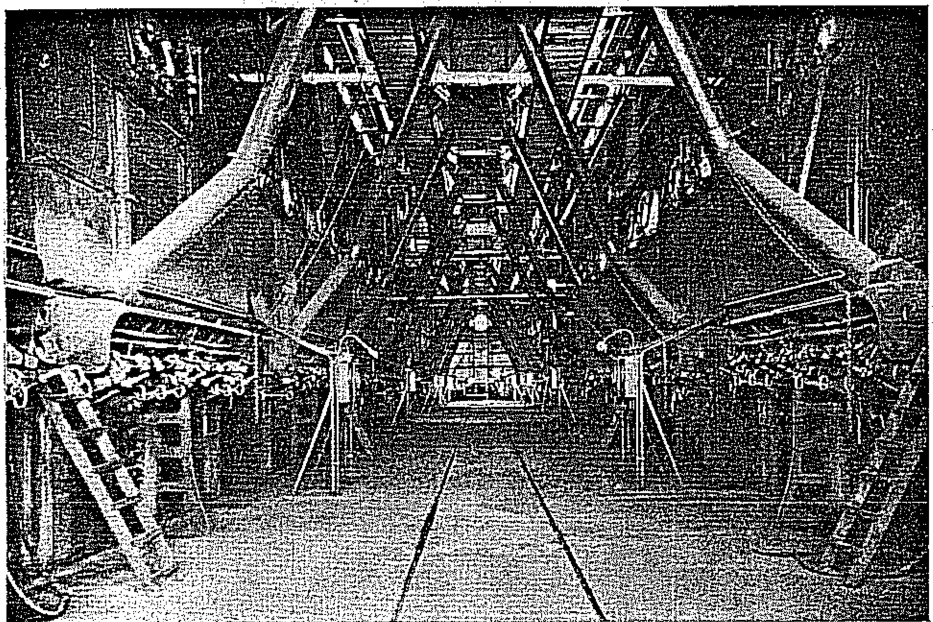

Figure 1. Boiler house at Lake Linden

Electric Power Generation

By
Robert McIntosh* and **A. L. Burgan†**

ELECTRIC power used by the Calumet & Hecla Consolidated Copper Company is generated by steam turbines at its mill and smelter plants. These are located along Torch Lake, which gives good condensing water facilities. The coal dock is adjacent, and a canal connecting to Portage Lake and through this to Lake Superior makes the dock accessible to all lake steamers. Thus excellent West Virginia coal is available at a low freight rate. These factors, together with economy resulting from the use of exhaust and process steam and waste heat, make for a low cost of power.

Power is generated at 25 cycles, 3 phase, with 13,600 volts on outside and interconnecting lines. There are eight turbines arranged to operate in parallel as one system. Their total generating capacity is 31,800 kw. at 80 percent power factor, or about 40,000 kva. They are located as follows:

At the LAKE LINDEN POWER PLANT

No. 1 turbine—8,000 kw. mixed pressure.
No. 2 turbine—9,000 kw. mixed pressure.
No. 3 turbine—2,000 kw. low pressure.

In the Still House at Lake Linden

No. 4 turbine—1,250 kw. back pressure.

At the SMELTING WORKS

No. 5 turbine—800 kw. on waste heat boilers.

At the AHMEEK MILL

No. 6 turbine—2,000 kw. low pressure.
No. 7 turbine—1,250 kw. back pressure.
No. 8 turbine—7,500 kw. high pressure.

The kw. ratings given are for 80 percent power factor and 40 degrees Centigrade temperature rise with the exception of turbines 4, 7 and 8, which are rated for 50 degrees rise.

At the Lake Linden boiler plant, built in 1908, there are 24 512-hp. Babcock and Wilcox boilers. (*Figure 1.*) Roney stokers are used with natural draft. Coal is delivered in railroad cars over a hopper leading to a link-belt double-roll crusher. It is crushed to 1 in. size and delivered to overhead coal bunkers by a Peck carrier. Each boiler is fed by a separate chute from the bunkers. The ash pits discharge to launders below them, pitched ¼ in. per foot, through which the ashes are flushed to a central sump. Coarse clinker is crushed through grate bars at the top of the sump box to prevent choking the cen-

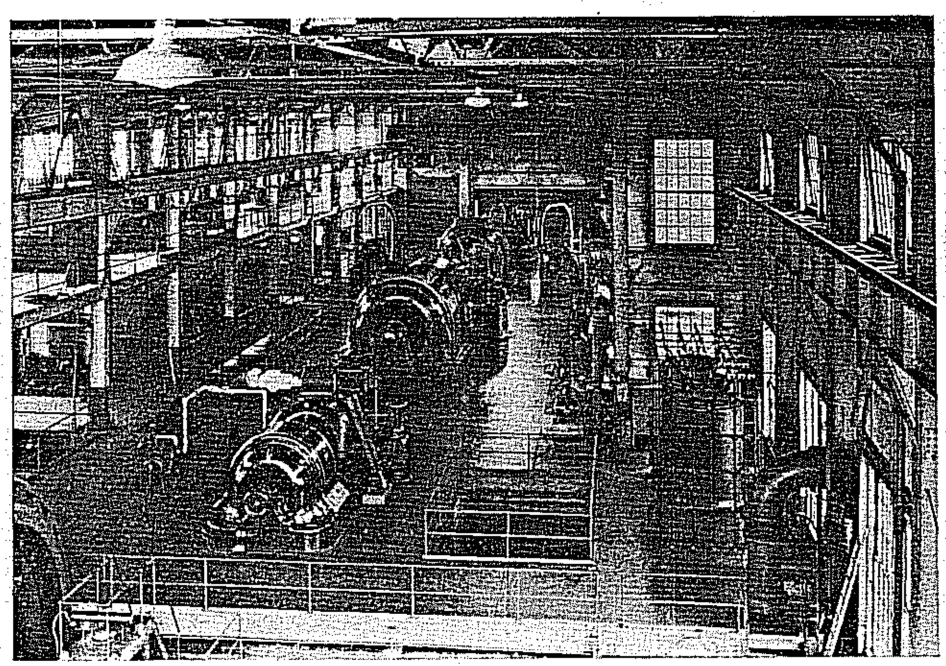

Figure 2. Power plant at Lake Linden

* Mill Superintendent—Lake Linden Plants.
† Mill Superintendent—Ahmeek and Tamarack Plants.

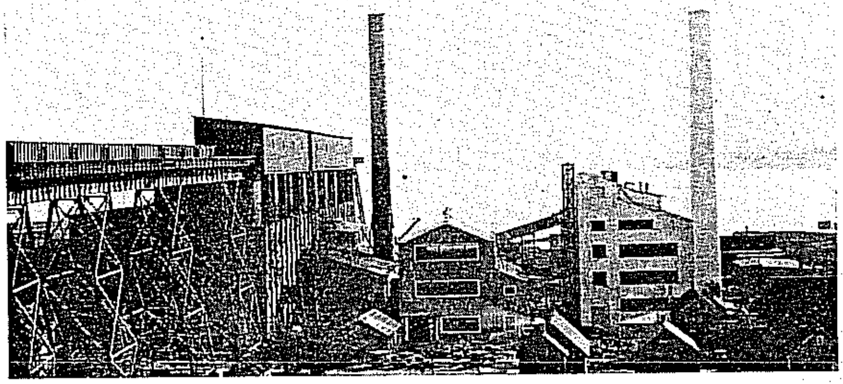

Figure 3. Ahmeek Mill and Power Plant, looking east. Above the concrete are the steel ore bins served by a double track. Coal chutes under the rear track lead to coal bins built into the concrete supporting structure.

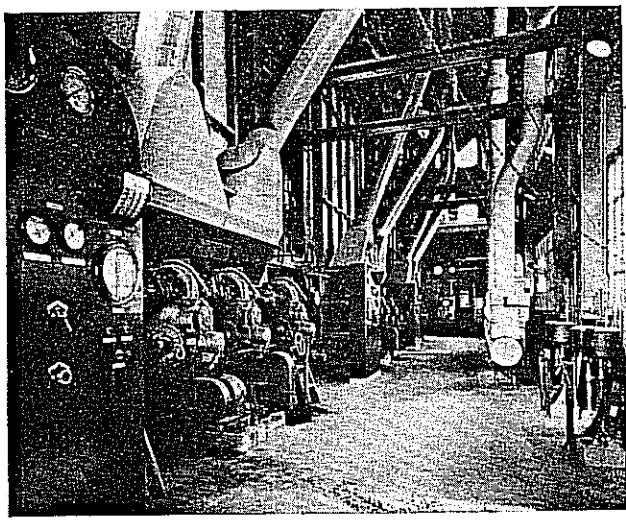

Figure 4. Ahmeek Mill Boiler House. Operating floor showing stokers, main steam piping and control panels.

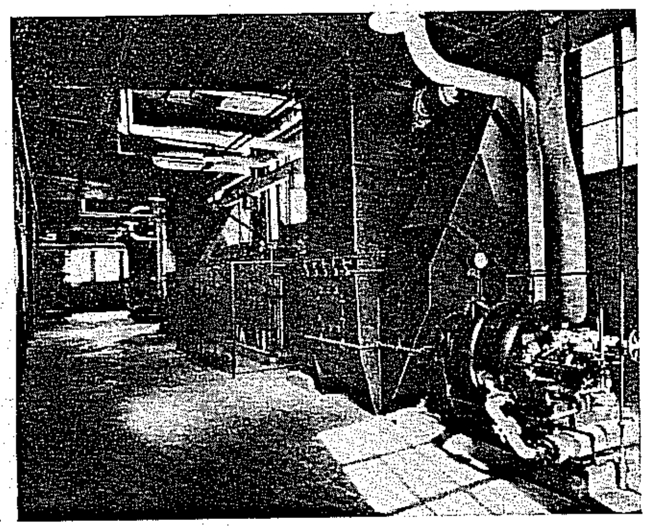

Figure 5. Ahmeek Mill Boiler House. Forced draft fans with steam turbine drives.

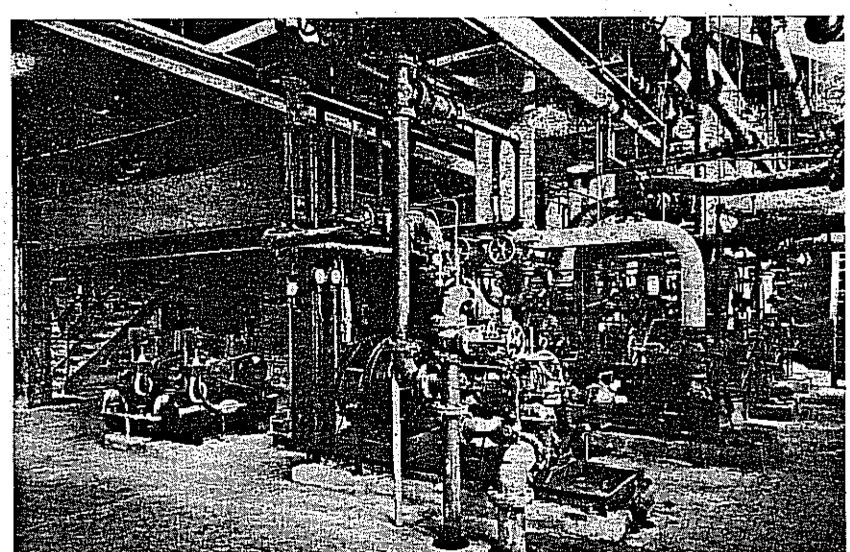

Figure 6. Ahmeek Mill Boiler House. Control compressors, ash pump and boiler feed pump.

trifugal pump which delivers the ashes to a sand-wheel to be disposed of with mill tailings.

Feed water is largely condensate from the surface condensers of the turbines and general heating system drains. Steam used for leaching and distillation in the ammonia leaching process is necessarily lost from the system so that considerable make-up is required. Raw Lake Superior water is used for this purpose. Cold feed water is circulated through ammonia condensing and cooling apparatus in the still house, accomplishing the necessary cooling without waste of mill water and substantially raising the feed water temperature. This is then brought up to about 200 degrees F. in open feed water heaters taking exhaust steam from the boiler feed pumps and steam stamps.

Each boiler is equipped with soot blowers which are operated at 8-hour intervals. After four or five weeks of service boilers are cut out for external washing and furnace repairs, and on alternate washings the tubes are turbined for scale removal.

Steam is generated at 180 lbs., at which pressure it is supplied through an 18-in. pipe to the turbines in the power plant and through an 8-in. pipe to the still house turbine. Steam for steam stamps, pumping, heating systems, and leaching, passes through a reducing valve set at 140 lbs., thence through a 24-in. pipe to the mills. Flow meters in each of these mains give the basis for steam charges to power, mill purposes and distillation. Each boiler is equipped with a Bailey meter, recording steam flow, air flow, and flue gas temperature, and indicating draft over the fire.

The power house, (*Figure 2*) separate from the boiler house, contains two Allis-Chalmers mixed-pressure turbines of equal size connected to generators of 8,000 and 9,000 kw. capacity, respectively, and one General Electric 2,000 kw. low-pressure turbine. The low-pressure turbine is connected to an independent 6-in. high-pressure steam line from the boilers for use should its power be needed when low-pressure steam is not available. Old reciprocating units which the turbines replaced have been removed, two of their generators being retained for use as synchronous condensers.

TABLE 1

	Kwh.	Percent of total
Lake Linden plant from high-pressure steam	101,053,000	76.0
Lake Linden plant from stamp exhaust	10,750,000	8.1
Lake Linden still house from process steam	2,763,500	2.1
Smelting Works waste heat	5,686,800	4.3
Ahmeek mill stamp exhaust	12,746,200	9.5
Total	132,999,500	100.0

The two mixed-pressure turbines each have a h'gh- and a low-pressure cylinder,

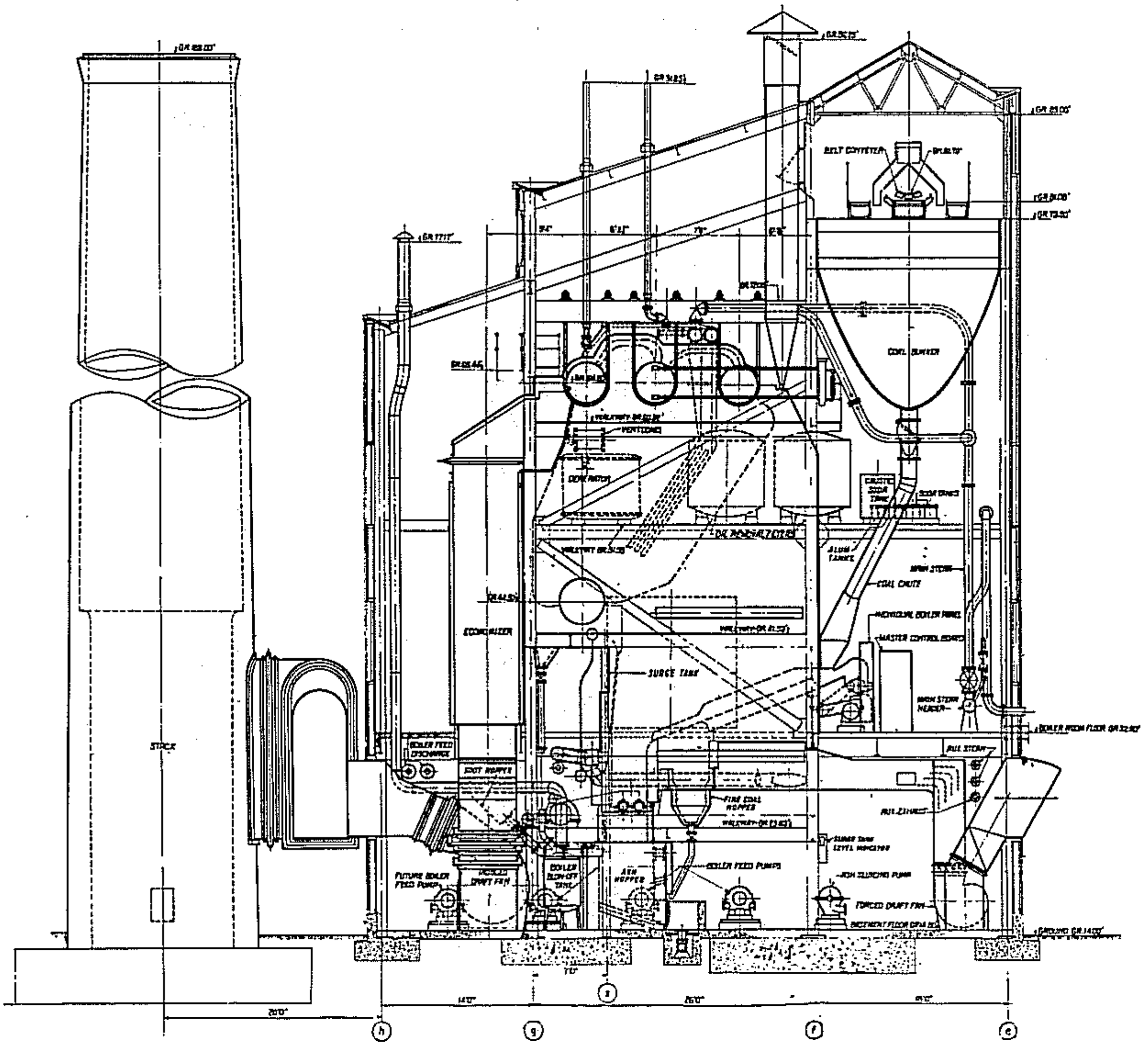

Figure 7. Ahmeek Mill Boiler House. Cross section.

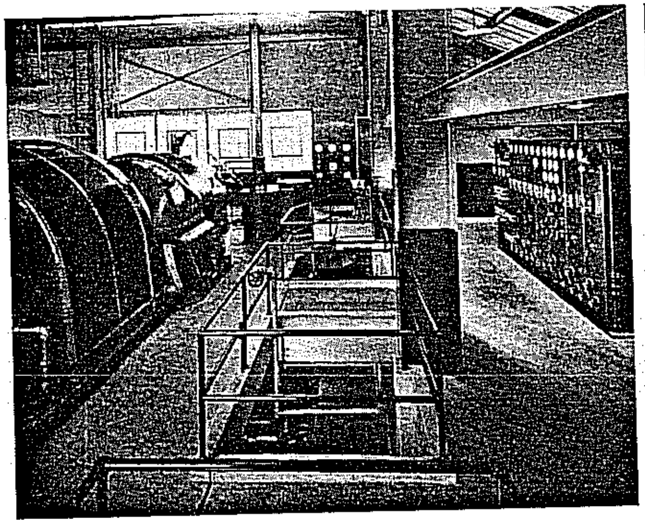

Figure 8. Ahmeek Mill Power House. No. 8 steam turbine generator unit with its 13,600-vold switchboard.

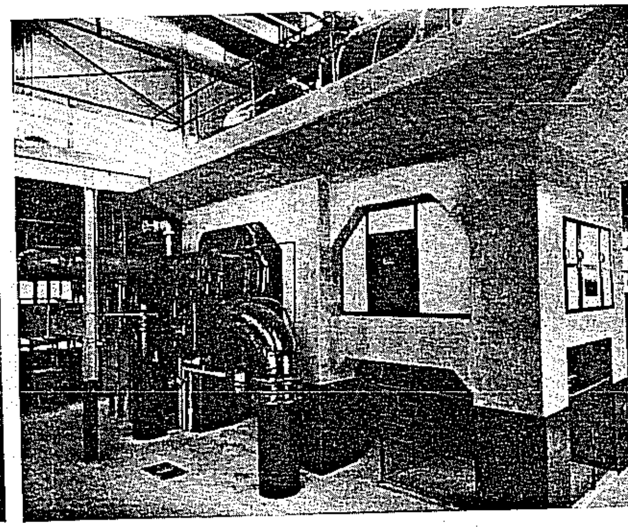

Figure 9. Ahmeek Mill Power House. No. 8 turbine room, showing reinforced concrete turbine foundation and condenser.

the high-pressure cylinders operating on boiler pressure of 180 lbs. and exhausting to receivers connected to the low-pressure cylinders. Exhaust from the steam stamps also comes to the low-pressure cylinders through a 36-in. pipe from the mill. Pressure in this line is maintained at about 1 lb. above atmosphere by flow regulating valves at the turbines, to insure against leakage of air into the system. This 36-in. pipe acts as a low-pressure steam reservoir into which comes exhaust steam from the stamps, high-pressure turbine cylinders, feed pumps, and if required, part of the exhaust from the still house turbine. From it steam is taken for the low-pressure cylinders of the turbines, feed water heating and the heating systems of the main mill buildings. When stamps are not operating, low-pressure steam for heating is still available from the mixed-pressure turbines which then act as bleeder turbines.

Circulating water is taken from the mill pumping system. The pump house is located at the shore of Torch Lake about 800 ft. distant from the power plant with the mills between them. The pumps in regular use there are a 30-in. Alberger centrifugal pump, motor driven, with a capacity of 40 million gallons per day, and the pump Michigan which is a triple expansion reciprocating steam pump of 60 million gallons per day capacity. Both operate against a total head of 60 ft. and either can supply water for condensing or mill purposes. Condensing water used in the power plant is returned for mill use by a 30-in. motor driven centrifugal pump.

Located in the still house is a 1,250 kw. DeLaval geared turbine unit receiving steam at 180 lbs. and exhausting at 18 lbs. above atmosphere, as required for use in distillation of copper-ammonia solution from the leaching plant. Its purpose is to utilize for the production of power the necessary drop in pressure. The amount of power produced depends upon the demand for steam by the stills and is controlled by a pressure governor on the exhaust side of the turbine. Speed is fixed by synchronous operation with the main power system. Operation of the stills on this exhaust steam has been quite satisfactory and is better than when the necessary pressure reduction takes place by throttling. Steam used by the stills does not fully load the turbine and provision is made to bring it up to capacity by passing more steam than the stills require and returning the excess exhaust to the low-pressure steam system to be used in the low-pressure cylinders of the turbines in the power plant.

At the Smelting Works a Westinghouse 800 kw. turbine operating at 150 lbs. pressure, condensing, is supplied with steam from waste heat boilers. Two melting furnaces discharge their hot gases through 800 and 396 hp. boilers respectively and two refining furnaces each have a 396 hp. boiler. Steam is thus available for power and heating purposes most of the time and two of the boilers can be fired independently if required. This is not ordinarily done for power generation because at times when steam from waste heat is not available power can be taken from the general system at less cost.

At the Ahmeek mill exhaust steam from the stamps goes to a 2,000 kw. low-pressure turbine, which may also be operated by high-pressure steam under governor control.

The 1929 records show the gross output of the system 132,999,500 kwh. That year is representative of recent operation without the new units at the Ahmeek mill which have been operating but a short time and under unfavorable load conditions. Power supplied by the various units was as shown in Table I.

The first item, 76 percent, represents output by fuel burned primarily for power generation. The other four items amounting to 24 percent of the total show the amount of power developed as a by-product of the milling and smelting operations. The units supplying by-product power necessarily operate to suit the work of the plants at which they are located. The Smelting Works and Still House turbines are not depended on to follow power demand, but they effect a substantial saving in coal, amounting to about 6,000 tons in 1929. The output of the turbines from stamp exhaust follows demand closely since it is about equal to the amount of power used for mill operation, and is always supplied when the mills work.

Steam stamp economy is not more than 10 or 15 percent better with condensing than with non-condensing operation. Experience at the Ahmeek mill showed an increase in steam consumption for the entire plant of 8,000 lbs. per hour when the change was made from operating stamps condensing, to operating them non-condensing and generating electricity with their exhaust steam. The exhaust steam turbine generated 2,000 kw. with an increase in steam consumption for the whole system of only 8,000 lbs. per hour, equilavent to 4 lbs. steam per kwh. produced.

New Power Plant—Ahmeek Mill

The Ahmeek Mill power plant, at this writing in operation only four weeks, was designed to generate 8,750 kw. and in addition, to supply 80,000 lbs. of steam per hour to the mill at 160 lbs. pressure to take the place of a boiler house in need of replacement.

The scheme adopted after careful consideration and in consultation with Stone & Webster Engineering Corporation, was to make steam at 425 lbs. pressure and 200 deg. superheat, to generate 7,500 kw. with boiler pressure steam direct to a condensing steam turbine unit, and 1,250 kw. from a high-pressure turbine generating unit acting as a reducing valve, and supplying steam at 160 lbs. pressure for the mill.

Freedom from interruption of service being of paramount importance, the boilers were installed of such size that although all three boilers are normally in use, two can carry the load.

Auxiliaries common to all three boilers are in the west end of the boiler house, and large enough to serve a fourth boiler. The east end of the building is constructed to provide possible extension for a fourth boiler should the future make such an addition desirable.

Buildings

Both the boiler house and the 7,500 kw. turbine room are of steel frame covered with galvanized corrugated iron over 2 in. matched wood sheathing with paper between. Steel sash with hinged windows and roof ventilators furnish light and ventilation. The roofs are of

CALUMET AND HECLA CONSOLIDATED COPPER COMPANY

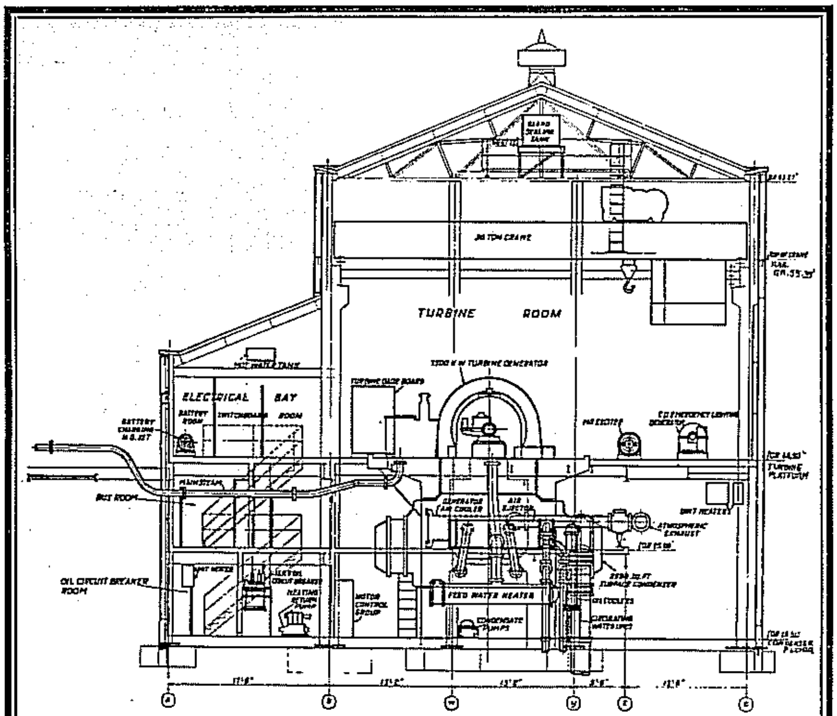

Figure 10. Ahmeek Mill Power Plant. Cross section, mechanical equipment.

precast gypsum supported on steel framing and covered with 4-ply composition roofing. The inside walls are finished with cement plaster on metal lath. Concrete piling supports all columns of buildings and conveyor as well as the foundations for turbines, boilers, and stack.

The turbine building is equipped with a traveling crane designed for a 30 ton normal load, and 47½ ton occasional load. The necessary heat in this building is provided by unit heaters, the condensate being returned by pumping to the turbine condensate pipe line.

Figure 3 gives the general layout of buildings and their relation to the mill.

Coal Handling

Existing coal bins which served the old boiler plant are utilized. They are incorporated in the concrete structure which supports the mill rock bins about 55 ft. above the ground. Coal is delivered in 22-ton cars over the company railroad and dumped from the rock service track through hoppers and chutes into the bins.

From the bins coal runs by gravity to a 24-in. apron conveyor traveling east 12 ft. per minute, which conveyor delivers the coal to a 26-in. by 24-in belt driven 2-roll crusher. The crusher drops the coal in sizes 1½ in. and smaller to a troughing belt conveyor traveling south. This belt is 170 ft. between centers, is 20 in. wide and inclined at an angle of 18 degrees. It in turn delivers the coal to another similar conveyor, 213 ft. centers, traveling west over the suspended bunkers in the boiler house and distributes the coal by means of a tank type tripper.

Boilers

The boiler house equipment is designed to furnish at normal load 180,000 lbs. of steam per hour at 425 lbs. pressure, 200 degrees superheat, corresponding to a temperature of 675 degrees. Deducting the steam used by auxiliaries, about one-half is for mill purposes and the other half for power generation.

There are three 8,955 sq. ft. Stirling, 4-drum boilers built for 450 lbs. pressure. Each is provided with superheater, soot blowers, 5,800 sq. ft. economizer and stoker. The stokers are the single ended 7-retort, 38-tuyere underfeed type with double roll clinker grinder and coal hopper agitator. The stokers are driven by individual steam turbines using boiler pressure steam and exhausting at about 5 lbs. pressure. They are equipped with hand and automatic speed regulators.

Each boiler has a turbine driven forced draft fan and a motor driven exhaust fan. This latter may be operated at either of two speeds, being coupled to two motors, one at either end, with speeds 710 and 460 r. p. m., respectively. The forced draft fan has a capacity of

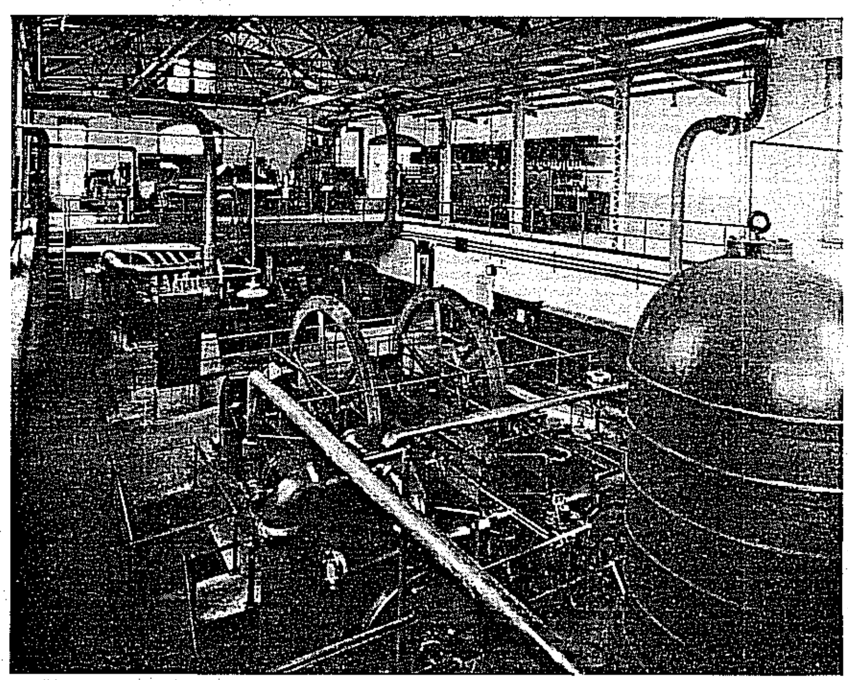

Figure 11. Ahmeek Mill Pump and Turbine Room. In the foreground is the 28,000-g. p. m. triple expansion reciprocating pump. On the same floor is the No. 7, 1,250-kw. reducing turbine unit and the by-pass reducing valves. In the rear is the No. 6 2,000-kw. exhaust steam turbine unit and the 2,300-volt switchboard.

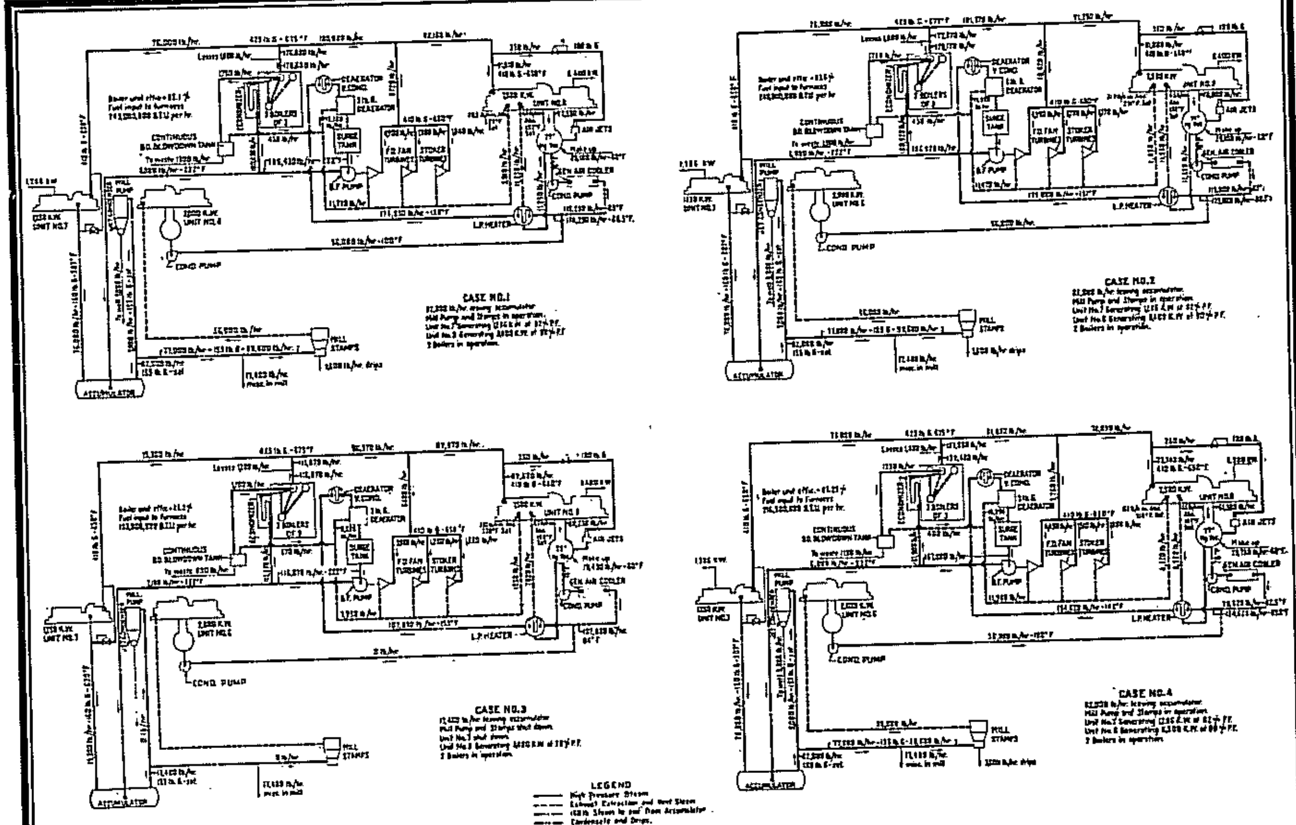

Figure 12. Heat Balance Diagram. Piping system, Power Plant, Ahmeek Mill.

40,000 c. f. m. against a static pressure of 9 in. of water. The exhaust fan capacity against the same head is 70,000 c. f. m. at 710 r. p. m. and 35,000 c. f. m. at 460 r. p. m. The exhaust fans deliver to the stack which is of reinforced concrete 12 ft. inside diameter and 175 ft. high.

Three 450 g. p. m. four-stage centrifugal boiler feed pumps direct connected to steam turbines and with duplicate water lines to economizers are provided, one pump having sufficient capacity to serve all three boilers at normal load of 180,000 lbs. of steam per hour.

Figure 4 gives a view of the main steam piping, stokers and control panels. *Figures 5* and *6* show the forced draft fans and feed pumps. *Figure 7* is a cross-section of the boiler house which gives the general layout.

Combustion Control

By means of combustion control equipment the boiler uptake draft and the quantities of air and fuel supplied to the furnace are adjusted to suit the load on the boilers. As the load varies, the pressure in the main steam header changes, slightly, actuating a master controller which changes the settings of the three induced draft controllers, one for each boiler. These in turn adjust the uptake draft dampers and the settings of the stoker turbine speed governors. Furnace pressure controllers actuated by the master controllers operate to hold constant furnace pressure by adjusting the forced draft dampers. This maintains main header pressure within 5 lbs. above or below normal. Compensating relays permit of adjusting the relative load on the different boilers at the will of the operator or of holding any boiler at a fixed load while the other boilers take the load changes.

Ash Handling

Airtight ash hoppers 12 ft. by 5 ft. by 8 ft. deep are built directly under the clinker grinders and reach to the boiler house floor which is at surface grade. Hand-operated water nozzles direct streams of water which sluice the ash through doors at the floor level into the hydraulic system. The hydraulic system consists of 560 ft. of 8-in. hard white cast-iron pipe and fittings laid under the boiler house floor in front of the ash hoppers, and continued in a concrete trough just below surface grade to the mill slime tailings pump. The sluicing nozzles located at proper points along the line of 8-in. pipe are supplied by a 600 g. p. m. motor driven pump, at 160 lbs. pressure. Fifteen tons of ash per hour can be handled.

7,500 Kw. Turbine

The 7,500-kw. unit operates at 1,500 r. p. m. and takes steam at 425 lbs. pressure and 650 degrees temperature. Three extraction nozzles are provided for heating the condensate and make-up water for boiler feed.

Condensing equipment consists of an Ingersoll Rand suspended two-pass, single compartment surface condenser, with 2-stage steam-jet air ejector. A horizontal double suction motor driven pump located in the mill pump house furnishes 11,000 g. p. m. circulating water required by the condenser. The 30,000 g. p. m. required by the Ahmeek mill is pumped from a well which is fed at its south end by gravity from Torch Lake. The 11,000 g. p. m. circulating pump takes its water from the south or inlet end of this well and when the mill pumps are running, which is 80 percent of the time, the circulating water discharge from the condenser returns to the north end of the well below water, to eliminate static head on the pump. The excess water required by the mill pumps over the amount taken by the circulating pump assures condensing water of lake temperature. When the mill pumps are not operating, the circulating water from the condenser is by-passed to Torch Lake.

Figures 8 and *9* show the turbine with its auxiliaries and switchboard, and *Figure 10* is a cross-section of the plant showing the general arrangement of turbines, auxiliaries and switchboard.

1,250 Kw. Turbo-Generator-Reducing Valves-De-Superheater

The Ahmeek mill requires 80,000 lbs. per hour of dry saturated steam. A 1,250-kw., back-pressure unit is used to reduce the boiler pressure of 425 lbs. to

165 lbs. The turbine running at 4,500 r. p. m. operates the generator at 750 r. p. m. through reduction gears.

The exhaust steam from this turbine carries about 140 degrees of superheat. When the mill is shut down or if for any other reason the 1,250-kw. turbine is not running, the necessary steam for the mill is by-passed. Three by-passes are provided; one 4-in. with hand control, and one 4-in. and one 2-in. with regulators set to hold a constant pressure slightly under the back pressure of the turbine. When all the mill steam is taken through the by-passes, its superheat is 250 degrees as compared with 140 degrees in the turbine exhaust.

As the mill machinery is not adapted to the use of superheated steam, it is necessary to use a de-superheater to give dry saturated steam for mill purposes. This is of the accumulator type, 8 ft. in diameter by 30 ft. long. It requires for de-superheating approximately 6,500 lbs. of water per hour when the turbine furnishes the steam and about 12,000 lbs. per hour when steam is taken through the by-pass system. About 3,000 lbs. per hour of the de-superheating water returns by gravity to the accumulator as condensates from steam stamp re-heaters and main steam lines.

Figure 11 shows the turbine together with the by-pass equipment. It also shows the exhaust steam turbine and 2,300-volt switchboard as well as the Nordberg 28,000 g. p. m. mill pump.

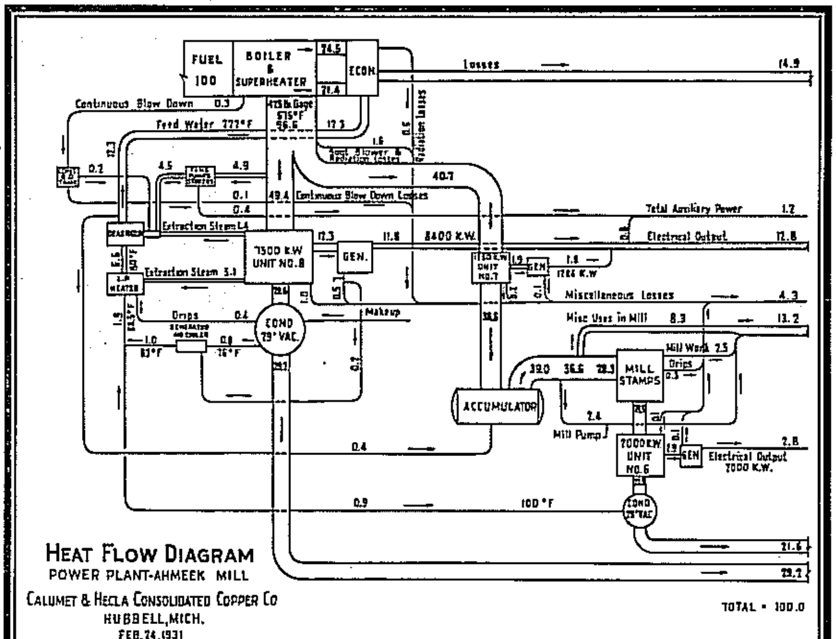

Figure 13

Feed Water

Under normal conditions the boiler feed water is made up of approximately 50 percent condensate from the 7,500-kw. unit, 35 percent from the 2,000-kw. exhaust steam unit, and 15 percent Lake Superior make-up water.

Water is pumped from Lake Superior for boiler feed and domestic purposes. To protect against lengthy interruption of this service, occasionally of 24 hours duration, a reservoir is provided at a convenient elevation a few hundred feet from the boiler house. It has a capacity of 350,000 gallons, sufficient to take care of make-up for 96 hours. A float valve on the inlet keeps the reservoir full.

The make-up water enters the condenser of the 7,500 kw. turbine and is pumped with the condensate through the generator air cooler, adding a few degrees to the water temperature. The condensate from the condenser of the 2,000 kw. turbine then joins the water coming from the air cooler and passes through a closed heater supplied with steam at 2 to 3 lbs. absolute from an extraction nozzle on the 7,500 kw. turbine. This feed water now at a temperature of 125 deg. F. passes through a deaërator vent condenser and a vertical cylindrical deaërating heater in the boiler house. The steam for the deaërating heater consists of the exhaust from the turbines driving the boiler feed pumps, forced draft fans, and stokers, supplemented by additional steam at 3 to 6 lbs. gauge pressure from an extraction nozzle on the 7,500 kw. turbine. The water leaving this equipment at 220 deg. flows to a surge tank and then to the boiler feed pumps from which it passes through the economizers, entering the boilers at a temperature of 330 deg.

A 10,000-gal. surge tank is provided with an upper float valve which controls the flow of make-up water entering the condenser of the 7,500 kw. unit by admitting just the amount necessary to maintain the surge tank water level below the overflow point. A second float valve about 4 ft. lower than the first provides for the control of make-up water direct to the deaërating heater when the 7,500 kw. turbine is idle, or if for any other reason that source of feed water fails. In this case the condensate from the 2,000 kw. turbine also is passed to the deaërating heater instead of entering the feed water system ahead of the closed heater in the turbine room.

Feed Water Treatment

The steam for the 2,000 kw. turbine being the exhaust from the stamps, the condensate from this turbine contains lubricating oil. This condensate represents 35 percent of the total feed water. Two pressure type sand filters with coagulent and alkali feeding equipment are used to remove this oil before it joins the rest of the boiler feed water.

To provide for the desired limitation of the boiler water concentration, a continuous blow-down pipe leading to a flash tank is placed in the middle upper drum of each boiler. The major part of the heat in the water so blown down is reclaimed by the steam flashing to the deaërating heater.

The Hall Laboratories system is used to control the chemical composition of the boiler water and to prevent the precipitation of dissolved solids in a form which would cause adherent scale on the boiler surfaces. Phosphate, which is fed direct to the boilers, by combining with the scale-forming elements in the feed water, forms finely divided insoluble phosphates which remain in suspension and are removed by blow-down. As this phosphate reduces alkalinity, caustic soda is added to maintain the proper basic condition of the boiler water to protect against corrosion, foaming, and caustic embrittlement. Sodium sulphate, which is fed into the surge tank, tends toward the same result. These measures, together with the deaërating heater, assure protection against impure water.

Instruments

Recording and indicating meters are used to furnish information for efficient operation of boilers and turbines as well as to determine the proper distribution of steam and power costs.

Counters on the stoker retort drive-shafts, when calibrated in service over a period of months, will permit of determining coal consumption rate for any boiler. This, together with steam flow integrating meters for each boiler as well as for total plant load, makes it possible to follow daily the plant or individual boiler efficiency.

Figure 12 gives the heat balance with four different sets of conditions as to mill and electrical load, and *Figure 13* is the heat flow diagram under full load.

Power Costs

Without interest and depreciation charges, exhaust steam turbine costs are under .20 cents per kwh. It is too early to give the power costs of the new turbines, but it is expected that these will be under .20 cents per kwh. for the 1,250 kw. unit, and under .33 cents per kwh. for the 7,500 kw. unit.

Stone & Webster Engineering Corporation started field work on this plant July 1, 1930, and seven months later, on February 1 of this year, the plant was in full service.

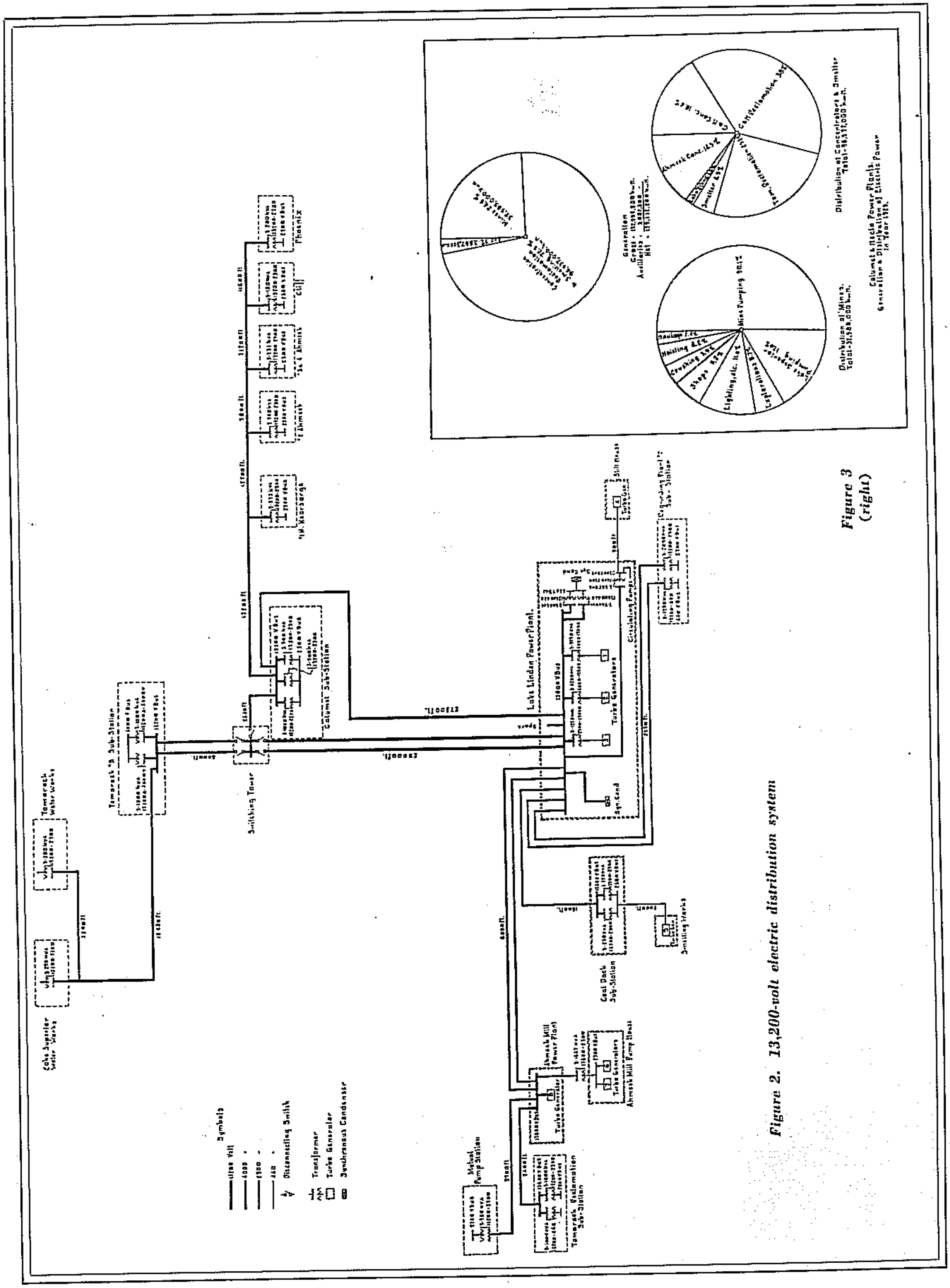

Figure 2. 13,200-volt electric distribution system

Figure 3 (right)