[14]

Heap and vat leaching both require removal of the ore by conventional blasting and haulage (see ch. 6), and therefore would consume approximately the same amount of energy as mining, plus any electricity needed to pump the leach solution and the pregnant leachate. The main variables in the cost of pumping are the concentration of copper in the leachate (i.e., how much has to be pumped), and the vertical and horizontal distances between the leachate recovery area and the precipitation or solvent extraction facility.

Dump leaching exploits the waste remaining after conventional mining. Assuming that the costs are charged to the mining operation, dump leaching will have a relatively low energy cost. The energy is used primarily to drive the pumps, but can also include the energy equivalent of the chemical leaching solutions. Electricity for the pumps is estimated at around 13.5 million Btu/ton of cathode copper produced. In situ leaching energy consumption will vary depending on whether the ore needs to be drilled or otherwise fractured to provide enough permeability prior to pumping of the solution and leachate.

In dump leaching, energy savings can be achieved by optimizing the cut-off grade, taking into account the trade-off between conventional processing and leaching. potential energy savings using this strategy are estimated at 20 to 25 million Btu/ton of cathode copper. Also, improving aeration, maintaining even fracture and porosity in the dump, and making more efficient use of the natural heat given off during oxidation will increase leachate-mineral contact and improve oxidation. These steps could save 10 to 20 million Btu/ton of cathode copper by making the most of each cycle of the leachate through the dump and thus reducing the amount of pumping necessary to recover the copper.

The pregnant leachate is processed through either precipitation or solvent extraction. Solvent extraction[15] is an extremely low energy process. Precipitation of copper on scrap iron consumes a small amount of electricity (50,000 Btu/ton of cement copper) for pumping the solution through the precipitation cell. The scrap iron's energy equivalent has been estimated to be 45 million Btu/ton of cathode copper. The primary difference in energy cost between the two processes is that cathode copper can be produced directly from the electrolyte from solvent extraction, but cement copper usually must be smelted, converted, and fire refined before it can be refined into cathodes.

[14] Hydrometallurgy is the recovery of copper from ore using water or water-based chemical solutions (see ch. 6).

[15] Solvent extraction uses an active organic reagent that preferentially extracts copper ions from the leachate in order to increase the concentration of copper ions in the process solution

ELECTROMETALLURGY

Electricity is used to produce copper cathodes, either by transferring the copper from the electrolyte produced in solvent extraction onto cathode starter sheets (electrowinning), or by purifying copper anodes from smelting/converting by electroplating (electrorefining). Electrowinning uses around 24 million Btu/ton of cathode copper—the electrical energy required to overcome voltage differences in the electrowinning cells, allowing copper to deposit on the starter sheets.

Electrorefining (including fire refining) requires approximately 6 million Btu/ton of cathode copper produced.

Other hydrometallurgical techniques are used to process concentrates (rather than leaching ore). These methods are not competitive with state-of-the-art smelting/refining on the basis of energy requirements, primarily due to the difference in energy use in electrowinning versus electrorefining. Table 7-6 shows the total direct and electrowinning energy demand of various hydrometallurgical methods for processing concentrates, and indicates to what extent electrowinning affects the total energy used.

Reducing the energy required for electrowinning requires decreasing the cell voltage while simultaneously maintaining a high current efficiency.[16] There is a critical current density at which an acceptable cathode deposit can be expected. If this value is exceeded, the cathode becomes less dense, less pure, rough, and in general unacceptable as a commercial product. The critical current density can be increased by bubbling air through the cells (or other means of agitation).[17] Periodically reversing the current also can improve energy use (see ch. 6).

Electrowinning copper from cuprous (Cu^{+}) as opposed to cupric (Cu^{++}) electrolytes is another means of reducing the energy demand. Cuprous electrolytes have shown an energy savings potential of 70 percent. They exhibit performance problems, however, primarily with regard to inadequate separation of impurities, and the cathodes are of lower quality than those from conventional electrorefining or electrowinning.

[16] W.C. Cooper, "Reduction in the Energy Requirements in Copper Electrowinning," *Metall*, vol. *39, No,* 11, November 1985, pp. 1049-1055.

[17] Ibid.

[18] Alan P, Brown et al., "The Electrorefining of Copper from a Cuprous Ion Complexing Electrolyte," *Journal of Metals*, July 1981, pp. *49-57, see* also Cooper, supra note 16.

Table 7-6.—The Direct and Electrowinning Energy Demand of Selected Hydrometallurgical Processes for Treating Concentrates

Operation or process	Direct energy requirement (10^6 Btu/ton cathode Cu)	Materials energy equivalent (10^6 Btu/ton cathode Cu)	Electrowinning energy requirement (10^6 Btu/ton cathode Cu)	Electrowinning energy as percent of the total energy demand
Arbiter ammonia leach[a b]	37.9	24.2	24.0	38.60/o
Roast leach electrowin[ac]	28.8	1.6	22.4	73.6
Cymet ferric chloride leach[c]	23.8	7.1	NA	
Sherritt-Cominco [c]	38.7	9.4	24.0	49.8
Nitric-sulfuric acid leach[b]	62.4	12.1	24.2	32.4
Electroslurry-Envirotech	31.2	8.4	19.4	48.9
Roast/sulfite reduction	17.8	5.9	NA	
Ferric sulfate acid leach[b]	39.4	10.1	25.7	51.9

MM = million
NA indicates that electrowinning is not part of the process
[a]Processes that have been used Commercially.
[b]All hydrometallurgical processes
[c]Combination processes, using both pyrometallurglcal and hydrometallurgical steps

SOURCE Charles H. Pitt and Milton E. Wadsworth. *An Assessment of Energy Requirements m Proven and New Copper Processes,* report prepared for the U S Department of Energy. contract no EM-78-S-07-1743, December 1980