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OWLHEAD IRON DEPOSITS

PINAL COUNTY, ARIZONA

September, 1960

E. N. PENNEBAKER
CONSULTING GEOLOGIST
SCOTTSDALE, ARIZONA

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Submitted to Mr. M. R. Prestridge

September 7, 1960.

By E. N. Pennebaker

E. N. PENNEBAKER

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INTRODUCTION

An extensive occurrence of magnetite-bearing sands and gravels is found along U. S. Highway 80 between Tucson and Florence. This is approximately 45 miles northwest of Tucson and 25 miles southeast of Florence, where there are Southern Pacific Railroad connections arrived at over paved highways. The nearest railroad line, however, is at Red Rock, some 15 miles to the southwest, presently reached by a very poor dirt road. The town of Coolidge, near the Gila River and some 12 miles southwest of Florence, is a possible industrial site also served by the Southern Pacific Railroad.

A branch line of El Paso Natural Gas Company crosses the property, and electric power is also available.

The writer made a very brief inspection of a small part of this magnetite-bearing placer deposit on August 3, 1960, in company with Messrs. J. D. Madaras, Marnel Lindekugel and Pace Foster. This quick viewof the property was supplemented by study of two comprehensive reports. One of these, dated August 20, 1957, is by Mr. O. A. Sundness, an eminent iron mining engineer of many years' experience. This report covers shallow drill hole exploration of a small fraction of the magnetite-bearing ground, metallurgical testing of the samples, and an estimate of the tonnage revealed by this drilling.

A second available report is by Western-Knapp Engineering Company of San Francisco, dated May 25, 1960. This presents a study of metallurgical tests, economic factors, and plant design. It is based on test work by this company and results of pilot plant operations.

The following remarks are largely based on these reports and on discussions with Messrs. Madaras, Lindekugel, Foster and Sundness.

PROPERTY

At the time of the Sundness report (August 20, 1957), the property was stated to consist of 4,160 acres made up of sections 1, 2, 3, 4, 5 and 12, along with the north ½ of Section 11, in T8S; R12E Gila and Salt River Base and Meridian.

We are now advised that the property has been expanded to include all of T8S; R12E (some 23,000 acres) plus other adjacent holdings of about equal amount to give a total of around 43,000 acres, or about 70 square miles. The property now is said to be situate in Townships 7 and 8 South, Ranges 11, 12 and 13 East.

The writer was informed that this ground is held as unpatented association placer claims, of which 13,000 acres are covered by claims on State Land. This imposes a considerable annual financial burden for assessment work, the actual amount depending upon the precise number of claims involved. Probably this is in the neighborhood of not less than $20,000 to $25,000.

It is the writer's understanding that these claims are held by Southwestern Iron and Steel Industries, Inc., which corporation has recently leased these to Patrick Feeney and associates under the terms of the Supplement Agreement, a copy of which accompanies this report.

GEOLOGY

The "ore" in the area of interest consists of magnetite-bearing sand and gravel. It makes up an alluvial plain that is traversed by several large dry washes whose general course is westerly.

The material containing the magnetite is an unconsolidated, cross-bedded alternation of fine sand and fairly coarse gravel. As described by Sundness the magnetite was deposited "in a non-uniform and irregular manner with worthless, slightly moist.......silt, sand and gravel........" Magnetite occurs in rich streaks, layers and lenses where it is "dry, high grade, and free running......", making it very difficult to obtain an accurate sample. The magnetite is everywhere fine-grained. Pebbles in the gravel seldom exceed four inches in diameter.

The source area lies to the east, where mountains are composed of granite and schist that contain very minor amounts of magnetite. This has been freed by erosion and rock decomposition and carried westerly where it was concentrated and deposited in the area of interest. Here it occurs as irregular small bodies in sand and gravel in amounts that give a general average iron content of about 5% to the mixture, and the mixture is such that the entire body must be mined in order to win the magnetite.

One troublesome feature is the irregular cementation of parts of the sand and gravel by a limy material called "caliche".

As a result of his sampling procedure, Sundness advises that much of the ground sampled is of a hard, cemented nature. In addition to this, there is evidently a local, roughly horizontal hard cementation by caliche. This is reported from depths as shallow as 15 feet. The extent of its development in the area has not been determined.

Sundness reports that the magnetite-bearing sands are very dirty where encountered away from the washes. These impurities consist of attached particles of quartz and feldspar, and the magnetite grains are coated with earthy limonite no doubt derived by oxidation of the magnetite grains. Because of this a considerable amount of iron is lost in the treatment process, and the extent and variation of this contamination at depth has not been determined.

SUNDNESS' REPORT
EXPLORATION AND SAMPLE PROCESSING

EXTENT

The Sundness exploration campaign covered about 10 square miles where 57 holes were drilled, all but one to a depth of 28 feet, and generally sampled to a depth of 25 feet. These holes were located at ½ mile intervals on a grid 2 miles wide and running for 5 miles to the east. In addition there are 13 other holes drilled at random locations on the southwest.

DRILLING AND SAMPLING

It is evident that great care was exercised in the drilling and sampling of these holes under Mr. Sundness' supervision. Holes of 40-inch diameter were bored and then cased with slotted iron culverts, the samples being cut through these slots to prevent salting. The actual sample cutting was performed by a man lowered into the hole on a bosun's chair.

Sample intervals of 5 feet were employed, giving a sample volume of .555 cubic feet.

SAMPLE TREATMENT

Screening

The entire sample was weighed and then was put over a 6-Mesh screen. In this manner the coarser material, rarely four inches or more in diameter was discarded. The amount of material thus eliminated was determined by weight to be the following. This is a general average for the entire area tested.

	6-Mesh Oversize	6-Mesh Undersize	Total
Average	41.1% @ 3.03 % Fe	58.9% @ 6.53 % Fe	100.00 @ 5.09% Fe
High	44.7% @ 3.50 "	61.0% @ 6.96 "	
Low	39.0% @ 2.96 "	55.3% @ 7.81 "	

Thus about 40% of the material was eliminated from further handling. This reject contains a substantial amount of iron that can be recovered, but it has not yet been established that it can be done at a profit.

Density Determination

The weight per cubic foot of material in place was estimated to be as follows:

	Cu. Ft.
Average	120 lbs.
High	135 lbs.
Low	100 lbs.

It is stated that the density varies more with the physical characteristics of each 5-foot sample than it does with the iron content.

From the foregoing, Mr. Sundness derived the following general averages:

18.66 cu. ft. in places equals 1 long ton

16.66 " " " " " 1 short ton

There are 1.45 long tons in each cubic yard

There are 1.62 short tons " " " "

Moisture Content

The moisture content of the 6-Mesh undersize was found to be generally low, the average being 2.0%.

Rough Magnetic Recovery

The 6-Mesh undersize material was dried in the University of Arizona School of Mines laboratory. It was then subjected to dry magnetic separation to produce a "Dirty Concentrate" containing, if possible, all of the magnetic material in the 6-Mesh undersize. This gave the following results for the 10 square miles tested:

6-Mesh Undersize

	Magnetic Fraction	Non-Magnetic Fraction	Total
Average	13.8% @ 28.17 % Fe	86.2% @ 3.09 % Fe	100 @ 6.53 % Fe
High	16.4% @ 24.46 "	88.8% @ 3.23 "	
Low	11.2% @ 26.21 "	83.8% @ 3.36 "	

From this we determine that, on the average, 8.13% (13.8% x 58.9%) by weight of the total material in place goes into the "dirty magnetic concentrate". It will be noted that here we have a very substantial loss of non-magnetic iron (which has been determined to be in the form of limonite).

Further Grinding and Magnetic Separation

The "dirty concentrates" were ground to 80 and 150 mesh, and the products were further separated by the wet magnetic method, with the following average results for the total area tested.

Recovery From 80-Mesh Grind of the "Dirty Concentrates"

	Magnetic Concentrate Recovery	% TiO_2	% P	% S
Average	35.5% @ 65.68 % Fe	1.48	0.072	0.009
High	41.1% @ 66.62 "	2.00	0.084	0.028
Low	31.4% @ 64.74 "	1.01	0.063	0.006

From which we derive: 35.5% x 8.13% is 2.89% recovery of iron from total sand and gravel dug.

Recovery from 150-Mesh Grind of Dirty Concentrates

	Magnetic Concentrate Recovery	% TiO_2	% P	% S
Average	34.2% @ 67.18% Fe	0.86	0.047	0.007
High	38.4% @ 68.06% "	1.08	0.072	0.011
Low	28.0% @ 66.35% "	0.50	0.034	0.005

From which we derive: 34.2% x 8.13% is 2.78% recovery of iron from total sand and gravel dug, but the amount of contained titanium and phosphorus has been substantially lowered.

APPROXIMATE TONNAGE

Mr. Sundness states in his report (page 14), "With drill holes spaced ½ mile apart and samples taken to only 25 foot depth in this 10 square mile area, no accurate estimate of recoverable magnetite can be made. However, since some approximate figure must be developed", he arrives at the following approximation as a yard stick:

1 acre contains	43,560	sq. ft. of sand in place
to a 25 ft. depth	1,089,000	cu. ft. " " " "
@ 120 lbs/cu. ft.	130,680,000	lbs. " " " "
2240 lbs/long ton	58,339	tons " " " "
@ average magnetic recovery, as derived, 2.9%	1,692	tons magnetite @ 65% Fe
on 40 acres	67,680	" " " "
on 640 acres (1 sq.mi.)	1,082,880	" " " "
Area sampled (10 sq.mi.)	10,828,800 to 25 ft. depth	" " " "

In other words, this approximation indicates about 1 million tons of recoverable magnetite assaying 65% Fe for each square mile to a depth of 25 feet, based on the average magnetic recovery of 2.9%.

With a daily production of 1,000 tons of concentrate per day this amounts to a life of about 30 years.

A POSSIBLE OPEN PIT AREA

Mr. Sundness has selected an area in the southerly part of the 10 square mile area tested as being richer than the average and suitable for an open pit. The estimate here is for a recovery of 4.36% of magnetite vs. the general average of 2.9% (or about 97½ vs. ~~62½~~ 65 lbs. recoverable magnetite per long ton of sand and gravel in place). He estimates that this richer section will provide about 8 million tons recoverable magnetite from 5 square miles to a depth of 25 feet. At production rate of 1,000 tons per day of product, this would last for about 24 years.

SUNDNESS CONCLUSIONS

These are as follows:

1. His study has proved that this placer deposit contains a magnetite content of varying amounts, which can be processed by fine grinding and wet magnetic separation into a very desirable product with no deleterious components.

2. The continuity at depth has not been proved below 25 feet, but one hole that goes to 43 feet shows that iron units from 25 to 43 feet were nearly double the units from 0 to 25 feet.

3. No local supply of water has yet been developed.

4. It may be possible to recover some iron from the screened oversize, and tests should be made to determine the economic feasibility of treating this fraction.

5. An economic study should be made of the most desirable separation point in the screening operation.

WESTERN-KNAPP REPORT

Western-Knapp Engineering Company of San Francisco issued a comprehensive report under date of May 25, 1960. This presents a study of metallurgical tests, economic factors, and plant design. This report was available to the writer for a short time only, and the following conclusions and excerpts were taken from it.

The locality tested was apparently in the westerly part of the higher grade area pointed out by Mr. Sundness. Here Western-Knapp obtained a recovery of 71 pounds of iron per (short?) ton of ore treated, and its figures are based on this amount, whereas the Sundness general average figures are based on 2.9% recovery or 65 pounds of magnetite (47 pounds of metallic iron) per long ton. Consequently the Western-Knapp reserve estimate per square mile is much larger than the Sundness figure.

The Western-Knapp conclusions are quoted as follows:

1. The cost estimates show the following cost/ton of concentrate:

Concentrate Production Rate TPD	1000 Wet	1000 Dry	400 Wet	400 Dry	150 PILOT Wet
Treatment Cost	$3.67	$3.67	$4.5225	$4.52	$8.43
Haulage Cost	1.44	1.44	1.44	1.44	1.44
Depreciation & Interest	1.3827	1.27	1.8878	1.80	5.54
Total Cost	$6.4978	6.38	7.8503	7.76	15.41

a. While the dry plant shows a slightly lower total cost reflecting the least capital costs, treatment costs including the operating costs, labor and power are virtually the same for wet and dry cleaning plants.

b. The 1000 tpd wet cleaning plant requires the expenditure of about $370,000 for a 17 mile water line which is not required for the 1000 tpd dry cleaning plant. The increased costs of the ball mills and dryer for the dry cleaning plant just about equal the costs of the water line.

2. The costs shown above are for the recovery of 71 pounds of iron (Fe) per ton of ore treated. At the present prices quoted for iron ore the 1000 tpd treatment plant appears economically justified on the assumption the ore body contains 71 pounds of recoverable iron (Fe) per ton of ore. I wish to emphasize that an extended sampling program is required to determine the actual amount of magnetic iron present in the average ore body. The sampling and testwork conducted during March and April 1960 established this figure of 71 pounds of iron as the probable recovery possible for the 27,000 tons of ore treated. The sampling of this tonnage appears to be reliable. No attempt was made to thoroughly sample other parts of the ore body.

3. There does not appear to be any technical or mechanical problem related to treating the ore by the flowsheet 660-1G with final wet cleaning, except the possibility of wet ore during rainy periods. This water in the ore can and has, caused blinding of 5 mesh screens. Proper mining techniques can provide for draining any particularly wet ore in place.

With our present information concerning the occurrence of the ore, size distribution and moisture content, screening at 1/4" ahead of the rough magnetic separation is readily accomplished. The minus 1/4" undersize from the screens even though damp is amenable to treatment as outlined on flowsheet 660-1G, with final wet cleaning.

4. We have insufficient information to predict if the magnetite can be concentrated dry to give less than 1.0% TiO_2 in the finished product.

Wet final cleaning on laboratory scale has demonstrated that all the ores investigated can be concentrated to give a premium grade product containing from 0.54 to 0.91% TiO_2. Other impurities such as As, Cu, Ni, Pb, Zn, are virtually all rejected by the wet cleaning methods. Phosphorous is present to the extent of 0.05% and S to the extent of 0.01%.

The grade of iron in the concentrates made on laboratory scale wet cleaning varied from 69.0 to 70.0% Fe. TiO_2 as above, and SiO_2 and Al_2O_3 constitute the balance with a ratio of SiO_2/Al_2O_3 of about 4/1.

5. A few samples of ore taken from various different locations of the ore deposit all showed virtually the same chemical and physical characteristics. All were amenable to treatment by the methods outlined in this report with overall recovery and grade as outlined above.

6. Wet cleaning of the magnetic concentrates would not be required provided a market is found for concentrates containing between 2% and 3% TiO_2.

Dry cleaning without fine grinding will produce an iron concentrate containing 2-3% TiO_2 and up to 66% Fe. A considerable saving in treatment costs could be made if a market is developed for concentrates containing 2-3% TiO_2.

7. The optimum production rate of concentrates has not been accurately established but it appears to be in the order of 1000 tons per day.

(End of quotation)

The following excerpt gives the production cost of magnetite concentrate plus a profit of $2.00 per short ton, as derived by Western-Knapp. The quotation is as follows:

SELLING PRICE FOR Fe CONCENTRATES DELIVERED
at Florence, Arizona

1000 TPD

WET CLEANING

	PRICE PER SHORT TON OF CONC.
Concentrate Haulage	1.4400
Treatment Costs	3.6751
Profit Desired before Income Tax	2.0000
Sub Total	7.1151
Amortization and Interest	1.3827
Proposed Price	8.4978

400 TPD

WET CLEANING

Concentrate Haulage	1.4400
Treatment Cost	4.5225
Profit Desired before Income Taxes	2.0000
Sub Total	7.9625
Depreciation, Interest and Amortization	1.8478
Proposed Price	9.8103

(End of quotation)

To the above should be added the royalty of $0.50 to $1.00 per ton of concentrates.

The following excerpt from the Western-Knapp report gives the indicated tons of recoverable concentrate in a square mile. This is based on results obtained in the area tested by Western-Knapp, which is richer than the general average obtained by Sundness. Also the grade of concentrate is 60%, compared to the 65% used by Sundness, and apparently the tonnage is expressed as short tons. The quotation is as follows:

INDICATED RESERVES

Metallurgical studies indicate that approximately 18 tons of 6% gravel must be mined and processed to obtain one ton of magnetic concentrate assaying 60% metallic iron.

Using a calculated weight of 3287 pounds per dry bank yard and assuming a metallurgical recovery of 80%, this would be equivalent to 10.95 bank yards per ton of 60% concentrate.

To obtain the equivalent of one ton of concentrate, an area of 296 square feet would have to be excavated to a depth of one foot. (10.95 x 27 cubic feet per cubic yard). On this basis, one square mile contains 94,000 tons of concentrate-equivalent for each foot of depth (5280 feet squared and divided by 296). From this, the following table has been prepared. Note that these are "order-of-magnitude" figures only and are subject to revision depending on TiO_2 content and on product specifications regarding contained TiO_2. Also, the accuracy of these figures is commensurate with the accuracy of the sampling program recently conducted by the client.

INDICATED TONS OF 60% CONCENTRATE PER SQUARE MILE

DEPTH IN FEET	TONS
1	94,000
5	471,000
10	942,000
20	1,884,000
40	3,768,000
60	5,652,000

(End of quotation)

PENNEBAKER COMMENTS

Based on the foregoing reports, various discussions, and the writer's very brief inspection of the ground, the following comments are offered:

GENERAL

There is a vast amount of iron in the area under consideration, but exploration to date is inadequate to prove the extent, depth, tonnage, and average recoverable iron content of the entire deposit.

DEPTH

Drilling and sampling in a 10 square mile tract of the 70 square miles controlled has been to a depth of 25 feet, except for one hole to 43 feet. The latter showed iron values much improved at depth, but the results of this one hole do not yet warrant extension throughout the entire property.

At present a deep hole in search of water is being drilled by a Government agency a short distance off the northeast side of the highway. To a depth of over 400 feet this shows substantial amounts of magnetite, but the water well samples are not suitably taken to provide an accurate estimate of the amount of magnetite in place at depth. Below 400 feet in this hole, magnetite persists but is associated with somewhat more clay. Iron was still abundant in the bottom of the hole on August 30, which was at about 650 feet. The results of this hole are generally encouraging, but how far laterally its results can be projected is problematical.

In about 1949 Magma Copper Company drilled a number of deep holes in this area in search of copper. It is rumored that a considerable thicknessof iron-bearing sand and gravel was cut by these holes.

GRADE

The Sundness drilling showed the crude sand and gravel to average 5.09% iron (Fe) in the area tested, of which 2.9% of the total contained magnetite was recoverable. About half of the tract, amounting to 5 square miles, was richer, with an estimated recoverable magnetite content of 4.36%. The Western-Knapp results are based on a 6% (Fe?) gravel from which 71 pounds of iron per (short?) ton were recovered.

The above make it evident that there are substantial variations in the recoverable magnetite content of the sand and gravel in various nearby areas, and that more drilling is needed to outline the tracts where operations might be profitable. In discussions the writer was advised that several promising areas are evident by visual examination and that certain dry washes are locally far richer than the average. There is also the suggestion that the magnetite may be replenished in a "mined out" wash by subsequent rainwash and flash floods.

FURTHER EXPLORATION

It is obvious that the drilled area needs more and deeper holes at closer spacing and that drilling should be carried into adjacent areas. The annual expenditure for assessment work can be used to advantage to help accomplish this.

The drilling exploration technique employed by Mr. Sundness is admirably suited to this testing, but it is undoubtedly expensive and the depth to which this type of sampling can be carried is problematical.

It might be desirable to drill experimental auger holes along-side the Sundness holes and alongside operating excavations in order to try to develop an empirical factor relating the quickly and cheaply taken auger samples to recoverable magnetite.

Regardless of the type of exploration employed, it should be under Mr. Sundness' experienced direction.

RESERVES

There is considerable difference in the amount of recoverable magnetite in an average square mile as estimated by Mr.

Sundness and by Western-Knapp, but the bases of their estimate are somewhat different in a number of respects. The range is from about 1 million to 2 or more million tons of recoverable concentrate per square mile to a depth of 25 feet, and the problem is to select the richer tracts for initial production.

SCALE OF OPERATIONS

Western-Knapp concluded that at present prices quoted for iron ore, the 1000 tons per day treatment plant appears economically justified on the assumption that the ore body contains 71 pounds of recoverable iron (Fe) per (short?) ton of sand and gravel in place.

Consequently a pilot plant type of operation at a much smaller concentrate output per day will necessitate a richer magnetite-bearing sand for a profitable operation. Feeney, Lindekugel and associates believe such is available at certain localities.

HAZARDS

There are two hazards to watch out for, neither of which can be properly appraised at present.

One is the amount of ground cemented irregularly at depth by hard caliche. An abundance of this material could seriously interfere with low-cost mining.

The other is the amount of oxidization of the magnetite grains laterally and at depth, which would affect the iron recovery by the magnetic process.

TITANIUM CONTENT

The writer was advised that the titanium content can be reduced satisfactorily by sufficient grinding and dry magnetic concentration.

PAST PRODUCTION

Pilot plant recovery operations have recently been conducted at the property and these have produced a substantial pile of good-looking magnetic iron concentrates.

BUSINESS ARRANGEMENTS

Feeney, Lindekugel and associates have recently leased the property from Southwestern Iron and Steel Industries, Inc., under the terms of an Agreement and a Supplement Agreement. The writer has not seen a copy of the original Agreement, but a copy of the recently executed Supplement Agreement is attached as an appendix to this report. As provided by the two agreements, it is the writer's understanding that the royalty paid by Feeney, Lindekugel and associates shall be 50 cents per ton of concentrates for the first 200,000 tons and then $1.00 per ton from there on out. (The original Agreement should be checked to determine whether this is on a long ton or short ton basis, and to make sure that it is based on concentrate production of a specified grade.)

Feeney, Lindekugel and associates propose to produce magnetite concentrates from the property and to reduce them to sponge iron by the so-called Madaras process. For this purpose they have contracted with Julius D. Madaras and Madaras Corporation for use of the process and for a certain ore reduction pilot plant now at Longview, Texas. A copy of this agreement (which was signed by Lindekugel and Madaras in the writer's office on September 1, 1960) is attached as an appendix to this report.

It will be noted that as a condition of this agreement, a corporation to be set up by Feeney, Lindekugel and associates shall have an exclusive right to license the use of the Madaras process in Arizona (only), provided:

1. Southwestern Iron and Steel Industries, Inc. assigns its license to use and sub-license the Madaras process to this corporation, and
2. That, after two years, only as long as the new corporation "expands production and adds facilities..... ......as long as a profitable market develops for sponge iron or pig iron or steel".

This requirement of continuous expansion could prove burdensome and should be modified.

PENNEBAKER CONCLUSIONS

It is difficult to analyze the property and the project at the present stage of its development. The writer is generally optimistic but inclines to the view that a small-tonnage pilot plant for concentrate production may turn out to be a high-cost operation.

Nevertheless, the showing is so large that it warrants adequate exploration and investigation.

E. N. Pennebaker

E. N. PENNEBAKER

Scottsdale, Arizona
September 7, 1960

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SUPPLEMENT AGREEMENT

BETWEEN

SOUTHWESTERN IRON AND STEEL INDUSTRIES, INC.

AND

PATRICK FEENEY AND ASSOCIATES

DATED JULY 14, 1960

SUPPLEMENT AGREEMENT

THIS SUPPLEMENT AGREEMENT made and entered into the 14th day of July, 1960, by and between SOUTHWESTERN IRON AND STEEL INDUSTRIES, INC., an Arizona corporation, lessors, and PATRICK FEENEY and associates, hereinafter called lessees, WITNESSETH:

WHEREAS, the lessors and the lessees entered into a lease agreement on or about the 30th day of December, 1959, a copy of which is attached hereto and made a party hereof; and,

WHEREAS, the lessees have presented ample proof that they are unable to fulfill and perform all the terms and conditions of said lease agreement due to the critical financing problems; and,

WHEREAS, the lessees desire certain modifications and amendments to said lease agreement so that the financing problems can be solved; and,

WHEREAS, the lessors are willing to make said modifications and amendments based upon certain additional consideration being forth coming.

NOW THEREFORE, it is hereby covenanted and agreed as follows:

1. The lessor hereby covenants and agrees to remove all minimum royalties and production schedules and set forth in paragraph two (2) B and C of the original lease agreement mentioned heretofore.

2. Both parties hereto covenant and agree that all of the State of Arizona mineral leases or unpatented mining claims mentioned in the original lease agreement and clearly set forth in the recitals on page one (1) be delivered to an escrow agent and remain in escrow until such time as the lessee has built and is maintaining a 500-ton-per-day Madaras reduction plant producing not less than 500 tons per day of sponge iron in which the total F. E. is ninty-five per cent (95%) reduced to metallic iron, using

the lessor's ore exclusively. Lessee further agrees that the above mentioned plant shall reach the 500-ton-per-day capacity in not less than five (5) years from the date of this agreement. The purpose of the escrow is merely to maintain expenses at the lowest level.

3. The lessor hereby covenants and agrees that in the event the lessee presents sound and definite evidence that it is necessary to have all leases assigned to them in order to obtain the financing necessary in their mining program, that they will release the escrow and assign and deliver unto the lessee all leases necessary to acquire the financing desired. The expenses involved in this assignment is being born and paid for by the lessee.

4. The lessor hereby covenants and agrees to reduce the minimum royalties or payments due to the lessee from the lessor as set forth in paragraph two (2), section B on page 4, from TWO DOLLARS ($2.00) per ton to ONE DOLLAR ($1.00) per ton for each ton in excess of one million (1,000,000) tons. All royalties or payments due from the lessee to the lessor belwo the one million (1,000,000) ton level shall be payable on the terms and conditions of the original agreement.

5. The lessees hereby covenant and agree to sublicense to lessees the exclusive use of the Madaras process within the State of Arizona subject to and conditioned to any and all terms, restrictions, and covenants contained in that certain agreement between BLACK MINING & EXPLORATION COMPANY and JULIUS D. MADARAS executed on the 24th day of September, 1957 and assigned to the lessors.

6. The lessees hereby covenant and agree to commence within sixty (60) days from the date of this agreement to erect and construct a Madaras reduction plant having a capacity of not less than fifty (50) tons per day of sponge iron using the lessor's ore exclusively and to be completed and in production on or before eight (8) months thereafter.

7. The lessees hereby covenant and agree that they will expand production and add facilities including melting equipment as rapadly as a profitable market develops for spong iron or pig iron or steel and that they further agree that within five (5) years from date of this agreement, the plant mentioned heretofore shall have an output capacity of not less than 500 tons per day. The lessees further agree that ten (10) years from date of this agreement they will pay and guarantee a minimum royalty to the lessee of not less than FIVE HUNDRED THOUSAND DOLLARS ($500,000.00) per year payable in semi-annaul installments or by agreements of the parties hereto. In the event the lessees are unable to pay the above mentioned sum they hereby covenant and agree to return and reassign at their expense seventy-five per cent (75%) of all leases or unpatented mining claims mentioned heretofore and the Madaras process with the exception that the lessees may select the twenty-five per cent (25%) to be retained by them plus having the right to use the Madaras process on that property using the lessee's ore exclusively.

8. The lessee hereby covenants and agrees that they shall pay to the lessor the sum of FIVE HUNDRED DOLLARS ($500.00) per month to commence on August 1, 1960. This sum is being applied on the purchase price of the equipment located on the lesser's property with a total purchase price to be agreed upon by the parties hereto or as advanced royalties of the lessee's option.

THIS SUPPLEMENTAL AGREEMENT is subject to and conditioned upon the approval of two-thirds (2/3) of the stockholders of SOUTHWESTERN IRON & STEEL INDUSTRIES.

IN WITNESS WHEREOF, the lessor has caused this agreement to be executed by its duly authorized president, and PATRICK FEENEY and MARNEL LINDEKUGEL have executed this agreement on behalf of themselves and their associates as lessee as of the day and year first here and above written.

PATRICK FEENEY - LESSOR

MARNEL LINDEKUGEL and ASSOCIATES

SOUTHWESTERN IRON & STEEL INDUSTRIES, INC.

By HARLEY E. GRAFF

AGREEMENT

THIS AGREEMENT made the 14th day of July, 1960, by and between SOUTHWESTERN IRON & STEEL INDUSTRIES, INC., first party, and JULIUS D. MADARAS, second party, WITNESSETH:

WHEREAS, second party will benefit materially if first party enters into the above contract with PATRICK H. FEENEY and MARNEL LINDEKUGEL; and,

WHEREAS, first party will benefit materially if paragraph two (2) page two (2) in that certain agreement by and between BLACK HILLS MINING & EXPLORATION COMPANY and JULIUS D. MADARAS entered into on the 24th day of September, 1957, is modified whereby second party does not have a continuing fifteen per cent (15%) of SOUTHWESTERN IRON & STEEL INDUSTRIES INC. capital stock issued and outstanding; and,

WHEREAS, second party hereby agrees that the consideration received is the consent of SOUTHWESTERN IRON & STEEL INDUSTRIES INC. to enter into the above mentioned contract.

NOW THEREFORE, it is hereby agreed as follows:

1. First party hereby covenants and agrees to enter into and execute the above mentioned contract with PATRICK H. FEENEY and MARNEL LINDEKUGEL.

2. Second party hereby agrees and covenants to relinquish all right, title, and interest that he may have to any and all capital stock of first party with the exception of the capital that is now within his possession.

3. Both parties hereby agree and covenant that this agreement is conditioned upon the following:

A. the execution of the supplemental agreement by and between SOUTHWESTERN IRON & STEEL INDUSTRIES INC. and PATRICK H. FEENEY and MERNEL LINDEKUGEL.

B. the acquisition of SOUTHWESTERN IRON & STEEL INDUSTRIES INC. board of directors approval and stockholders approval

C. the erection of the fifty (50) ton per day plant mentioned in the supplemental agreement.

IN WITNESS WHEREOF the parties hereto have executed this agreement the day and year first above written.

JULIUS D. MADARAS

SOUTHWESTERN IRON & STEEL
INDUSTRIES INC.

By________________________

HARLEY B. GRAFF

MADARAS AGREEMENT

BETWEEN

PATRICK FEENEY AND MARNEL LINDEKUGEL

AND

JULIUS D. MADARAS

AND

MADARAS CORPORATION

DATED SEPTEMBER 1, 1960

This AGREEMENT made the ______ day of ______________, 1960, between PATRICK H. FERREY, of Pierre, South Dakota, and MARCEL LINDEKUGEL, of Mitchell, South Dakota, first parties, JULIUS D. MADARAS, of Longview, Texas, second party, and MADARAS CORPORATION, a Delaware corporation, whose principal office is located at 3456 Penobscot Building, Detroit, Michigan, third party:

WHEREAS, first parties have leased from Southwestern Iron & Steel Industries, Inc., an Arizona corporation, hereinafter called Southwestern, for a term of 99 years commencing in 1959, certain mineral leases and mining claims situate in Townships 7 and 8 South, Ranges 11, 12 and 13 East, Gila and Salt River Base and Meridian, Pinal County, Arizona, from which first parties propose to produce iron ore concentrate;

AND WHEREAS, second party has invented and developed a process, hereinafter called the Madaras process, for reducing to sponge iron the type of iron ore concentrate which first parties propose to produce, using natural gas as fuel;

AND WHEREAS, second party controls the disposition of certain machinery and equipment at Longview, Texas, constituting the pilot plant in which the Madaras process was developed, hereinafter called the Longview equipment;

AND WHEREAS, third party holds the United States patents pertaining to the Madaras process, and has the right to license the use of the process in Arizona, subject only to a non-exclusive license granted to Southwestern by agreement dated November 30, 1957, with which first parties are familiar;

AND WHEREAS, the parties intend to move the useful parts of the entire ore reduction plant at Longview, Texas, excepting the buildings and the parts originally put up by the Madaras Steel Corporation of Texas, to the vicinity of the mineral leases and mining claims abovementioned, and reerect them there, together with such additional equipment as may be necessary, for the purpose of producing by means of the Madaras Process 50 tons/day of sponge iron from the iron ore concentrate which first parties propose to produce from said property:

IT IS AGREED:

1. First parties forthwith will negotiate with Southwestern, Inc., for an equitable adjustment of the severance royalty payable under their lease of the mining property above-mentioned, and for an assignment of Southwestern's license to use and sublicense the use of the Madaras process in Arizona. The obligations of all parties under this agreement are contingent upon the satisfactory conclusion of such negotiations within sixty days from date and notice to second party.

2. First parties will organize a corporation, hereinafter called X Corporation, with an authorized capital stock of not less than $1,000,000.00 divided into 1,000,000 shares of $1.00 par value. First parties will subscribe and pay cash for 250,000 shares at par, such cash to be paid into X Corporation as rapidly as required by the purposes of this agreement, and first parties will transfer to X Corporation their lease from Southwestern of the mining properties above-mentioned in consideration of the issuance to them of an additional 400,000 shares. Second party will cause to be transferred to X Corporation the parts of the Longview equipment selected by first parties in consideration of the issuance to him or to his order of 50,000 shares, and payments to him or to his order of the additional sum of $25,000.00, such additional payment to be made, however, only as and when earned from the operation of the proposed ore reduction plant. For other good and valuable consideration, receipt of which is hereby acknowledged by first parties, X Corporation shall issue to second party or to his order an additional 50,000 shares. The balance of the unissued authorized capital stock of X Corporation, consisting of 250,000 shares, shall be subscribed or sold for cash only, at par.

3. Third party consents to assignment by Southwestern to X Corporation of its license to use and sublicense the use of the

Madaras process in Arizona, and agrees that it will not license the process for use in Arizona, by any one other than X Corporation for a period of two years from date, and thereafter as long as X Corporation expands production and adds facilities, including melting equipment, as rapidly as a profitable market develops for sponge iron or pig iron or steel.

4. Second party will prepare adequate drawings and specifications for construction of the proposed ore reduction plant at a cost not to exceed $6,000.00, this amount, however, not to include the fees for services rendered by Julius D. Madaras, M. M. Ross and Ralph J. Fenton. Second party will be consulted in the selection of the plant site, will supervise the removal and reconditioning of the Longview equipment and the construction and initial operation of the proposed ore reduction plant, will keep accurate records of all costs and expenses and submit a monthly accounting for audit, and will submit to X Corporation for advance approval all contracts for expenditure of $1,000 or more. For such services second party will receive from first parties the consulting fee of $1,500.00 per month, payable in advance, commencing on the date of the notice specified in paragraph 1, plus his actual expenses for travel and subsistence away from Longview, Texas. The expenses and fees due to M. M. Ross and Ralph J. Fenton shall be paid by X Corporation.

5. Second party undertakes that the proposed plant will be ready to operate within eight months from the date that sufficient funds are paid into X Corporation to commence the work, and that the total cost of the completed plant, including second party's consulting fee, but excluding the cost of the plant site, ad valorem taxes, insurance, any deposits or other payments required to bring utilities to the plant site, the value of the shares issued for the Longview equipment, and any expenditures not recommended by second party, will not exceed $239,000. Delays caused by acts of God, labor trouble, failure of suppliers to meet promised delivery dates, personal illness of second party, or other causes beyong the reasonable control of second party will not be counted as part of the eight

months, and the cost limit assumes no significant increase in present labor rates, freight rates, steel prices, and quotations for fabrication and installation of equipment.

6. Second party undertakes that the completed plant, after a reasonable period for training crews and balancing the operation, will be capable of producing 30 tons per day of sponge iron in which the total Fe is 95% average reduced to metallic iron, at a cost for materials and direct labor of not more than $40.00 per long ton of sponge iron, assuming that iron ore concentrate containing 67% Fe minimum average is delivered to the plant at $6.50 per long ton, dry basis; that bentonite is delivered to the plant at $10.00 per ton; that natural gas of 1000 BTU/cu. ft. minimum is available at 15¢ per 1000 cu. ft. maximum; that electric power is available at 1¢ per KWH maximum; that no charge is made for water; and that present labor rates in the area are substantially maintained.

7. Second party pledges to first parties his 132,500 shares of Southwestern and his right to receive an overriding royalty on ore mined from the Southwestern property, and the 50,000 shares of X Corporation to be issued for the Longview equipment, as security for performance of the undertakings set forth in paragraphs 6 and 7.

8. Second party will indemnify first parties and X Corporation on account of patent infringement arising out of any part of the original ore reduction plant built for first parties; provided, however, that said obligation may be satisfied in full by transferring to the indemnitee the assets mentioned in paragraph 7.

9. X Corporation will make the proposed plant available for testing other ores upon payment of the direct cost of materials and labor plus 200%, and the plant and all operating records will be open to unlimited inspection by any person authorized in writing by second party.

10. If work on the proposed plant is stopped by reason of the failure of first parties to pay into X Corporation the cash stipulated in paragraph 2, first parties will cause the Longview equipment,

together with all additions thereto which may have been made during the progress of the work, to be reconveyed to second party free and clear of all encumbrances, or in the alternative will cause the Arizona plant site, together with all improvements, to be conveyed to second party free from encumbrance; and thereupon all rights of first parties and X Corporation to use or sublicense the use of the Madaras process, will cease and terminate.

IN WITNESS WHEREOF the parties have executed this agreement on the date first above written.

PATRICK H. FENNEY

MARCEL [illegible]

JULIUS D. MADARAS

MADARAS CORPORATION

By JULIUS D. MADARAS, President

The MADARAS ORE REDUCTION AND STEEL MAKING PROCESS

Biography—Julius D. Madaras

Julius D. Madaras, inventor of the Madaras Ore Reduction process, was born in Hungary on April 10, 1894.

Studying engineering subjects in Paris, he was caught in the web of World War I and with 1200 scientists, artists, writers, engineers and explorers was interned on the island of Corsica. The four and a half years in the company of such illustrious associates greatly contributed to his scientific knowledge and his interest in the humanities. On his release he attended courses on engineering and scientific subjects in Zurich and later in Berlin.

Returning to Hungary in 1920, he came to the attention of the American General Bandholz, High Commissioner of the Allied Forces then occupying the country. Through the General's personal interest in Madaras and his scientific career, Madaras was able to come to the United States and continue his studies at Michigan State University and at the University of Michigan.

Soon after arriving in the United States he founded the American Hungarian Foundation for the purpose of bringing scientists and engineers together from both countries to work on problems of mutual scientific and cultural interests. Through this philanthropic activity he was able to meet leading American scientists, economists, university and college presidents, statesmen, churchmen and leading businessmen.

In 1924, he came to the attention of Henry Ford who set him to work on assembly line and production problems, with a view to simplifying these and allied activities.

Later, he joined Allied Engineers, Jackson, Michigan. This organization handled the engineering work for the Commonwealth and Southern power and gas utility groups. This gave him an opportunity to advance his work on the Madaras Rotor Power Plant and to meet important power utility executives. The process involved the generation of electric power from the wind through the use of giant rotating cylinders mounted on flat cars set on a circular railroad track. The seven largest utility companies in the country were impressed and financed a two thousand kilowatt unit. Tests proved 30 per cent beyond expectation. The process seemed destined for commercial production, but along came 1933—bank closures and the collapse of five of the seven utility companies involved.

Recognizing his ability and original approach to power problems, Dr. Oswaldo Aranha, then the Brazilian ambassador to the United States, was instrumental in having his government invite Madaras to Brazil to study its power problems.

While Brazil was rich in high-grade iron ore and other ore deposits, like in other South American countries, there was a complete lack of essential coking coal. The problem led Madaras to invent his process for reducing iron ore directly through use of natural gas.

The MADARAS
ORE REDUCTION AND
STEEL MAKING PROCES

MADARAS CORPORATION 550 W. Lafayette Boulevard
Field Office: Longview, Texas
DETR

erating equipment. The hot gas is passed upward through the ore. Some of the used gas is regenerated and recirculated. This process is adaptable only to ores of special hardness and grain. The use of electric power is excessive and the cost of equipment is high. The plant capacity is limited to well below 100 tons of iron per day.

The Fluidized Bed

This is a gaseous reduction process. The ore is reduced in powdered form. The hot hydrogen is passed upward through the powdered ore which is maintained in a suspended agitated state. When hydrogen is used, the reaction is very cooling, the temperature is low where the heat efficiency is very low. If carbon monoxide is mixed into the gas it usually cracks into CO_2 and carbon which chokes the furnace and stops the whole operation. The control of heat and gas is difficult, the reduction is slow and usually incomplete unless excessive amount of gas is circulated through the ore. Nevertheless, several steel companies are experimenting with it. It is still in a laboratory stage.

The Herreshoff Furnace

This furnace has been tried for reducing iron ore with hydrogen during the War by a combination comprising the U.S. Bureau of Mines, two engineering organizations and two steel companies. Conducted at Government expense the process never really reduced iron. The very nature of this furnace is such that it is adapted for oxidizing the ore which is exactly the opposite of removing the oxygen from the ore.

Hoganas Process (Carbonaceous)

Crushed iron ore is mixed with coke or charcoal and charged into small open containers made from clay or stainless steel. A large number of such containers (usually hundreds of them) are placed on small cars. A whole chain of such cars is pushed through a tunnel that is fired into, similar to a brick burning tunnel. As the ore becomes heated it is reduced.

In this process the plant investment as well as the maintenance of the containers (saggers) is excessive, the plant capacity is small, the reduction of ore is incomplete. The Madaras licensee in Mexico had been using this process until the Madaras process plant was installed, whereupon the Hoganas furnace was dismantled and removed.

Miscellaneous Methods

Among other ore reduction methods is the *R-N* process. This is a further development of the Krupp-Renn process. The *Esso-Little* process is a fluidized bed, ore reduction process utilizing a higher temperature than the H-iron process.

Still another, the *Udy* process partially reduces the ore in separate equipment and finishes the reduction in an electric carbonacious smelting furnace.

Where special problems exist and where high original plant costs and high operating costs are not a deterrent factor, these processes, on a limited scale, more or less accomplish their purpose.

Methods of Ore Reduction

The iron is always reduced from the ore with reducing gas. This is always carbon monoxide (CO) and hydrogen (H_2). The whole basic chemistry of reducing iron ore is removing the oxygen of the oxidized iron by combining (burning) the oxygen with CO and H_2. The burned product is CO_2 and H_2O.

In nature the iron is combined with the oxygen in two forms: F_e20_3 which is called hematite and F_e3^04 called magnetite. The latter has about 50% of the magnetism of the fully reduced iron, while the former has no magnetism. In some ores the iron is combined with sulphur.

In general, iron is made by—

(1) *Smelting in the blast furnace and in electric furnace;* (2) *Mixing the ore with carbon and heating the mixture externally or in a rotating kiln. This method is called carbonaceous reduction which also includes the electric smelting;* (3) *Reducing the ore with gas (CO and H_2). The reducing gas is formed separately and is circulated through ore. This is the gaseous reduction method. The Madaras process belongs in this group.*

Krupp-Renn Process (Carbonaceous)

This process utilizes the rotating horizontal cement kiln for reducing the ore. A mixture of iron ore, coal and coke and limestone is charged through one end of a rotating kiln. Through the opposite end gas, oil or powdered coke is fired into the retort. As the charge becomes heated the ore is reduced. By adjusting the temperature in the furnace, the reduced iron becomes semi-fluid and forms beads or glomerules. The gangue and flux form slag clinkers in which the iron beads are imbedded. The whole charge is then cooled in water, broken up and the iron is extracted by magnets.

The plant cost is high (four times the cost of the Madaras process), fuel is excessive and expensive, thermal efficiency is low, the iron absorbs too much sulphur from the fuel. Maintenance of the refractory lining of the kiln is high.

This process has been adopted and developed for handling a particular type of low-grade granular ore where the gangue is mostly self-fluxing and is not amenable to easy or economic concentration.

Electric Smelting (Carbonaceous Process)

A mixture of iron ore, coke and limestone is charged into a stack type furnace. At the bottom of the furnace there are electrodes reaching into the furnace at an angle. The electric power provides the heat for the carbonaceous reduction and for melting the reduced iron and the gangue which forms molten slag with the flux.

Characteristics: It requires 2400-2500 kw/hrs. to make a ton of pig iron. That is about five times the power it takes to melt a ton of steel from cold scrap. The cost of power and of electrodes is excessive and practically prohibitive except at places where the power rate is very low and the high-priced steel products will absorb the high cost of power, electrodes and maintenance. Even at a high cost, this process is suitable only to small operation.

The Wiberg Process

This process reduces the iron ore with reducing gas. The plant consists mainly of a very tall stack approximately 100 ft. high, with 5-6 ft. thick wall and of gas regen-

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was a patriotic duty. Then, gradually, I received other confirming reports from engineers of recognized ability, with a reaffirming report from Giffels & Vallet on costs in producing sponge iron under the process and the cost of melting the sponge iron derived therefrom in electric furnace and, lastly, the report of Dr. Karl T. Compton, who, as you know, is the acknowledged leading scientist in the field of engineering. As a result of these supporting letters and reports many of my colleagues, to whom I had generally explained the process, became more and more interested from the standpoint of National defense and the economy of the country, and have indicated their support of the process.

In my service of 45 years, I have seen much history in the making. Scientific, industrial, economic and social history has always been made by the individuals who have been doing the new "impossible" things while the crowd in the grandstand has remained passive and exclaimed "it cannot be done". We need the new things. The greatness of this country is built on the individuals who do things. In this instance, I believe Mr. Madaras has accomplished something that will inure to the great benefit of our country.

I again respectfully suggest and urge, in view of the clarification of the Bureau of Standards' first and second reports, that you act favorably in the matter at this time.

(Hon.) A. J. SABATH, *Chairman*
A. J. SABATH, M.C.
House Rules Committee

June 30, 1951

Letter to Hon. Charles Sawyer, Secretary of Commerce, Department of Commerce, Washington, D. C.

It is further our viewpoint that the prevailing philosophy has been to prove that the process will not work rather than to give it a fair chance to work.

During this period of critical steel shortage, it is obvious to us that the appropriate governmental agencies must promptly take the affirmative action and I hope you will promptly lend your efforts in that behalf.

MELVIN A. PRICE, *Chairman*
Special Subcommittee Investigating
the Madaras Ore Reduction Process

November 27, 1951

Excerpt of letter to Hon. Charles Sawyer, Secretary of Commerce and to Hon. Oscar Chapman, Secretary of Interior, Washington, D. C.

The chairman of the Metallurgical Committee of the National Academy of Sciences who, incidentally, depends on the steel companies for business, disregarded all favorable opinion of other members and, instead, delegated Arthur G. McKee & Company—the largest blast furnace builders, mind you—to report on the process. They found no objection to the soundness and economy of the process, but they reported, in effect, that the Madaras process would interfere with blast furnace practice and, therefore, it should not be used. This report was transmitted by the National Academy of Sciences as its own and, needless to say, Government support for the process was blocked.

Sincerely yours,
(Hon.) A. J. SABATH, *Chairman*
House Rules Committee

June 29, 1951

Excerpt of letter to Hon. Charles Sawyer, Secretary of Commerce, and to Hon. Oscar Chapman, Secretary of Interior, Washington, D. C.

Before concluding I wish to add a little personal explanation how I became and stayed interested in the Madaras process.

During the First and Second World Wars I devoted much time and study to various inventions which I considered important to the Government and to the country. At the outbreak of the Korean trouble I was approached by several small steel fabricators in my District who were almost desperate for steel. About this time a very able engineer, whom I have known for a long time and who never met Madaras, told me about his process. Shortly afterward, I met Madaras, spent several evenings with him, discussing the process and reading his references and brochures. Then I did some more checking of my own on him, his process, his associates and Giffels & Vallet, Inc., engineers, of Detroit, Michigan. I became convinced that giving as much help to bring this process into use

Preface

Our industrial civilization is based on iron. The free and abundant use of iron means not only economic freedom but also national security and political power. The problem of iron production, therefore, is no longer only a matter of national economy, but also a concern of national defense and, indeed, of national survival.

The early method of making iron was with charcoal and coke. But the iron contained impurities and an excessive amount of carbon, which made it unusable for steel making. The invention of the Bessemer process started greater production of steel from pig iron. After that, the advent of the open hearth made possible the refining and the production of better quality steel, and brought the mass production of steel under control. This created the present industrial age.

With the advent of the early mass production of steel, iron was produced on a small scale by the undeveloped blast furnace. As the demand for iron increased, the size and output of the blast furnace was pushed to the limit. With the blast furnace, however, production of iron was tied to the coking coal which was found only in a few regions. The iron ore had to be transported to the source of coking coal hundreds or even thousands of miles, with the result that the comparatively few deposits of coking coal practically dominate our industrial and economic life.

At the same time, the iron ore regions themselves are left in economic servitude and so to a considerable extent are most consumption areas. These areas are now ready for intensive industrialization, and the key is cheap steel made locally.

For many years high grade ores were abundant, the demand for steel was small, and labor was cheap. Thus the production of pig iron was acceptably cheap and satisfactory. Now, however, the demand for steel has increased enormously at the same time the high grade iron ore is being exhausted. It will be costly to produce concentrates from low grade ores.

In every step of producing iron, costs are rapidly increasing, in mining, concentrating the ore, transportation of ore and coal, and operating and maintaining the furnaces. Furthermore, we have exhausted most of the accumulated steel scrap and what is left is badly contaminated, making it even more difficult to provide a suitable supply of melting stock for making steel.

It has been recognized for over a hundred years that important advantages would accrue from a process of using gases to reduce iron ore and other oxides in quantity without the costs and complications inherent in the blast furnace.

Under the pressure of economic need, in practically every industrially conscious country in the world, intensive research and experiments have been conducted to find and develop a practical ore reducing process, and great sums of money have been expended for this purpose.

A few processes resulted that worked on a small scale, but all failed when tried on a large industrial basis. In every case, the failure has been due to difficulties that are so evidently inherent in the processes themselves.

The Madaras process has succeeded where others have failed. It is a *commercial* and *industrial* success. It is a process that can be utilized to produce iron and steel in a low cost, economically-operating plant with a capacity as small as 100 tons of iron or steel per day to as much as 10,000 tons per day. It utilizes reducing gas made from natural gas, coke oven gas, oil, or from hydrocarbons extracted from low grade coal and lignite, for making iron from ore and other metals from their oxides. This process brings the centuries-old chemical production of iron under mechanical control in this mechanical age.

The Madaras process additionally provides an efficient and economical method of melting continuously hot or cold sponge iron into highly refined steel or high quality pig iron.

witnesses, your brother Dr. Arthur Compton, was present and gave rather extensive testimony on the problem before the committee, the net effect of his testimony being a strong recommendation that the Government immediately encourage, by loan or grant, the erection of a 100-ton plant, it being agreed by all interested parties that a plant of that size would not only provide a conclusive test of all present criticisms of the process, but might also be self-sustaining economically.

Referring again to Secretary Sawyer's letter of August 10 to Congressman Sabath, he states "in view of your great confidence in Dr. Compton, which of course I share, would it be agreeable to you to refer to him our correspondence and the reports that have been made to you and me, and ask his advice as to whether or not I should, without further research, authorize the expenditure of the sum requested by Madaras for the building of his plant at Longview?"

(HON.) MELVIN PRICE, *Chairman*

September 19, 1951

Summation excerpt of reply of Dr. Karl T. Compton, president, Massachusetts Institute of Technology, Cambridge, Mass., to letter of Hon. Melvin Price.

Perhaps the most direct way in which I can answer the question posed in your letter of 19 September 1951 is to say that, if I had the responsibility for making the decision, I would certainly approve an investment by the Government of between $2 and $3 million for the construction and early operation of a 100-ton Madaras plant.

KARL T. COMPTON

September 22, 1951

Excerpts from the Special Subcommittee on the Madaras (Steel) Process of the House Armed Services Committee appointed by Chairman Fred M. Vinson, February, 1951, Washington, D. C.

On the basis of the evidence presented to the Subcommittee, it is the conclusion of the Subcommittee that the prospects for the success of the Madaras process sufficiently outweigh the prospects of failure that a production development plant of 100 tons per day capacity should be constructed with financial assistance from the Government.

On the basis of the foregoing conclusion, it is the recommendation of the Subcommittee that financial assistance to the extent of $2½ to $3 million in the form of a loan, grant or combination of the two should be given by the Government.

MELVIN PRICE, *Chairman*
Special Subcommittee Investigating
the Madaras Ore Reduction Process
L. GARY CLEMENTE
LEROY JOHNSON

November, 1951

Excerpts from the Report and Recommendation of the Special Subcommittee on the Madaras Process (Steel) of the House Armed Services Committee—November 27, 1951

The Madaras Ore Reduction Process was brought to the attention of the House Committee on Armed Services in February, 1951. Subsequently for the first time in the history of the United States Congress a special subcommittee was appointed to study an industrial process. Hon. Melvin A. Price was appointed chairman of this Special Subcommittee Investigating the Madaras Ore Reduction Process. Other members of the committee were Hon. L. Gary Clemente and Hon. LeRoy Johnson.

On the basis of the study of the process and the testimony of scientists and production experts as well as members of Congress, the committee subcommittee unanimously recommended "that financial assistance to the extent of $2.5 to $3 million in the form of a loan, grant or combination of the two should be given by the Government." Why this financial recommendation did not become a reality is shown by the transcripts of the various forms of opposition adoption of this far-reaching revolutionary iron reduction process encountered.

Transcript of testimony given by Dr. Arthur H. Compton before Special Subcommittee Investigating the Madaras Ore Reduction Process, September, 1951.*

Mr. Price. In the common lay language, so the ordinary man could understand it, what would be the advantages in this process?

Dr. Compton. I would consider the advantages—first, the lower cost, if one can rely, as I believe one can, on the cost estimates made by the engineering firm of Giffels and Vallet.

Second would be the fact that there is no scrap needed, which would make steel production go ahead without the need for obtaining scrap.

In the third place, the process can be carried out in widely dispersed areas and need not be confined in the neighborhood of a combination of coking coal and iron ore. That would make it available to areas such as the Pacific Coast, the Mississippi Valley, the south coast, the northeast coast, and so on.

There are a number of other secondary values such as, for example, the quality of the steel. The steel is free, thus produced, from alloys that come naturally with the scrap that is used. Thus to produce a steel of superior quality. That is the experience of, for example, the Swedes who use steel from sponge iron. Those would be typical advantages.

**Dr. Arthur H. Compton, who with T. R. Wilson was awarded the Nobel Prize in Physics in 1927, is presently Chancellor of Washington University, St. Louis, Mo. As head of the University of Chicago's Metallurgical Laboratory and the Manhattan District's Metallurgical Project for the production of plutonium for the atomic bomb, Dr. Compton had well over 600 skilled metallurgists working for him. His calculations and predictions in that monumental undertaking were subsequently proved to be entirely correct.*

Excerpt of letter from Hon. Melvin Price, chairman of committee, Special Subcommittee (of House Armed Services Committee) to Investigate the Madaras Process.

On August 10, 1951, Secretary of Commerce Sawyer directed a letter to Congressman A. J. Sabath, who has maintained a keen and continuing interest in the Madaras process, indicating his desire to have a Congressional Committee make an investigation which would be preliminary to any substantial investment of Government money in the Madaras process. Subsequently, Mr. Vinson, Chairman of the House Armed Services Committee, appointed a Special Subcommittee to make further inquiry. That Subcommittee of three, of which I am Chairman, held its first meeting on September 17. In addition to other

World Iron Ore Deposits

New Type Ore Reducer Retort Developed and Tested

Since the Bureau's investigations an entirely new type of ore reducer retort has been developed and tested. This retort permits the use of high reduction temperatures, extremely fast and uniform heating of the ore, fast circulation of the reducing gas, complete and efficient reduction, good temperature control and it eliminates any sticking of the reduced iron.

1. The Bureau of Mines report shows that the Madaras process utilizes reducing gases with full efficiency.

2. The ore is reduced as fast as the gas is circulated throughout the charge with your injection method and can be accomplished in less than one hour.

3. The melting and refining of the reduced iron is no problem whatsoever.

RALPH L. DOWDELL
Professor and Head of Department of Metallurgy
University of Minnesota

RICHARD E. TOWNSEND
Associate Professor of Chemical Engineering
University of Michigan

WILLIAM P. WOOD
Professor of Metallurgical Engineering
University of Michigan

January 15, 1951

Pulsating Pressure Best Approach to Production of Sponge Iron

The rate of reduction of iron ore with hydrogen is extremely rapid and only limited by the rate at which the reactants are brought together and the rate at which the products are removed. The use of a pulsating pressure to increase the rate factors controlling the reaction speed is novel and appears to be the best approach to the production of sponge iron. The principle appears to be sound and no doubt production rates, which are the chief drawback of other methods, could be reasonably high.

Further, practically all of the hydrogen is used in the reduction process.

Because of the low capital costs and low cost of operation the Madaras sponge iron process should be given further careful consideration as a means of increasing pig iron output as well as a scrap substitute in order to decrease operating costs.

JOHN STUKEL, *Development Engineer*
The Youngstown Sheet and Tube Company
Youngstown, Ohio

October 10, 1950

Offered to Finance Plant and Pay Royalty

The Madaras Syndicate has built and tested a commercial pilot plant of about four or five tons capacity in one charge. Executives and other officials of our company and our metallurgists witnessed tests, took samples of the sponge iron and analyzed them. As a result of our study of the process, we made an offer to Mr. Madaras to build at our own expense in our own yards a plant to produce a minimum of 100 tons of iron or steel per day. Our condition was that we would have an exclusive license of the Madaras invention in the United States for the manufacture of iron and steel used for wire products only and the rights to all other products would have been retained by Mr. Madaras and his associates. In addition to financing the plant, we also offered to pay some royalty for every ton of iron and steel produced.

We regretted that Mr. Madaras and his associates did not see fit to accept our proposition.

The cost of gas and iron ore delivered in Peoria may have been one of the reasons for their refusal to accept our proposition, hoping to find a more favorable location for the erection of their first plant.

W. H. Sommer, *President*
Keystone Steel & Wire Company
Peoria, Illinois

January 20, 1942

May Be Means of Establishing a Sound Commercial Operation

Where natural gas is available at low rates in localities in the proximity of hematite ores of sufficient volume and iron content, the Madaras process may be the means of establishing a sound commercial operation.

Frank H. Adams
Vice-President and General Manager
Surface Combustion Division of
General Properties Company, Inc.
Toledo, Ohio

January 27, 1942

A Uniform and Satisfactory Reduction of Ores

In tests we made we found the Madaras process using a pulsating pressure gave a uniform and satisfactory reduction of the ores we tested.

Frank H. Adams
Vice-President and General Manager
Surface Combustion Division of
General Properties Company, Inc.
Toledo, Ohio

January 27, 1942

UNITED STATES

While iron ore deposits are scattered all over the United States, the richest area is in the Great Lakes region. The main source of commercial grade iron ore is, of course, the Mesabi Range in Minnesota. Other important sources of iron ore are northern New York, Michigan, Pennsylvania, Alabama, Texas, Missouri, Utah, Colorado and California. These commercial grade ores are being rapidly depleted.

There are, however, huge deposits of lower grade ores from which very high grade ore concentrates are being made or can be made. These low grade deposits are expected to supply the country with iron for hundreds of years to come.

The low grade Taconite ore deposits in the Lake Superior region are probably the greatest known source of such ore in the world. Elsewhere in the country, there are many alluvial placer deposits containing substantial amounts of iron ore. Probably the largest of this type is in Arizona. Here such deposits are estimated to contain several hundred million tons of iron oxide economically recoverable by magnetic concentration.

CANADA

Canada has large deposits of high grade as well as low grade iron ores. The large Labrador ore deposits as well as the central Quebec and other eastern Canada deposits are the most extensive. They are either already being fully exploited chiefly by the major United States steel companies or exploitation is being planned.

The Lake Superior region of Canada contains much high grade ore. In addition there are practically inexhaustible deposits of low grade Taconite and Jasper ores.

Many known ore deposits are located in western Canada and particularly in British Columbia. This province is particularly rich in minerals. And when need for more iron ore develops, other extensive deposits are sure to be found and exploited.

LATIN AMERICA

Latin America has by far the greatest share of the world's known high grade iron ore deposits.

Venezuela has deposits running into hundreds of millions of tons each. Their exploitation is just beginning. As it is normal in mineral-rich countries, when the need for iron ore develops, new deposits are usually discovered far beyond present expectation.

Brazil has the richest and most extensive iron ore deposits known. It possesses mountains of almost pure iron oxide. There are hard as well as fine powdery ores. It is logical to expect that when need arises for more ore, other rich deposits will be discovered.

Since there is no adequate source of coking coal in Brazil or in the neighboring countries, gaseous reduction is the only possible way for processing these ores into iron in Brazil.

Mexico, Peru, Chile, Argentine and other Latin-American countries are all rich in iron ore. Many celebrated high grade deposits are known or being exploited and new deposits are being discovered all over these countries.

EUROPE

Europe has only a few rich and extensive iron ore deposits, mainly in Sweden, Spain, England, eastern France and some in western Germany. Low grade ores are scattered in many countries behind the Iron Curtain. Rich ore deposits are in Poland, Czechoslovakia and mainly in the southern and eastern part of Russia.

ASIA

In Asia the most extensive deposits of high grade iron ores are in India, China and Asiatic U.S.S.R. While in general the explored deposits are not as extensive and rich as on the American Continent, they are adequate for their need. Many of the Asiatic islands have rich deposits. However, the most industrial island country, Japan, is singularly lacking in commercial grade iron ore.

AFRICA

Rich iron ores are scattered in south, middle and northern parts of Africa. Liberia has some of the highest grade ores known. The only export is to the United States. Rich ore deposits have lately been discovered in Algeria.

AUSTRALIA—NEW ZEALAND

Australia is rich in iron ore deposits. Some of the deposits are extensively worked and many others are held in reserve. Until further exploration, their quantity cannot be estimated. New Zealand has vast magnetic sand deposits from which high grade magnetic concentrates can be easily and economically prepared.

May Eliminate the Problem of the Long Haul of Raw Materials

I am familiar with the Madaras process and believe that it would be, indeed, in the interest of National Defense and national economy that the Government cooperate in testing the plant and bringing it to a logical conclusion. Evidently, the process has solved some of the most difficult problems in gaseous reduction of iron ore, that is, the sticking of the iron, handling the gas, and mechanically controlling the production of iron. Should the process prove to be successful, it may eliminate, in some cases at least, the problem of long haul of raw materials, and may quickly provide an additional source of iron (i.e.—not pig iron) and steel, so badly needed under the present emergency.

BRADLEY STROUGHTON, *Chief*
Heat Treating Equipment
War Production Board
Washington, D.C.

March 26, 1942

Good Standard Grades of Steel from the Sponge Iron

We melted the sponge iron (produced by the Madaras Process) and made good standard grades of steel.

GERALD SMITH, *Manager*
Sollberger Engineering Co.
Marshall, Texas

November 30, 1950

Complete Removal of Phosphorus Would be Effected

If my phosphorous data are correct for the Texas and Arkansas ores, I see no serious objection to the use of the basic electric furnace for remelting the reduced iron and virtually complete removal of the phosphorus would be effected in that process.

KARL L. FETTERS
Ass't to the Vice-President
in Charge Operations
Youngstown Steel and Tube Co.,
Youngstown, Ohio

January 9, 1951

Provides a Sound Basis for an Industrial Process

His (Madaras) ability to make sponge iron has not been questioned . . . he has operated in a manner which could be considered as sufficiently advanced to provide a sound basis for an industrial process.

A. V. ASTIN, *Associate Director*
National Bureau of Standards
Washington, D.C.

June 19, 1951

Soundness of Process Demonstrated

We have followed the progress and development of your process from the time of testing your pilot plant at the University of Michigan. The soundness of your process was soon demonstrated. . . .

William R. Wood
Prof. of Metallurgical Engineering
Richard E. Townsend
Asst. Prof. of Chemical Engineering
University of Michigan

June 16, 1947

Should Succeed on a Larger Scale

Under my supervision, a semi-continuous process was developed whereby this molten sponge iron was melted in an electric arc furnace of orthodox design, the molten iron was refined and made into steels of various commercial compositions. These steels had entirely normal properties. All technical difficulties were apparently overcome . . . I see no reason why it (the process) should not succeed technically on a larger scale.

C. E. Sims, *Supervising Metallurgist*
Battle Memorial Institute
Industrial and Scientific Research
Columbus, Ohio

January 20, 1942

Have Made Very Good Grade Steel from the Sponge Iron

I have melted several charges of sponge iron produced by Southwestern Metals, one from Texas ores as well as Minnesota ores. We have made very good grade standard steel from the sponge iron and made standard steel castings for the market. I feel certain . . . that sponge iron can be melted economically in any desired commercial quantity.

W. E. Linville
Sollberger Engineering Co., Inc.
Marshall, Texas

November 16, 1950

Convinced of Practicability of Madaras Process

For the past few years we have melted a large quantity of sponge iron produced by the Madaras process in our electric furnaces.

We are convinced of the practicability of the Madaras Process and feel that it will soon take place in the industry of the nations.

Roy E. Hearne
Executive Vice-President
East Texas Electric Steel Co., Inc.

November 23, 1950

The Madaras Ore Reduction Proces

Comments and Testimonials on Process

Operation Proceeded Smoothly

The Bureau of Mines' tests at Longview, Texas, have demonstrated that reformed Texas natural gas can be produced and can be used in the plant of the Madaras Steel Corporation for the reduction of Texas iron ore to sponge iron. This sponge iron was melted in a commercial electric furnace with a recovery of 96% of the total iron which operation proceeded smoothly and without difficulty.

R. R. Sayers, *Director*
Bureau of Mines
U.S. Department of the Interior
Washington, D.C.

November 29, 1943

Offers to Build Plant at Own Expense

As a result of our study of the process, we made an offer to Mr. Madaras to build at our own expense in our own yards a plant to produce a minimum of 100 tons of iron or steel a day.

W. H. Sommer, *President*
Keystone Steel & Wire Company
Peoria, Ill.

January 20, 1942

No Other Process Provides this Mechanical Control

The process (Madaras Ore Reduction) is of utmost simplicity and its operation is self-evident. It not only eliminates the troublesome sticking of iron ore, the nightmare of all other processes, and operates with good gas efficiency, but it can also operate on almost any scale as fast as the gas is pumped through the ore with that particular changing pressure that forms the basis of the process. In other words, this process produces iron as fast as the gas is pumped through the ore. This mechanical control of production of iron, in my opinion, is an essential and most desirable feature of any industrial plant and no other process has been able to provide this mechanical control.

Ralph L. Dowdell, MET. E.M.S. Ph.D.
St. Paul, Minn.

March 26, 1942

automatically and need no refractory lining; efficient gas cracker; method of quick heating of ore and automatic heat control and other operations. Complete demonstrations were made to a large group of delegates from many steel and engineering companies. This demonstration included all operations: ore handling, heating and reducing, gas cracking, heat control, melting the produced sponge iron and making steel from it.

1949 and 1950 *Building a large plant.* Buildings and other facilities were extended or added, large industrial size gas cracker and large ore reducers were added and tested. The cost of this step alone amounted to over $300,000.00. Through this work all new equipment and operations were fully worked out on an industrial scale.

1953 *Contract with Hojalata y Lamina, S.A. of Monterrey, Mexico.* License was granted to Hojalata y Lamina, S.A. (HYLSA) for the use of the Madaras processes. The first plant produced about 35 tons of iron a day.

The plant was designed, erected, and the operating crew trained, and the efficient melting of the sponge iron was worked out under the supervision of Julius D. Madaras.

In 1956 the plant was enlarged to produce 250 tons of iron per day and work is now in progress to expand the plant capacity to produce 500-600 tons of iron per day. After this, still further increase is contemplated.

1956 *Formation of Madiron, Inc.* This new company was formed to finance the expansion of the plant at Longview. New gas reforming and gas recirculating equipment was added.

Controls for temperature and quality of gas were installed. A large new retort to reduce 10 tons of iron in one charge was erected. Many carloads of ore from Texas, Venezuela, Tucson and other places were reduced under the supervision of various interested steel companies and sponge iron was melted in their own large commercial electric furnaces. At least 40 delegates from various steel companies witnessed tests. All phases of the Madaras industrial plant of any desired capacity have been worked out to design, erect and operate any size commercial plant.

1957 Substantial additions were made to the plant at Longview, Texas. Catalytic gas reforming, super reforming and gas recirculating equipment were added on a scale that is considered industrial. A large ore reducing retort was installed to make over ten tons of iron in one charge. This size retort is large enough for a 200-ton a day iron plant.

In these units several types of iron ores in lumpy and pelletized forms from the United States, South America and Canada were reduced. Hundreds of tons of sponge iron were made for a number of steel companies under their supervision. These steel companies melted the sponge iron in their own large industrial furnaces with excellent results and stated that the Madaras process is ready for industrial plants of any desired capacity.

The Madaras process makes iron and steel with reducing gas directly from the iron ore. No coke is needed to reduce the iron from the ore, nor is scrap necessary to make steel from the iron.

The reducing gas (hydrogen and carbon monoxide) is economically obtained with standard equipment from natural gas, oil, low-grade coal or lignite, whichever is more readily available in any particular region.

A plant based on this process costs about one-fourth or less of the cost of the blast furnace and coke oven of the same iron capacity. In addition, there is much saving on fuel, labor, maintenance and capital charges. In many regions the total savings can amount to from $20.00 to $25.00 or more per ton of producing steel.

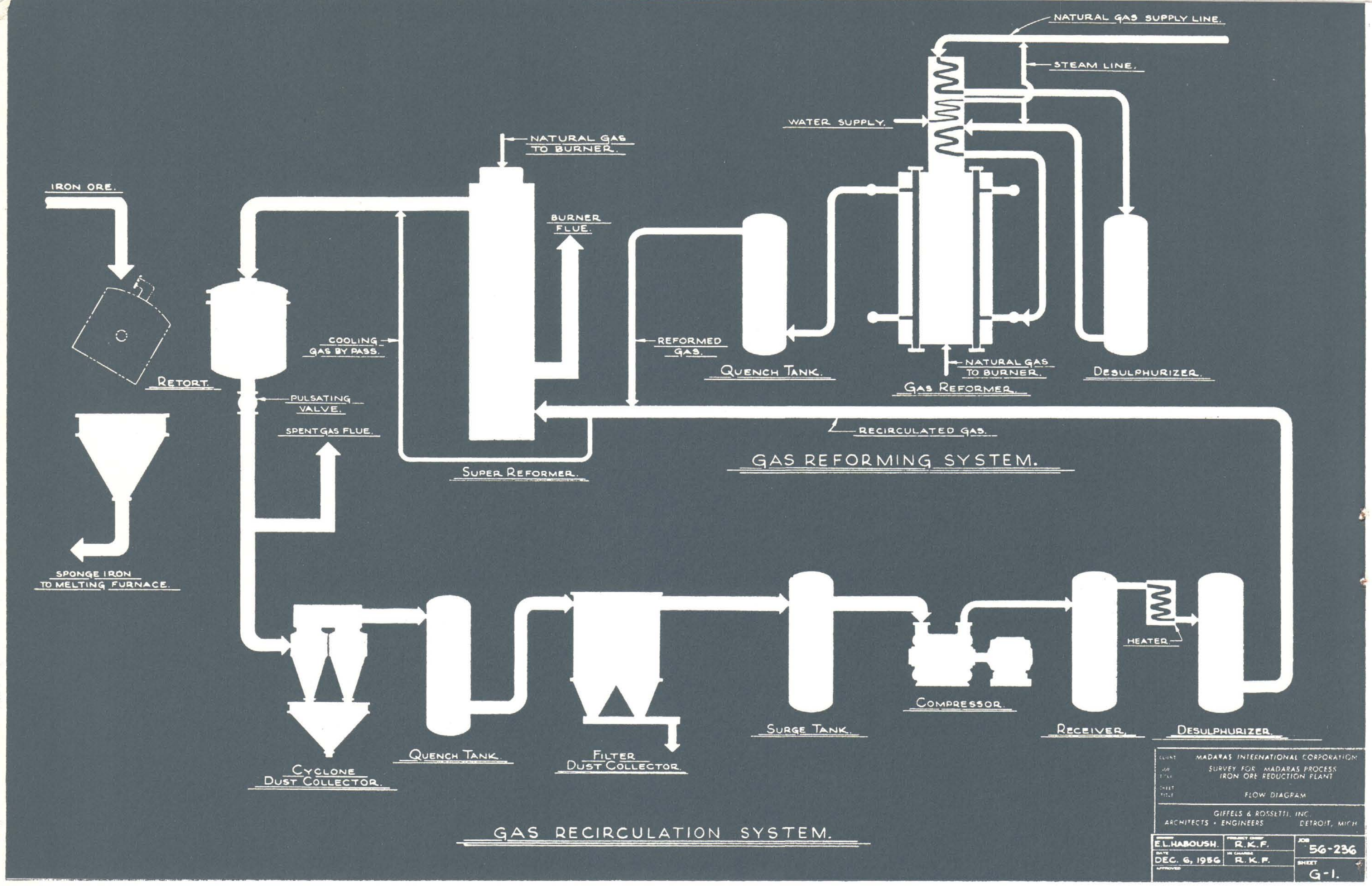
The Madaras plant can be built and operated commercially and profitably on a small or large scale ranging from 50 tons of iron a day to any desired capacity.

The process can use low-grade iron ore deposits not usable in the blast furnace but, of course, the higher grade ores are desirable for maximum savings in ore reduction.

The Madaras process works as follows:

A steel pressure retort is filled with cold or hot crushed iron ore or iron ore pellets and sealed gas-tight. Hot reducing gas (hydrogen and carbon monoxide) is injected into the retort through an exclusively designed inlet valve. The gas mixture penetrates the whole mass of ore. The hot reducing gas reacts instantaneously with the iron oxide, combining with its share of oxygen. The exhaust valve is opened, and the spent gas is discharged. By automatically alternately opening and closing the two valves, fresh reducing gas is passed through the whole mass of ore in a pulsating manner until all the oxygen is carried out and the iron ore is reduced.

In further explanation, the hydrogen (H_2) burns with the oxygen to form H_2O or water vapor. The CO burns into CO_2. The H_2O (steam) is condensed out of the exhaust gas. The remaining gas of the H_2, CO and CO_2 is mixed with fresh hydrocarbon gas and is passed through a gas reformer. Here the CO_2 is reformed to 2CO, according to the formula of $CO_2 + CH_4 = 2CO + 2H_2$. The heated reformed gas is recirculated through the ore. At an early stage of reduction the reducing gas oxidizes almost completely to CO_2 and H_2O and is exhausted into the atmosphere. In this manner the reducing gas is handled in a closed circuit and is almost completely utilized. In an industrial operation, from 6 to 8 charges of ore may be reduced in each retort in a 24-hour day.



MADARAS ORE REDUCTION PROCESS

Gas Recirculation System

The bottom row of the diagram illustrates the gas cleaning and recirculating system. The spent gas, as exhausted from the retort, contains some dust and much CO_2 and H_2O. The dust is removed by a cyclone separator and dust filter and the water vapor is removed through a quench tower.

The remaining unreacted CO, H_2 and CO_2 is recompressed and with the added CH_4 gas is passed through the hot Super Reformer where it is regenerated into 2CO and $2H_2$ and is passed through the Retort. Thus, the reducing gas is practically completely utilized.

After reduction the sponge iron is dumped from the Retort as shown at left, the Retort is filled again with another charge of ore and is reconnected into the gas circuit.

The iron ore is charged into the Retort, illustrated at the left of the diagram.

The natural gas or oil gas is mixed with steam and passed through a standard, commercial gas Reformer making a gas mixture of CO, H_2, CO_2, CH_4 and H_2O (steam). The H_2O is condensed through in water quench tower.

The reformed gas with its CO_2 content is passed through the hot Super Reformer where the CO_2 and CH_4 form 2CO and $2H_2$. This mixture of hot reducing gases at 1700°-2000° F. will pass through the ore in the Retort in a pulsating manner.

Chronology of Development of Process

1936 *Invention.* The Madaras process was invented and the theoretical factors worked out by Julius D. Madaras in Brazil while working on power problems by invitation of the Brazilian Government.

1937 *Syndicate.* A syndicate called Madaras Ore Reduction Project was formed to finance the development and tests of the process and to carry on all activities in an organized way. Members were a group of businessmen and engineers.

1937 *Laboratory tests.* At the University of Michigan extensive laboratory tests and development work were carried out with ores from different parts of the world. The University report stated in effect that the process is sound and efficient, it works and overcame all difficulties inherent in other processes. (See Brochure, Univ. of Mich. report pages 12-14.)

1938 *Pilot plant test.* A commercial pilot test unit was built and tested at Peoria, Ill. This unit reduced 5 tons of ore in one charge. It worked well and established the soundness of the process on a larger scale. (See letter Mr. W. H. Sommer, Pres. Keystone Steel & Wire Co.)

1939 *A further pilot unit* of modified design was tested to obtain design factors for larger commercial units. This unit also worked equally well for treating tin ores. (See letters from Surface Combustion Corporation, Battelle Memorial Institute and Ralph L. Dowdell.)

1940 *Industrial Unit at Longview.* A commercial size unit reducing about 15 tons of ore in one charge was erected with compressors and all other plant equipment. Also this retort reduced the ore with a theoretically possible maximum efficiency and proved that the process works and is practical on any large scale needed by the steel industry. This development and test work reached into 1942. Approximately $300,000.00 were spent on this plant and tests.

1942 *Bureau of Mines tests.* The Bureau of Mines tested the plant at Longview from 1942 to 1944. The Director of the Bureau of Mines reported that the process worked with maximum gas efficiency, the sponge iron melted easily and the difficulties encountered were only mechanical. (See letter by R. R. Sayers, Director of U. S. Bureau of Mines.) The Bureau's report R.I. 3925, 1946, confirmed these conclusions. The report also stated in effect that the plant cost will be about one-fifth of the cost of blast furnaces and coke ovens; that there will be great saving on fuel and that the cost of iron produced by the process at Longview will be about $17.00 per ton. (See R. I. 3925, page 55.)

1947 *Southwestern Metals, Inc. was formed and resumed work.* All needed new types of plant equipment were worked out and tested. Among them are: retorts that can operate

Interest in Direct Reduction Boosted by Cheap Natural Gas

The rising investment cost for coke ovens and blast furnaces to smelt pig iron, the discovery of some extremely rich natural ores, and improved procedures for beneficiating lower grade iron ores have resulted in increased interest in the manufacture of sponge iron. Gradual deterioration in quality of metallurgical coking coal is further stimulating interest, particularly in areas where natural gas is plentiful and economically advantageous.

T. F. OLT, *Director of Research*
Armco Steel Corp., Middletown, Ohio

STEEL, *January 6, 1958*

The resulting hot reduced ore, that is, the hot sponge iron,* is discharged from the ore reducer through a large door. The sponge iron may be melted into steel or rolled into natural wrought iron products. By preparing the iron oxide especially for the purpose, the iron powder may also be produced for powder metallurgy.

In the Madaras process the carbon content can be controlled easily within the limits of .005% to 5%. The sulphur found in the ore is burned out with hot air or carried out with the hydrogen. No impurities are added in the course of reduction. Iron superior to pig iron and scrap is produced.

In all other gaseous processes, the gas is passed through the mass of ore in a continuous flow and the reduction depends upon the diffusion of the reducing gas into the pores of ore which at best is slow, inefficient and incomplete. The gas usually builds up channels through the ore.

In the Madaras process the repeated injection and exhaust causes pulsation of the reducing gas uniformly through the whole ore body and eliminates all the difficulties that are inherent in other gaseous reduction processes. The process gives the whole ore body a pulmotor or lungs and brings the ore reduction under mechanical control.

All other gaseous reduction processes have adapted equipment that was designed and intended for other usually opposing or entirely different chemical and thermal operations. Contrary to this, our aim has been to give natural and free vent to the thermodynamic forces interacting in the reduction of iron ores with gas, and when necessary, discover methods, invent equipment, designs and operating techniques including preparing and reforming the reducing gas and melting the sponge iron, most of which are unique and peculiar to this process.

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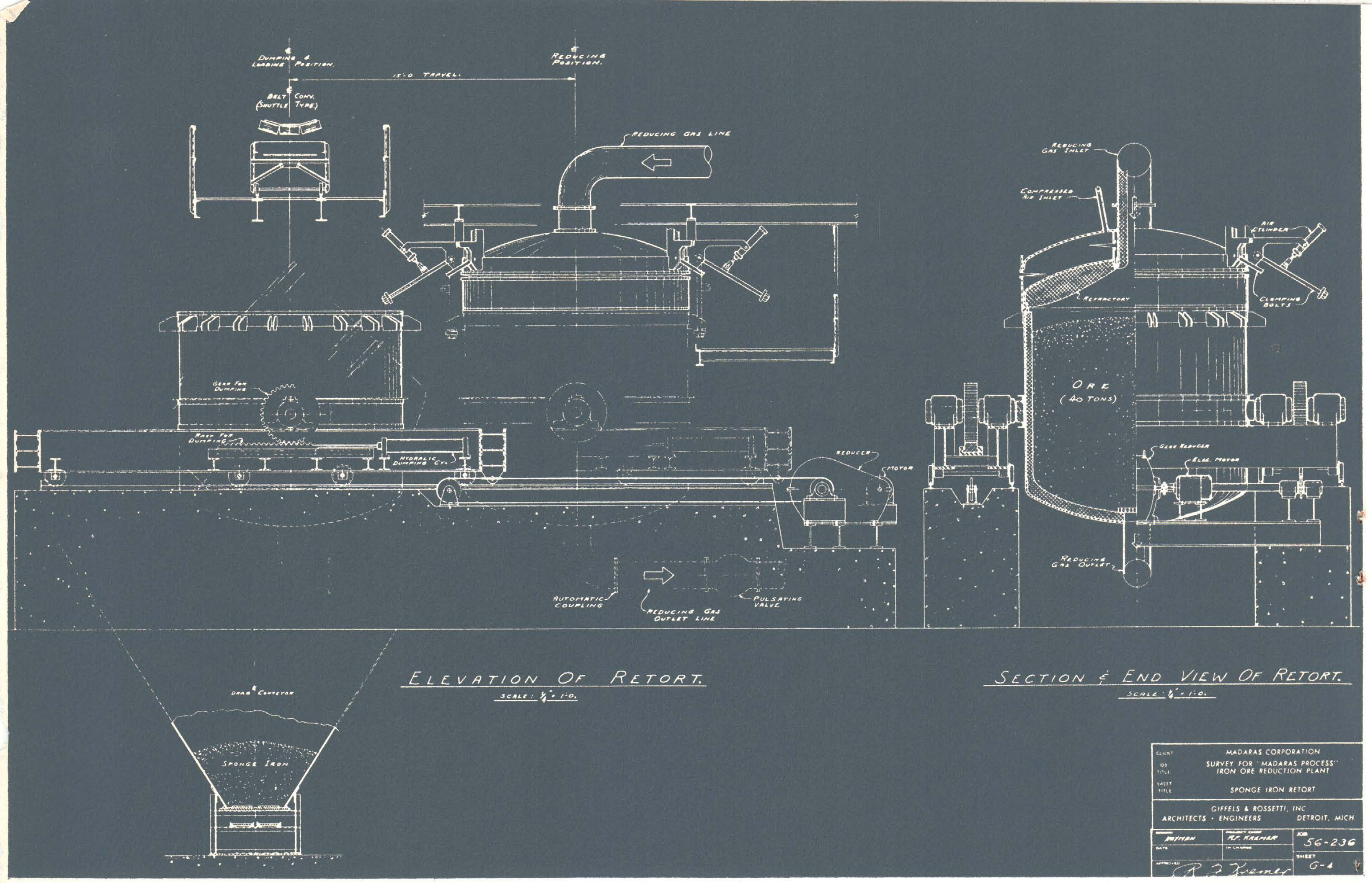
*Iron is made from iron ore which is oxidized iron mixed with various amounts of sand and clay and other earthy impurities. The impurities are called gangue. In making iron, the oxygen is removed from the iron—that is, the iron is deoxidized. This operation is called reducing the ore. The reduced ore, therefore, is solid iron mixed with the gangue. This is called sponge iron because of the porous nature of the iron after the removal of the oxygen.

The reduced ore then is melted so that the molten iron separates from the molten fluxed gangue which is called the slag. This really is what basically happens in the blast furnace where actually the ore reduces first in a solid form and then the reduced ore melts in the hot lower zone of the same furnace. In case of sponge iron, the reduced ore is melted in the electric arc furnace or, in some cases, in the cupola or open hearth.

An ancient classical way of separating the iron from the gangue was to heat the mixture to glowing bright (white) heat where the clay becomes molten but the iron is still solid. The molten clay then is squeezed out by either hammering or by squeezing. This iron is called wrought iron.

This wrought iron is usually soft but it becomes hard steel by carburizing. The famous Damascus sword was made this way, mainly from sponge iron made in India. In fact, practically all the steel was made by this method until the emergence of the Bessemer process.



MADARAS ORE REDUCTION PROCESS

Section and End View of Retort

On the right, the front view and the cross-section of the Retort and Retort Head are shown. The Retort is filled with iron ore. No unusually thick or costly construction is required, only a steel wall and a thin fire-brick lining.

In the middle of the unit the Retort is provided with trunnions, these resting on a moving rack, to move the Retort and dump the ore automatically.

Free swinging bolts pull the Retort tight to the pressure head. Arrows indicate path of reducing gas.

On left side, the Retort is shown disconnected, ready to be recharged with ore.

Reference Notes

The Monterrey, Mexico Plant

The first licensee of the Madaras process is Hojalata y Lamina, S.A. (HYLSA) of Monterrey, Mexico. This company is now making about 250 tons of high grade sponge iron per day and the work is on the way to expanding the plant to produce about 600 tons per day. The sponge iron is melted in the company's electric arc furnaces and the steel is rolled into sheets and strips. The quality of the products is exceptionally high.

After licensing "HYLSA" by Madaras International Corporation some of the old equipment originally erected and tested in Longview, Texas, was sold to "HYLSA", moved to Monterrey and put into operation. The plant was designed by Julius D. Madaras and the construction of the sponge iron plant and training of personnel to operate the sponge iron plant and melt the sponge iron were supervised by him and his engineers. The major equipment and the method of operation was also outlined and supervised by J. D. Madaras.

However, "HYLSA" has changed some of the gas equipment with the result that the gas consumption per ton of iron has increased more than twice over the gas consumption at our Longview plant as measured under the supervision of three American steel companies who also verified the log sheet of operation.

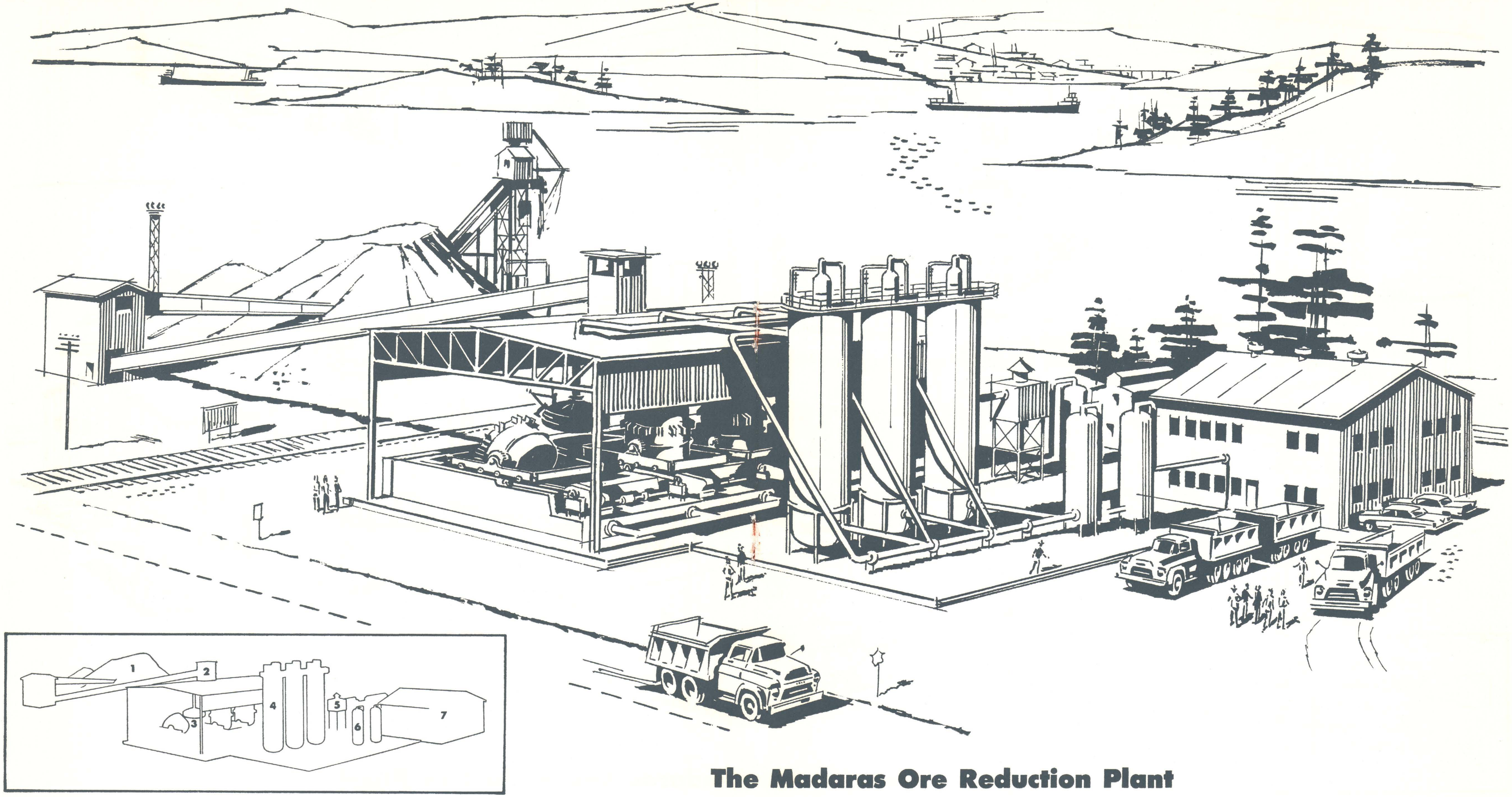
The test retort at Longview is about one-third larger capacity than the "HYLSA" retorts. "HYLSA" operates three retorts at present which are, of course, mechanized for production.

At first, "HYLSA" had an exclusive license for using the Madaras processes in Mexico.

In December, 1957, its contract with Madaras International Corporation was revised to the extent that "HYLSA" has released the exclusiveness of its license in Mexico and retained it only for the state of Nuova Leon in which Monterrey is located. Furthermore, "HYLSA" has paid a substantial amount in a lump sum to retain the Madaras license.

The Madaras Ore Reduction Plant

(Illustrated)



The Madaras Ore Reduction Plant

1 ***Iron ore pile.***

2 ***Ore conveyor system.***

3 ***Reducing retort discharging reduced ore.***

4 ***Gas heater and super reformer.***

5 ***Gas filter for removing dust from recirculated gas.***

6 ***Gas receiver and desulphurizer.***

7 ***Compressor room and analytical laboratory.***

THE Madaras plant comprises compact, standardized units that easily can be manufactured in multiples and assembled and installed economically, at comparatively low cost, near the source of the ore or as a supplement to present existing plants.

In many regions it will be far more economical to make iron near the source of ore with gas and process it either into pig iron and steel ingots at site or to ship the sponge iron to the existing melting and refining furnaces. With the Madaras Ore Reduction Plant it is possible to utilize numerous substantial ore deposits that are not economically suitable for present methods either because of their location or because of their physical and chemical composition.

The process can bring about the decentralization of the production of iron and steel. It will free the production of iron from coking coal. It will serve national defense, national economy and conservation of natural resources. It is the modern answer to the critical steel producing problems of the day, not the least of which are the continually mounting plant and labor costs.

The MADARAS ORE REDUCTION AND STEEL MAKING PROCESS

Biography—Julius D. Madaras

Julius D. Madaras, inventor of the Madaras Ore Reduction process, was born in Hungary on April 10, 1894.

Studying engineering subjects in Paris, he was caught in the web of World War I and with 1200 scientists, artists, writers, engineers and explorers was interned on the island of Corsica. The four and a half years in the company of such illustrious associates greatly contributed to his scientific knowledge and his interest in the humanities. On his release he attended courses on engineering and scientific subjects in Zurich and later in Berlin.

Returning to Hungary in 1920, he came to the attention of the American General Bandholz, High Commissioner of the Allied Forces then occupying the country. Through the General's personal interest in Madaras and his scientific career, Madaras was able to come to the United States and continue his studies at Michigan State University and at the University of Michigan.

Soon after arriving in the United States he founded the American Hungarian Foundation for the purpose of bringing scientists and engineers together from both countries to work on problems of mutual scientific and cultural interests. Through this philanthropic activity he was able to meet leading American scientists, economists, university and college presidents, statesmen, churchmen and leading businessmen.

In 1924, he came to the attention of Henry Ford who set him to work on assembly line and production problems, with a view to simplifying these and allied activities.

Later, he joined Allied Engineers, Jackson, Michigan. This organization handled the engineering work for the Commonwealth and Southern power and gas utility groups. This gave him an opportunity to advance his work on the Madaras Rotor Power Plant and to meet important power utility executives. The process involved the generation of electric power from the wind through the use of giant rotating cylinders mounted on flat cars set on a circular railroad track. The seven largest utility companies in the country were impressed and financed a two thousand kilowatt unit. Tests proved 30 per cent beyond expectation. The process seemed destined for commercial production, but along came 1933—bank closures and the collapse of five of the seven utility companies involved.

Recognizing his ability and original approach to power problems, Dr. Oswaldo Aranha, then the Brazilian ambassador to the United States, was instrumental in having his government invite Madaras to Brazil to study its power problems.

While Brazil was rich in high-grade iron ore and other ore deposits, like in other South American countries, there was a complete lack of essential coking coal. The problem led Madaras to invent his process for reducing iron ore directly through use of natural gas.

The MADARAS ORE REDUCTION AND STEEL MAKING PROCESS

MADARAS CORPORATION 550 W. Lafayette Boulevard
Field Office: Longview, Texas
DETROIT, MICHIG

erating equipment. The hot gas is passed upward through the ore. Some of the used gas is regenerated and recirculated. This process is adaptable only to ores of special hardness and grain. The use of electric power is excessive and the cost of equipment is high. The plant capacity is limited to well below 100 tons of iron per day.

The Fluidized Bed

This is a gaseous reduction process. The ore is reduced in powdered form. The hot hydrogen is passed upward through the powdered ore which is maintained in a suspended agitated state. When hydrogen is used, the reaction is very cooling, the temperature is low where the heat efficiency is very low. If carbon monoxide is mixed into the gas it usually cracks into CO_2 and carbon which chokes the furnace and stops the whole operation. The control of heat and gas is difficult, the reduction is slow and usually incomplete unless excessive amount of gas is circulated through the ore. Nevertheless, several steel companies are experimenting with it. It is still in a laboratory stage.

The Herreshoff Furnace

This furnace has been tried for reducing iron ore with hydrogen during the War by a combination comprising the U.S. Bureau of Mines, two engineering organizations and two steel companies. Conducted at Government expense the process never really reduced iron. The very nature of this furnace is such that it is adapted for oxidizing the ore which is exactly the opposite of removing the oxygen from the ore.

Hoganas Process (Carbonaceous)

Crushed iron ore is mixed with coke or charcoal and charged into small open containers made from clay or stainless steel. A large number of such containers (usually hundreds of them) are placed on small cars. A whole chain of such cars is pushed through a tunnel that is fired into, similar to a brick burning tunnel. As the ore becomes heated it is reduced.

In this process the plant investment as well as the maintenance of the containers (saggers) is excessive, the plant capacity is small, the reduction of ore is incomplete. The Madaras licensee in Mexico had been using this process until the Madaras process plant was installed, whereupon the Hoganas furnace was dismantled and removed.

Miscellaneous Methods

Among other ore reduction methods is the *R-N* process. This is a further development of the Krupp-Renn process. The *Esso-Little* process is a fluidized bed, ore reduction process utilizing a higher temperature than the H-iron process.

Still another, the *Udy* process partially reduces the ore in separate equipment and finishes the reduction in an electric carbonacious smelting furnace.

Where special problems exist and where high original plant costs and high operating costs are not a deterrent factor, these processes, on a limited scale, more or less accomplish their purpose.

Methods of Ore Reduction

The iron is always reduced from the ore with reducing gas. This is always carbon monoxide (CO) and hydrogen (H_2). The whole basic chemistry of reducing iron ore is removing the oxygen of the oxidized iron by combining (burning) the oxygen with CO and H_2. The burned product is CO_2 and H_2O.

In nature the iron is combined with the oxygen in two forms: F_e20_3 which is called hematite and F_e3^04 called magnetite. The latter has about 50% of the magnetism of the fully reduced iron, while the former has no magnetism. In some ores the iron is combined with sulphur.

In general, iron is made by—

(1) *Smelting in the blast furnace and in electric furnace;* (2) *Mixing the ore with carbon and heating the mixture externally or in a rotating kiln. This method is called carbonaceous reduction which also includes the electric smelting;* (3) *Reducing the ore with gas (CO and H_2). The reducing gas is formed separately and is circulated through ore. This is the gaseous reduction method. The Madaras process belongs in this group.*

Krupp-Renn Process (Carbonaceous)

This process utilizes the rotating horizontal cement kiln for reducing the ore. A mixture of iron ore, coal and coke and limestone is charged through one end of a rotating kiln. Through the opposite end gas, oil or powdered coke is fired into the retort. As the charge becomes heated the ore is reduced. By adjusting the temperature in the furnace, the reduced iron becomes semi-fluid and forms beads or glomerules. The gangue and flux form slag clinkers in which the iron beads are imbedded. The whole charge is then cooled in water, broken up and the iron is extracted by magnets.

The plant cost is high (four times the cost of the Madaras process), fuel is excessive and expensive, thermal efficiency is low, the iron absorbs too much sulphur from the fuel. Maintenance of the refractory lining of the kiln is high.

This process has been adopted and developed for handling a particular type of low-grade granular ore where the gangue is mostly self-fluxing and is not amenable to easy or economic concentration.

Electric Smelting (Carbonaceous Process)

A mixture of iron ore, coke and limestone is charged into a stack type furnace. At the bottom of the furnace there are electrodes reaching into the furnace at an angle. The electric power provides the heat for the carbonaceous reduction and for melting the reduced iron and the gangue which forms molten slag with the flux.

Characteristics: It requires 2400-2500 kw/hrs. to make a ton of pig iron. That is about five times the power it takes to melt a ton of steel from cold scrap. The cost of power and of electrodes is excessive and practically prohibitive except at places where the power rate is very low and the high-priced steel products will absorb the high cost of power, electrodes and maintenance. Even at a high cost, this process is suitable only to small operation.

The Wiberg Process

This process reduces the iron ore with reducing gas. The plant consists mainly of a very tall stack approximately 100 ft. high, with 5-6 ft. thick wall and of gas regen-

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was a patriotic duty. Then, gradually, I received other confirming reports from engineers of recognized ability, with a reaffirming report from Giffels & Vallet on costs in producing sponge iron under the process and the cost of melting the sponge iron derived therefrom in electric furnace and, lastly, the report of Dr. Karl T. Compton, who, as you know, is the acknowledged leading scientist in the field of engineering. As a result of these supporting letters and reports many of my colleagues, to whom I had generally explained the process, became more and more interested from the standpoint of National defense and the economy of the country, and have indicated their support of the process.

In my service of 45 years, I have seen much history in the making. Scientific, industrial, economic and social history has always been made by the individuals who have been doing the new "impossible" things while the crowd in the grandstand has remained passive and exclaimed "it cannot be done". We need the new things. The greatness of this country is built on the individuals who do things. In this instance, I believe Mr. Madaras has accomplished something that will inure to the great benefit of our country.

I again respectfully suggest and urge, in view of the clarification of the Bureau of Standards' first and second reports, that you act favorably in the matter at this time.

(Hon.) A. J. Sabath, *Chairman*
A. J. Sabath, M.C.
House Rules Committee

June 30, 1951

Letter to Hon. Charles Sawyer, Secretary of Commerce, Department of Commerce, Washington, D. C.

It is further our viewpoint that the prevailing philosophy has been to prove that the process will not work rather than to give it a fair chance to work.

During this period of critical steel shortage, it is obvious to us that the appropriate governmental agencies must promptly take the affirmative action and I hope you will promptly lend your efforts in that behalf.

MELVIN A. PRICE, *Chairman*
Special Subcommittee Investigating
the Madaras Ore Reduction Process

November 27, 1951

Excerpt of letter to Hon. Charles Sawyer, Secretary of Commerce and to Hon. Oscar Chapman, Secretary of Interior, Washington, D. C.

The chairman of the Metallurgical Committee of the National Academy of Sciences who, incidentally, depends on the steel companies for business, disregarded all favorable opinion of other members and, instead, delegated Arthur G. McKee & Company—the largest blast furnace builders, mind you—to report on the process. They found no objection to the soundness and economy of the process, but they reported, in effect, that the Madaras process would interfere with blast furnace practice and, therefore, it should not be used. This report was transmitted by the National Academy of Sciences as its own and, needless to say, Government support for the process was blocked.

Sincerely yours,
(Hon.) A. J. SABATH, *Chairman*
House Rules Committee

June 29, 1951

Excerpt of letter to Hon. Charles Sawyer, Secretary of Commerce, and to Hon. Oscar Chapman, Secretary of Interior, Washington, D. C.

Before concluding I wish to add a little personal explanation how I became and stayed interested in the Madaras process.

During the First and Second World Wars I devoted much time and study to various inventions which I considered important to the Government and to the country. At the outbreak of the Korean trouble I was approached by several small steel fabricators in my District who were almost desperate for steel. About this time a very able engineer, whom I have known for a long time and who never met Madaras, told me about his process. Shortly afterward, I met Madaras, spent several evenings with him, discussing the process and reading his references and brochures. Then I did some more checking of my own on him, his process, his associates and Giffels & Vallet, Inc., engineers, of Detroit, Michigan. I became convinced that giving as much help to bring this process into use

Preface

Our industrial civilization is based on iron. The free and abundant use of iron means not only economic freedom but also national security and political power. The problem of iron production, therefore, is no longer only a matter of national economy, but also a concern of national defense and, indeed, of national survival.

The early method of making iron was with charcoal and coke. But the iron contained impurities and an excessive amount of carbon, which made it unusable for steel making. The invention of the Bessemer process started greater production of steel from pig iron. After that, the advent of the open hearth made possible the refining and the production of better quality steel, and brought the mass production of steel under control. This created the present industrial age.

With the advent of the early mass production of steel, iron was produced on a small scale by the undeveloped blast furnace. As the demand for iron increased, the size and output of the blast furnace was pushed to the limit. With the blast furnace, however, production of iron was tied to the coking coal which was found only in a few regions. The iron ore had to be transported to the source of coking coal hundreds or even thousands of miles, with the result that the comparatively few deposits of coking coal practically dominate our industrial and economic life.

At the same time, the iron ore regions themselves are left in economic servitude and so to a considerable extent are most consumption areas. These areas are now ready for intensive industrialization, and the key is cheap steel made locally.

For many years high grade ores were abundant, the demand for steel was small, and labor was cheap. Thus the production of pig iron was acceptably cheap and satisfactory. Now, however, the demand for steel has increased enormously at the same time the high grade iron ore is being exhausted. It will be costly to produce concentrates from low grade ores.

In every step of producing iron, costs are rapidly increasing, in mining, concentrating the ore, transportation of ore and coal, and operating and maintaining the furnaces. Furthermore, we have exhausted most of the accumulated steel scrap and what is left is badly contaminated, making it even more difficult to provide a suitable supply of melting stock for making steel.

It has been recognized for over a hundred years that important advantages would accrue from a process of using gases to reduce iron ore and other oxides in quantity without the costs and complications inherent in the blast furnace.

Under the pressure of economic need, in practically every industrially conscious country in the world, intensive research and experiments have been conducted to find and develop a practical ore reducing process, and great sums of money have been expended for this purpose.

A few processes resulted that worked on a small scale, but all failed when tried on a large industrial basis. In every case, the failure has been due to difficulties that are so evidently inherent in the processes themselves.

The Madaras process has succeeded where others have failed. It is a *commercial* and *industrial* success. It is a process that can be utilized to produce iron and steel in a low cost, economically-operating plant with a capacity as small as 100 tons of iron or steel per day to as much as 10,000 tons per day. It utilizes reducing gas made from natural gas, coke oven gas, oil, or from hydrocarbons extracted from low grade coal and lignite, for making iron from ore and other metals from their oxides. This process brings the centuries-old chemical production of iron under mechanical control in this mechanical age.

The Madaras process additionally provides an efficient and economical method of melting continuously hot or cold sponge iron into highly refined steel or high quality pig iron.

witnesses, your brother Dr. Arthur Compton, was present and gave rather extensive testimony on the problem before the committee, the net effect of his testimony being a strong recommendation that the Government immediately encourage, by loan or grant, the erection of a 100-ton plant, it being agreed by all interested parties that a plant of that size would not only provide a conclusive test of all present criticisms of the process, but might also be self-sustaining economically.

Referring again to Secretary Sawyer's letter of August 10 to Congressman Sabath, he states "in view of your great confidence in Dr. Compton, which of course I share, would it be agreeable to you to refer to him our correspondence and the reports that have been made to you and me, and ask his advice as to whether or not I should, without further research, authorize the expenditure of the sum requested by Madaras for the building of his plant at Longview?"

(HON.) MELVIN PRICE, *Chairman*

September 19, 1951

Summation excerpt of reply of Dr. Karl T. Compton, president, Massachusetts Institute of Technology, Cambridge, Mass., to letter of Hon. Melvin Price.

Perhaps the most direct way in which I can answer the question posed in your letter of 19 September 1951 is to say that, if I had the responsibility for making the decision, I would certainly approve an investment by the Government of between $2 and $3 million for the construction and early operation of a 100-ton Madaras plant.

KARL T. COMPTON

September 22, 1951

Excerpts from the Special Subcommittee on the Madaras (Steel) Process of the House Armed Services Committee appointed by Chairman Fred M. Vinson, February, 1951, Washington, D. C.

On the basis of the evidence presented to the Subcommittee, it is the conclusion of the Subcommittee that the prospects for the success of the Madaras process sufficiently outweigh the prospects of failure that a production development plant of 100 tons per day capacity should be constructed with financial assistance from the Government.

On the basis of the foregoing conclusion, it is the recommendation of the Subcommittee that financial assistance to the extent of $2½ to $3 million in the form of a loan, grant or combination of the two should be given by the Government.

MELVIN PRICE, *Chairman*
Special Subcommittee Investigating
the Madaras Ore Reduction Process
L. GARY CLEMENTE
LEROY JOHNSON

November, 1951

Excerpts from the Report and Recommendation of the Special Subcommittee on the Madaras Process (Steel) of the House Armed Services Committee—November 27, 1951

The Madaras Ore Reduction Process was brought to the attention of the House Committee on Armed Services in February, 1951. Subsequently for the first time in the history of the United States Congress a special subcommittee was appointed to study an industrial process. Hon. Melvin A. Price was appointed chairman of this Special Subcommittee Investigating the Madaras Ore Reduction Process. Other members of the committee were Hon. L. Gary Clemente and Hon. LeRoy Johnson.

On the basis of the study of the process and the testimony of scientists and production experts as well as members of Congress, the committee subcommittee unanimously recommended "that financial assistance to the extent of $2.5 to $3 million in the form of a loan, grant or combination of the two should be given by the Government." Why this financial recommendation did not become a reality is shown by the transcripts of the various forms of opposition adoption of this far-reaching revolutionary iron reduction process encountered.

Transcript of testimony given by Dr. Arthur H. Compton before Special Subcommittee Investigating the Madaras Ore Reduction Process, September, 1951.*

Mr. Price. In the common lay language, so the ordinary man could understand it, what would be the advantages in this process?

Dr. Compton. I would consider the advantages—first, the lower cost, if one can rely, as I believe one can, on the cost estimates made by the engineering firm of Giffels and Vallet.

Second would be the fact that there is no scrap needed, which would make steel production go ahead without the need for obtaining scrap.

In the third place, the process can be carried out in widely dispersed areas and need not be confined in the neighborhood of a combination of coking coal and iron ore. That would make it available to areas such as the Pacific Coast, the Mississippi Valley, the south coast, the northeast coast, and so on.

There are a number of other secondary values such as, for example, the quality of the steel. The steel is free, thus produced, from alloys that come naturally with the scrap that is used. Thus to produce a steel of superior quality. That is the experience of, for example, the Swedes who use steel from sponge iron. Those would be typical advantages.

**Dr. Arthur H. Compton, who with T. R. Wilson was awarded the Nobel Prize in Physics in 1927, is presently Chancellor of Washington University, St. Louis, Mo. As head of the University of Chicago's Metallurgical Laboratory and the Manhattan District's Metallurgical Project for the production of plutonium for the atomic bomb, Dr. Compton had well over 600 skilled metallurgists working for him. His calculations and predictions in that monumental undertaking were subsequently proved to be entirely correct.*

Excerpt of letter from Hon. Melvin Price, chairman of committee, Special Subcommittee (of House Armed Services Committee) to Investigate the Madaras Process.

On August 10, 1951, Secretary of Commerce Sawyer directed a letter to Congressman A. J. Sabath, who has maintained a keen and continuing interest in the Madaras process, indicating his desire to have a Congressional Committee make an investigation which would be preliminary to any substantial investment of Government money in the Madaras process. Subsequently, Mr. Vinson, Chairman of the House Armed Services Committee, appointed a Special Subcommittee to make further inquiry. That Subcommittee of three, of which I am Chairman, held its first meeting on September 17. In addition to other

World Iron Ore Deposits

New Type Ore Reducer Retort Developed and Tested

Since the Bureau's investigations an entirely new type of ore reducer retort has been developed and tested. This retort permits the use of high reduction temperatures, extremely fast and uniform heating of the ore, fast circulation of the reducing gas, complete and efficient reduction, good temperature control and it eliminates any sticking of the reduced iron.

1. The Bureau of Mines report shows that the Madaras process utilizes reducing gases with full efficiency.

2. The ore is reduced as fast as the gas is circulated throughout the charge with your injection method and can be accomplished in less than one hour.

3. The melting and refining of the reduced iron is no problem whatsoever.

RALPH L. DOWDELL
Professor and Head of Department of Metallurgy
University of Minnesota

RICHARD E. TOWNSEND
Associate Professor of Chemical Engineering
University of Michigan

WILLIAM P. WOOD
Professor of Metallurgical Engineering
University of Michigan

January 15, 1951

Pulsating Pressure Best Approach to Production of Sponge Iron

The rate of reduction of iron ore with hydrogen is extremely rapid and only limited by the rate at which the reactants are brought together and the rate at which the products are removed. The use of a pulsating pressure to increase the rate factors controlling the reaction speed is novel and appears to be the best approach to the production of sponge iron. The principle appears to be sound and no doubt production rates, which are the chief drawback of other methods, could be reasonably high.

Further, practically all of the hydrogen is used in the reduction process.

Because of the low capital costs and low cost of operation the Madaras sponge iron process should be given further careful consideration as a means of increasing pig iron output as well as a scrap substitute in order to decrease operating costs.

JOHN STUKEL, *Development Engineer*
The Youngstown Sheet and Tube Company
Youngstown, Ohio

October 10, 1950

Offered to Finance Plant and Pay Royalty

The Madaras Syndicate has built and tested a commercial pilot plant of about four or five tons capacity in one charge. Executives and other officials of our company and our metallurgists witnessed tests, took samples of the sponge iron and analyzed them. As a result of our study of the process, we made an offer to Mr. Madaras to build at our own expense in our own yards a plant to produce a minimum of 100 tons of iron or steel per day. Our condition was that we would have an exclusive license of the Madaras invention in the United States for the manufacture of iron and steel used for wire products only and the rights to all other products would have been retained by Mr. Madaras and his associates. In addition to financing the plant, we also offered to pay some royalty for every ton of iron and steel produced.

We regretted that Mr. Madaras and his associates did not see fit to accept our proposition.

The cost of gas and iron ore delivered in Peoria may have been one of the reasons for their refusal to accept our proposition, hoping to find a more favorable location for the erection of their first plant.

W. H. Sommer, *President*
Keystone Steel & Wire Company
Peoria, Illinois

January 20, 1942

May Be Means of Establishing a Sound Commercial Operation

Where natural gas is available at low rates in localities in the proximity of hematite ores of sufficient volume and iron content, the Madaras process may be the means of establishing a sound commercial operation.

Frank H. Adams
Vice-President and General Manager
Surface Combustion Division of
General Properties Company, Inc.
Toledo, Ohio

January 27, 1942

A Uniform and Satisfactory Reduction of Ores

In tests we made we found the Madaras process using a pulsating pressure gave a uniform and satisfactory reduction of the ores we tested.

Frank H. Adams
Vice-President and General Manager
Surface Combustion Division of
General Properties Company, Inc.
Toledo, Ohio

January 27, 1942

UNITED STATES

While iron ore deposits are scattered all over the United States, the richest area is in the Great Lakes region. The main source of commercial grade iron ore is, of course, the Mesabi Range in Minnesota. Other important sources of iron ore are northern New York, Michigan, Pennsylvania, Alabama, Texas, Missouri, Utah, Colorado and California. These commercial grade ores are being rapidly depleted.

There are, however, huge deposits of lower grade ores from which very high grade ore concentrates are being made or can be made. These low grade deposits are expected to supply the country with iron for hundreds of years to come.

The low grade Taconite ore deposits in the Lake Superior region are probably the greatest known source of such ore in the world. Elsewhere in the country, there are many alluvial placer deposits containing substantial amounts of iron ore. Probably the largest of this type is in Arizona. Here such deposits are estimated to contain several hundred million tons of iron oxide economically recoverable by magnetic concentration.

CANADA

Canada has large deposits of high grade as well as low grade iron ores. The large Labrador ore deposits as well as the central Quebec and other eastern Canada deposits are the most extensive. They are either already being fully exploited chiefly by the major United States steel companies or exploitation is being planned.

The Lake Superior region of Canada contains much high grade ore. In addition there are practically inexhaustible deposits of low grade Taconite and Jasper ores.

Many known ore deposits are located in western Canada and particularly in British Columbia. This province is particularly rich in minerals. And when need for more iron ore develops, other extensive deposits are sure to be found and exploited.

LATIN AMERICA

Latin America has by far the greatest share of the world's known high grade iron ore deposits.

Venezuela has deposits running into hundreds of millions of tons each. Their exploitation is just beginning. As it is normal in mineral-rich countries, when the need for iron ore develops, new deposits are usually discovered far beyond present expectation.

Brazil has the richest and most extensive iron ore deposits known. It possesses mountains of almost pure iron oxide. There are hard as well as fine powdery ores. It is logical to expect that when need arises for more ore, other rich deposits will be discovered.

Since there is no adequate source of coking coal in Brazil or in the neighboring countries, gaseous reduction is the only possible way for processing these ores into iron in Brazil.

Mexico, Peru, Chile, Argentine and other Latin-American countries are all rich in iron ore. Many celebrated high grade deposits are known or being exploited and new deposits are being discovered all over these countries.

EUROPE

Europe has only a few rich and extensive iron ore deposits, mainly in Sweden, Spain, England, eastern France and some in western Germany. Low grade ores are scattered in many countries behind the Iron Curtain. Rich ore deposits are in Poland, Czechoslovakia and mainly in the southern and eastern part of Russia.

ASIA

In Asia the most extensive deposits of high grade iron ores are in India, China and Asiatic U.S.S.R. While in general the explored deposits are not as extensive and rich as on the American Continent, they are adequate for their need. Many of the Asiatic islands have rich deposits. However, the most industrial island country, Japan, is singularly lacking in commercial grade iron ore.

AFRICA

Rich iron ores are scattered in south, middle and northern parts of Africa. Liberia has some of the highest grade ores known. The only export is to the United States. Rich ore deposits have lately been discovered in Algeria.

AUSTRALIA—NEW ZEALAND

Australia is rich in iron ore deposits. Some of the deposits are extensively worked and many others are held in reserve. Until further exploration, their quantity cannot be estimated. New Zealand has vast magnetic sand deposits from which high grade magnetic concentrates can be easily and economically prepared.

May Eliminate the Problem of the Long Haul of Raw Materials

I am familiar with the Madaras process and believe that it would be, indeed, in the interest of National Defense and national economy that the Government cooperate in testing the plant and bringing it to a logical conclusion. Evidently, the process has solved some of the most difficult problems in gaseous reduction of iron ore, that is, the sticking of the iron, handling the gas, and mechanically controlling the production of iron. Should the process prove to be successful, it may eliminate, in some cases at least, the problem of long haul of raw materials, and may quickly provide an additional source of iron (i.e.—not pig iron) and steel, so badly needed under the present emergency.

BRADLEY STROUGHTON, *Chief*
Heat Treating Equipment
War Production Board
Washington, D.C.

March 26, 1942

Good Standard Grades of Steel from the Sponge Iron

We melted the sponge iron (produced by the Madaras Process) and made good standard grades of steel.

GERALD SMITH, *Manager*
Sollberger Engineering Co.
Marshall, Texas

November 30, 1950

Complete Removal of Phosphorus Would be Effected

If my phosphorous data are correct for the Texas and Arkansas ores, I see no serious objection to the use of the basic electric furnace for remelting the reduced iron and virtually complete removal of the phosphorus would be effected in that process.

KARL L. FETTERS
Ass't to the Vice-President
in Charge Operations
Youngstown Steel and Tube Co.,
Youngstown, Ohio

January 9, 1951

Provides a Sound Basis for an Industrial Process

His (Madaras) ability to make sponge iron has not been questioned . . . he has operated in a manner which could be considered as sufficiently advanced to provide a sound basis for an industrial process.

A. V. ASTIN, *Associate Director*
National Bureau of Standards
Washington, D.C.

June 19, 1951

Soundness of Process Demonstrated

We have followed the progress and development of your process from the time of testing your pilot plant at the University of Michigan. The soundness of your process was soon demonstrated. . . .

William R. Wood
Prof. of Metallurgical Engineering
Richard E. Townsend
Asst. Prof. of Chemical Engineering
University of Michigan

June 16, 1947

Should Succeed on a Larger Scale

Under my supervision, a semi-continuous process was developed whereby this molten sponge iron was melted in an electric arc furnace of orthodox design, the molten iron was refined and made into steels of various commercial compositions. These steels had entirely normal properties. All technical difficulties were apparently overcome . . . I see no reason why it (the process) should not succeed technically on a larger scale.

C. E. Sims, *Supervising Metallurgist*
Battle Memorial Institute
Industrial and Scientific Research
Columbus, Ohio

January 20, 1942

Have Made Very Good Grade Steel from the Sponge Iron

I have melted several charges of sponge iron produced by Southwestern Metals, one from Texas ores as well as Minnesota ores. We have made very good grade standard steel from the sponge iron and made standard steel castings for the market. I feel certain . . . that sponge iron can be melted economically in any desired commercial quantity.

W. E. Linville
Sollberger Engineering Co., Inc.
Marshall, Texas

November 16, 1950

Convinced of Practicability of Madaras Process

For the past few years we have melted a large quantity of sponge iron produced by the Madaras process in our electric furnaces.

We are convinced of the practicability of the Madaras Process and feel that it will soon take place in the industry of the nations.

Roy E. Hearne
Executive Vice-President
East Texas Electric Steel Co., Inc.

November 23, 1950

The Madaras Ore Reduction Process

Comments and Testimonials on Process

Operation Proceeded Smoothly

The Bureau of Mines' tests at Longview, Texas, have demonstrated that reformed Texas natural gas can be produced and can be used in the plant of the Madaras Steel Corporation for the reduction of Texas iron ore to sponge iron. This sponge iron was melted in a commercial electric furnace with a recovery of 96% of the total iron which operation proceeded smoothly and without difficulty.

R. R. Sayers, *Director*
Bureau of Mines
U.S. Department of the Interior
Washington, D.C.

November 29, 1943

Offers to Build Plant at Own Expense

As a result of our study of the process, we made an offer to Mr. Madaras to build at our own expense in our own yards a plant to produce a minimum of 100 tons of iron or steel a day.

W. H. Sommer, *President*
Keystone Steel & Wire Company
Peoria, Ill.

January 20, 1942

No Other Process Provides this Mechanical Control

The process (Madaras Ore Reduction) is of utmost simplicity and its operation is self-evident. It not only eliminates the troublesome sticking of iron ore, the nightmare of all other processes, and operates with good gas efficiency, but it can also operate on almost any scale as fast as the gas is pumped through the ore with that particular changing pressure that forms the basis of the process. In other words, this process produces iron as fast as the gas is pumped through the ore. This mechanical control of production of iron, in my opinion, is an essential and most desirable feature of any industrial plant and no other process has been able to provide this mechanical control.

Ralph L. Dowdell, MET. E.M.S. Ph.D.
St. Paul, Minn.

March 26, 1942

automatically and need no refractory lining; efficient gas cracker; method of quick heating of ore and automatic heat control and other operations. Complete demonstrations were made to a large group of delegates from many steel and engineering companies. This demonstration included all operations: ore handling, heating and reducing, gas cracking, heat control, melting the produced sponge iron and making steel from it.

1949 and 1950 *Building a large plant.* Buildings and other facilities were extended or added, large industrial size gas cracker and large ore reducers were added and tested. The cost of this step alone amounted to over $300,000.00. Through this work all new equipment and operations were fully worked out on an industrial scale.

1953 *Contract with Hojalata y Lamina, S.A. of Monterrey, Mexico.* License was granted to Hojalata y Lamina, S.A. (HYLSA) for the use of the Madaras processes. The first plant produced about 35 tons of iron a day.

The plant was designed, erected, and the operating crew trained, and the efficient melting of the sponge iron was worked out under the supervision of Julius D. Madaras.

In 1956 the plant was enlarged to produce 250 tons of iron per day and work is now in progress to expand the plant capacity to produce 500-600 tons of iron per day. After this, still further increase is contemplated.

1956 *Formation of Madiron, Inc.* This new company was formed to finance the expansion of the plant at Longview. New gas reforming and gas recirculating equipment was added.

Controls for temperature and quality of gas were installed. A large new retort to reduce 10 tons of iron in one charge was erected. Many carloads of ore from Texas, Venezuela, Tucson and other places were reduced under the supervision of various interested steel companies and sponge iron was melted in their own large commercial electric furnaces. At least 40 delegates from various steel companies witnessed tests. All phases of the Madaras industrial plant of any desired capacity have been worked out to design, erect and operate any size commercial plant.

1957 Substantial additions were made to the plant at Longview, Texas. Catalytic gas reforming, super reforming and gas recirculating equipment were added on a scale that is considered industrial. A large ore reducing retort was installed to make over ten tons of iron in one charge. This size retort is large enough for a 200-ton a day iron plant.

In these units several types of iron ores in lumpy and pelletized forms from the United States, South America and Canada were reduced. Hundreds of tons of sponge iron were made for a number of steel companies under their supervision. These steel companies melted the sponge iron in their own large industrial furnaces with excellent results and stated that the Madaras process is ready for industrial plants of any desired capacity.

The Madaras process makes iron and steel with reducing gas directly from the iron ore. No coke is needed to reduce the iron from the ore, nor is scrap necessary to make steel from the iron.

The reducing gas (hydrogen and carbon monoxide) is economically obtained with standard equipment from natural gas, oil, low-grade coal or lignite, whichever is more readily available in any particular region.

A plant based on this process costs about one-fourth or less of the cost of the blast furnace and coke oven of the same iron capacity. In addition, there is much saving on fuel, labor, maintenance and capital charges. In many regions the total savings can amount to from $20.00 to $25.00 or more per ton of producing steel.

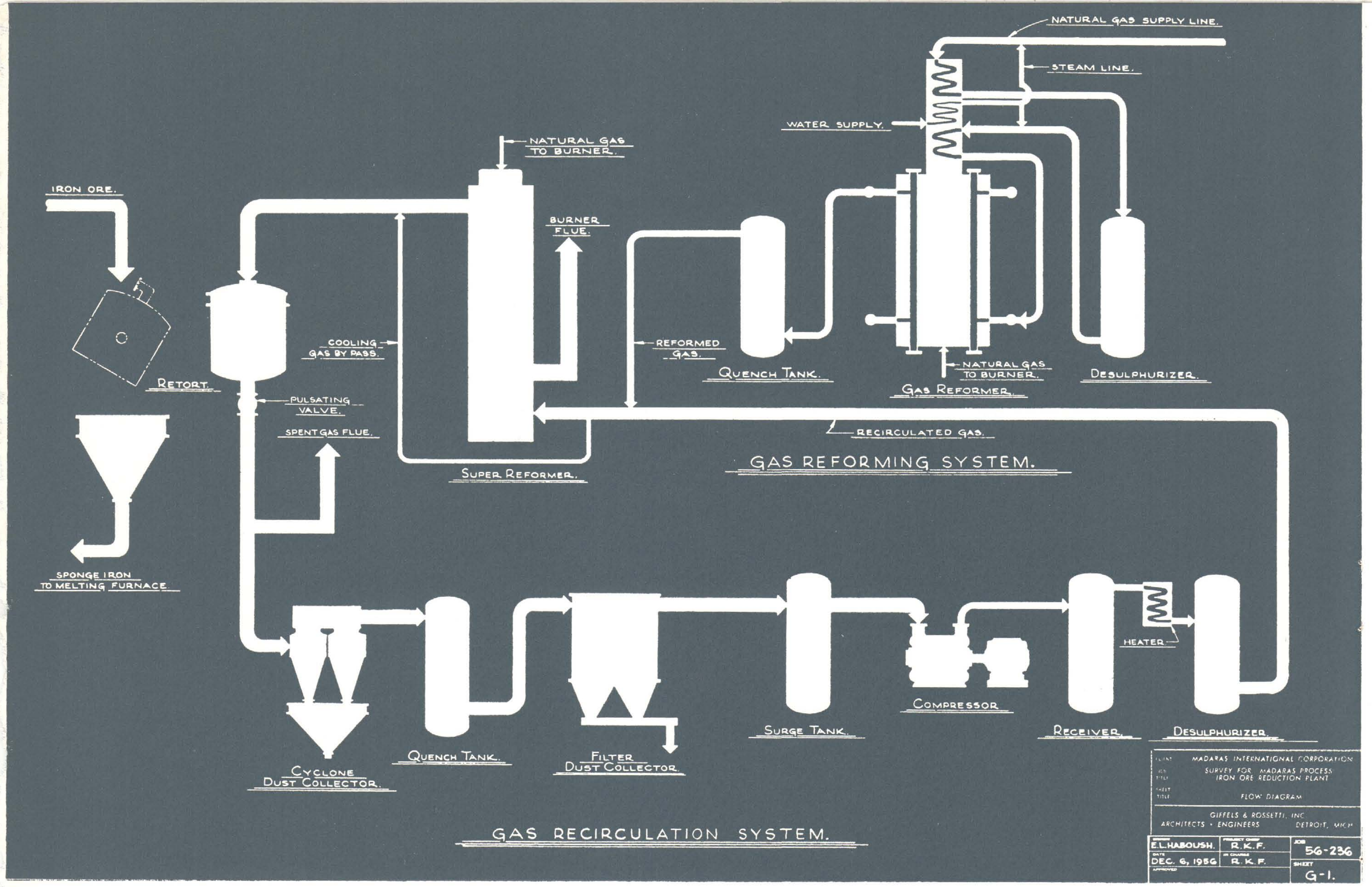
The Madaras plant can be built and operated commercially and profitably on a small or large scale ranging from 50 tons of iron a day to any desired capacity.

The process can use low-grade iron ore deposits not usable in the blast furnace but, of course, the higher grade ores are desirable for maximum savings in ore reduction.

The Madaras process works as follows:

A steel pressure retort is filled with cold or hot crushed iron ore or iron ore pellets and sealed gas-tight. Hot reducing gas (hydrogen and carbon monoxide) is injected into the retort through an exclusively designed inlet valve. The gas mixture penetrates the whole mass of ore. The hot reducing gas reacts instantaneously with the iron oxide, combining with its share of oxygen. The exhaust valve is opened, and the spent gas is discharged. By automatically alternately opening and closing the two valves, fresh reducing gas is passed through the whole mass of ore in a pulsating manner until all the oxygen is carried out and the iron ore is reduced.

In further explanation, the hydrogen (H_2) burns with the oxygen to form H_2O or water vapor. The CO burns into CO_2. The H_2O (steam) is condensed out of the exhaust gas. The remaining gas of the H_2, CO and CO_2 is mixed with fresh hydrocarbon gas and is passed through a gas reformer. Here the CO_2 is reformed to 2CO, according to the formula of $CO_2+CH_4=2CO+2H_2$. The heated reformed gas is recirculated through the ore. At an early stage of reduction the reducing gas oxidizes almost completely to CO_2 and H_2O and is exhausted into the atmosphere. In this manner the reducing gas is handled in a closed circuit and is almost completely utilized. In an industrial operation, from 6 to 8 charges of ore may be reduced in each retort in a 24-hour day.



MADARAS ORE REDUCTION PROCESS

Gas Recirculation System

The bottom row of the diagram illustrates the gas cleaning and recirculating system. The spent gas, as exhausted from the retort, contains some dust and much CO_2 and H_2O. The dust is removed by a cyclone separator and dust filter and the water vapor is removed through a quench tower.

The remaining unreacted CO, H_2 and CO_2 is recompressed and with the added CH_4 gas is passed through the hot Super Reformer where it is regenerated into 2CO and $2H_2$ and is passed through the Retort. Thus, the reducing gas is practically completely utilized.

After reduction the sponge iron is dumped from the Retort as shown at left, the Retort is filled again with another charge of ore and is reconnected into the gas circuit.

The iron ore is charged into the Retort, illustrated at the left of the diagram.

The natural gas or oil gas is mixed with steam and passed through a standard, commercial gas Reformer making a gas mixture of CO, H_2, CO_2, CH_4 and H_2O (steam). The H_2O is condensed through in water quench tower.

The reformed gas with its CO_2 content is passed through the hot Super Reformer where the CO_2 and CH_4 form 2CO and $2H_2$. This mixture of hot reducing gases at 1700°-2000° F. will pass through the ore in the Retort in a pulsating manner.

Chronology of Development of Process

1936 *Invention.* The Madaras process was invented and the theoretical factors worked out by Julius D. Madaras in Brazil while working on power problems by invitation of the Brazilian Government.

1937 *Syndicate.* A syndicate called Madaras Ore Reduction Project was formed to finance the development and tests of the process and to carry on all activities in an organized way. Members were a group of businessmen and engineers.

1937 *Laboratory tests.* At the University of Michigan extensive laboratory tests and development work were carried out with ores from different parts of the world. The University report stated in effect that the process is sound and efficient, it works and overcame all difficulties inherent in other processes. (See Brochure, Univ. of Mich. report pages 12-14.)

1938 *Pilot plant test.* A commercial pilot test unit was built and tested at Peoria, Ill. This unit reduced 5 tons of ore in one charge. It worked well and established the soundness of the process on a larger scale. (See letter Mr. W. H. Sommer, Pres. Keystone Steel & Wire Co.)

1939 *A further pilot unit* of modified design was tested to obtain design factors for larger commercial units. This unit also worked equally well for treating tin ores. (See letters from Surface Combustion Corporation, Battelle Memorial Institute and Ralph L. Dowdell.)

1940 *Industrial Unit at Longview.* A commercial size unit reducing about 15 tons of ore in one charge was erected with compressors and all other plant equipment. Also this retort reduced the ore with a theoretically possible maximum efficiency and proved that the process works and is practical on any large scale needed by the steel industry. This development and test work reached into 1942. Approximately $300,000.00 were spent on this plant and tests.

1942 *Bureau of Mines tests.* The Bureau of Mines tested the plant at Longview from 1942 to 1944. The Director of the Bureau of Mines reported that the process worked with maximum gas efficiency, the sponge iron melted easily and the difficulties encountered were only mechanical. (See letter by R. R. Sayers, Director of U. S. Bureau of Mines.) The Bureau's report R.I. 3925, 1946, confirmed these conclusions. The report also stated in effect that the plant cost will be about one-fifth of the cost of blast furnaces and coke ovens; that there will be great saving on fuel and that the cost of iron produced by the process at Longview will be about $17.00 per ton. (See R. I. 3925, page 55.)

1947 *Southwestern Metals, Inc. was formed and resumed work.* All needed new types of plant equipment were worked out and tested. Among them are: retorts that can operate

Interest in Direct Reduction Boosted by Cheap Natural Gas

The rising investment cost for coke ovens and blast furnaces to smelt pig iron, the discovery of some extremely rich natural ores, and improved procedures for beneficiating lower grade iron ores have resulted in increased interest in the manufacture of sponge iron. Gradual deterioration in quality of metallurgical coking coal is further stimulating interest, particularly in areas where natural gas is plentiful and economically advantageous.

T. F. OLT, *Director of Research*
Armco Steel Corp., Middletown, Ohio

STEEL, *January 6, 1958*

The resulting hot reduced ore, that is, the hot sponge iron,* is discharged from the ore reducer through a large door. The sponge iron may be melted into steel or rolled into natural wrought iron products. By preparing the iron oxide especially for the purpose, the iron powder may also be produced for powder metallurgy.

In the Madaras process the carbon content can be controlled easily within the limits of .005% to 5%. The sulphur found in the ore is burned out with hot air or carried out with the hydrogen. No impurities are added in the course of reduction. Iron superior to pig iron and scrap is produced.

In all other gaseous processes, the gas is passed through the mass of ore in a continuous flow and the reduction depends upon the diffusion of the reducing gas into the pores of ore which at best is slow, inefficient and incomplete. The gas usually builds up channels through the ore.

In the Madaras process the repeated injection and exhaust causes pulsation of the reducing gas uniformly through the whole ore body and eliminates all the difficulties that are inherent in other gaseous reduction processes. The process gives the whole ore body a pulmotor or lungs and brings the ore reduction under mechanical control.

All other gaseous reduction processes have adapted equipment that was designed and intended for other usually opposing or entirely different chemical and thermal operations. Contrary to this, our aim has been to give natural and free vent to the thermodynamic forces interacting in the reduction of iron ores with gas, and when necessary, discover methods, invent equipment, designs and operating techniques including preparing and reforming the reducing gas and melting the sponge iron, most of which are unique and peculiar to this process.

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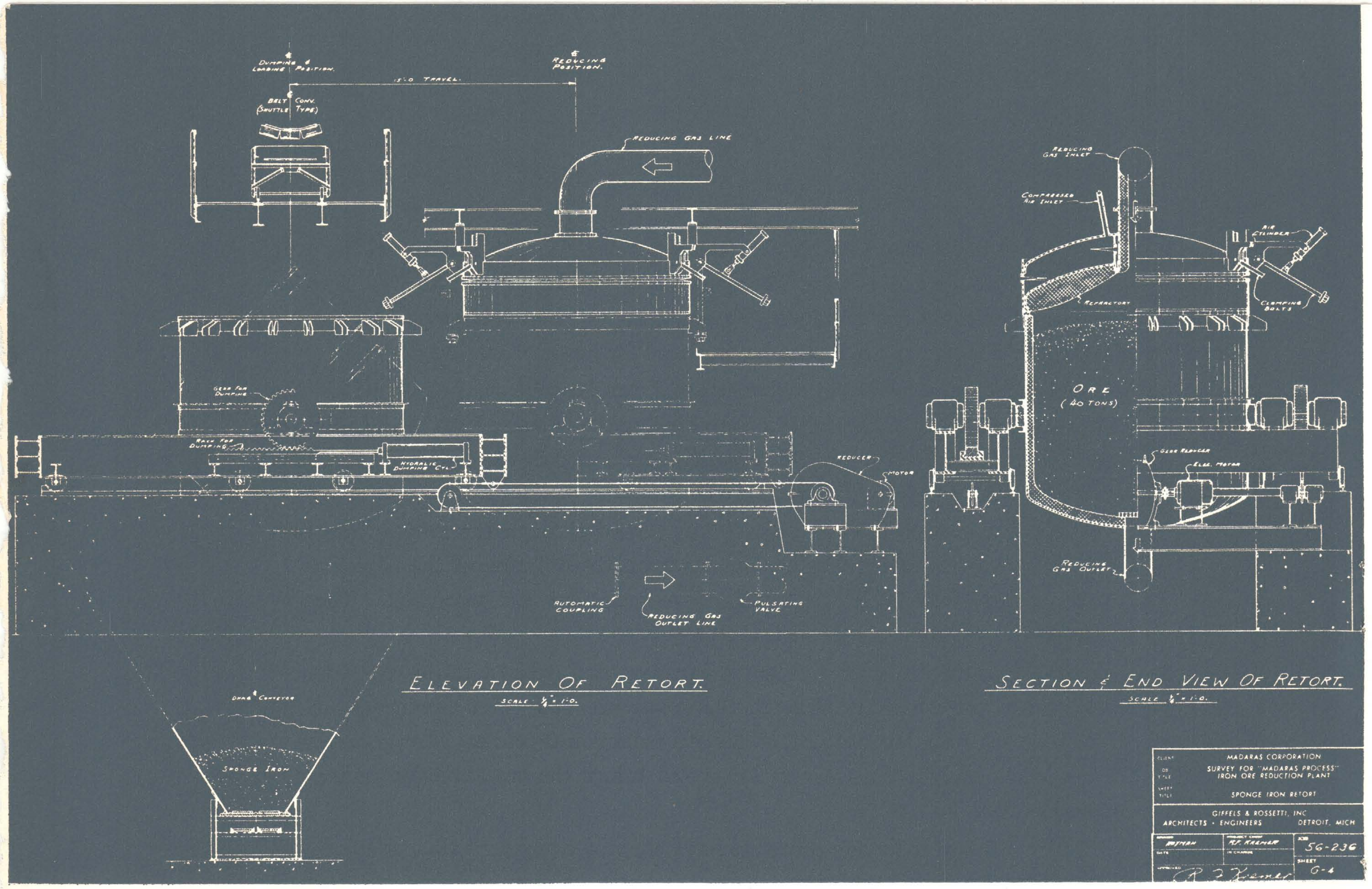
*Iron is made from iron ore which is oxidized iron mixed with various amounts of sand and clay and other earthy impurities. The impurities are called gangue. In making iron, the oxygen is removed from the iron—that is, the iron is deoxidized. This operation is called reducing the ore. The reduced ore, therefore, is solid iron mixed with the gangue. This is called sponge iron because of the porous nature of the iron after the removal of the oxygen.

The reduced ore then is melted so that the molten iron separates from the molten fluxed gangue which is called the slag. This really is what basically happens in the blast furnace where actually the ore reduces first in a solid form and then the reduced ore melts in the hot lower zone of the same furnace. In case of sponge iron, the reduced ore is melted in the electric arc furnace or, in some cases, in the cupola or open hearth.

An ancient classical way of separating the iron from the gangue was to heat the mixture to glowing bright (white) heat where the clay becomes molten but the iron is still solid. The molten clay then is squeezed out by either hammering or by squeezing. This iron is called wrought iron.

This wrought iron is usually soft but it becomes hard steel by carburizing. The famous Damascus sword was made this way, mainly from sponge iron made in India. In fact, practically all the steel was made by this method until the emergence of the Bessemer process.



MADARAS ORE REDUCTION PROCESS

Section and End View of Retort

On the right, the front view and the cross-section of the Retort and Retort Head are shown. The Retort is filled with iron ore. No unusually thick or costly construction is required, only a steel wall and a thin fire-brick lining.

In the middle of the unit the Retort is provided with trunnions, these resting on a moving rack, to move the Retort and dump the ore automatically.

Free swinging bolts pull the Retort tight to the pressure head. Arrows indicate path of reducing gas.

On left side, the Retort is shown disconnected, ready to be recharged with ore.

Reference Notes

The Monterrey, Mexico Plant

The first licensee of the Madaras process is Hojalata y Lamina, S.A. (HYLSA) of Monterrey, Mexico. This company is now making about 250 tons of high grade sponge iron per day and the work is on the way to expanding the plant to produce about 600 tons per day. The sponge iron is melted in the company's electric arc furnaces and the steel is rolled into sheets and strips. The quality of the products is exceptionally high.

After licensing "HYLSA" by Madaras International Corporation some of the old equipment originally erected and tested in Longview, Texas, was sold to "HYLSA", moved to Monterrey and put into operation. The plant was designed by Julius D. Madaras and the construction of the sponge iron plant and training of personnel to operate the sponge iron plant and melt the sponge iron were supervised by him and his engineers. The major equipment and the method of operation was also outlined and supervised by J. D. Madaras.

However, "HYLSA" has changed some of the gas equipment with the result that the gas consumption per ton of iron has increased more than twice over the gas consumption at our Longview plant as measured under the supervision of three American steel companies who also verified the log sheet of operation.

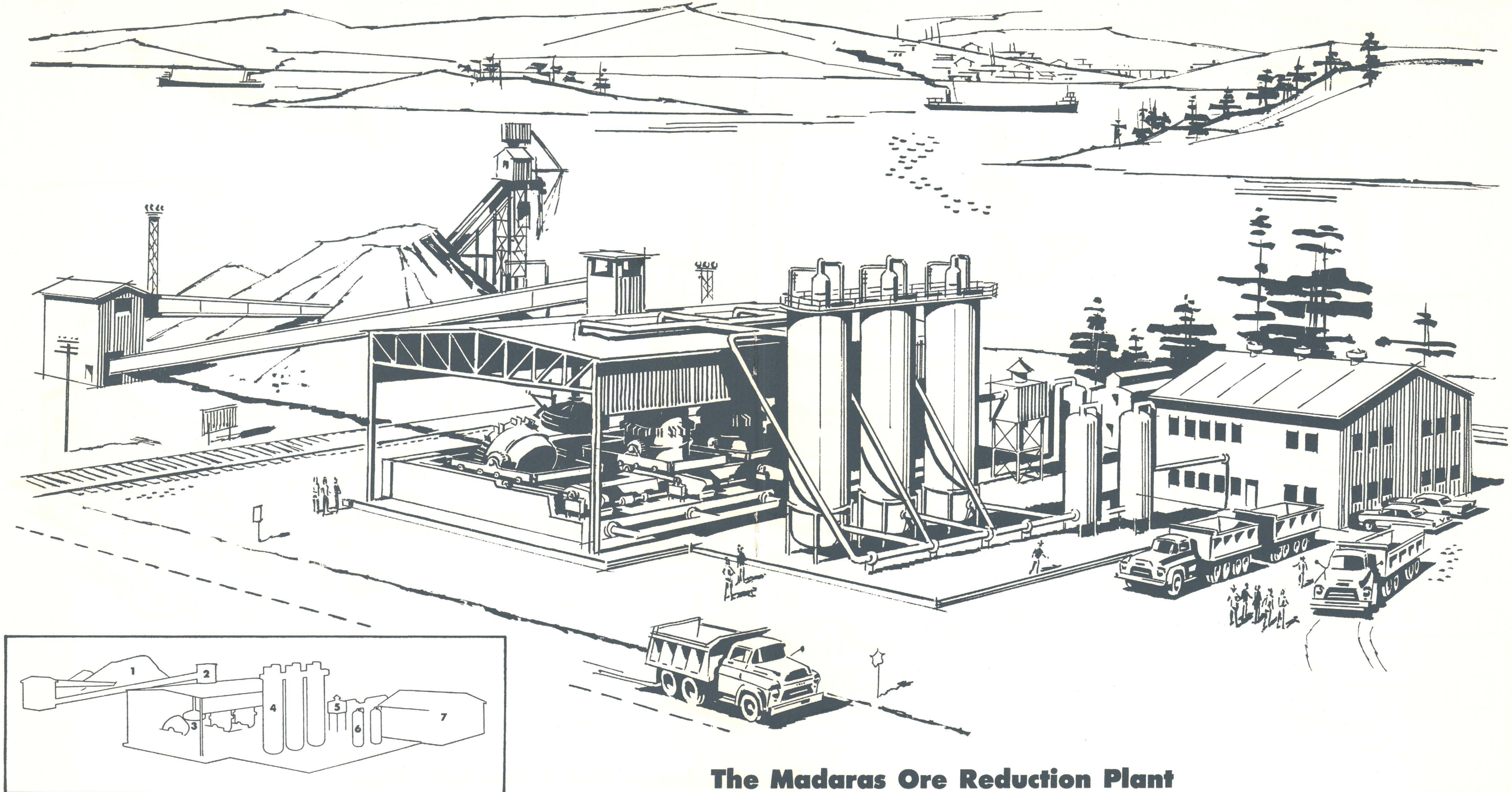
The test retort at Longview is about one-third larger capacity than the "HYLSA" retorts. "HYLSA" operates three retorts at present which are, of course, mechanized for production.

At first, "HYLSA" had an exclusive license for using the Madaras processes in Mexico.

In December, 1957, its contract with Madaras International Corporation was revised to the extent that "HYLSA" has released the exclusiveness of its license in Mexico and retained it only for the state of Nuova Leon in which Monterrey is located. Furthermore, "HYLSA" has paid a substantial amount in a lump sum to retain the Madaras license.

The Madaras Ore Reduction Plant

(Illustrated)



The Madaras Ore Reduction Plant

1 ***Iron ore pile.***

2 ***Ore conveyor system.***

3 ***Reducing retort discharging reduced ore.***

4 ***Gas heater and super reformer.***

5 ***Gas filter for removing dust from recirculated gas.***

6 ***Gas receiver and desulphurizer.***

7 ***Compressor room and analytical laboratory.***

THE Madaras plant comprises compact, standardized units that easily can be manufactured in multiples and assembled and installed economically, at comparatively low cost, near the source of the ore or as a supplement to present existing plants.

In many regions it will be far more economical to make iron near the source of ore with gas and process it either into pig iron and steel ingots at site or to ship the sponge iron to the existing melting and refining furnaces. With the Madaras Ore Reduction Plant it is possible to utilize numerous substantial ore deposits that are not economically suitable for present methods either because of their location or because of their physical and chemical composition.

The process can bring about the decentralization of the production of iron and steel. It will free the production of iron from coking coal. It will serve national defense, national economy and conservation of natural resources. It is the modern answer to the critical steel producing problems of the day, not the least of which are the continually mounting plant and labor costs.