TITANIUM METAL AS THE BASIS OF A POTENTIAL INDUSTRY IN THE PACIFIC NORTHWEST

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

TITANIUM METAL AS THE BASIS OF A POTENTIAL INDUSTRY IN THE PACIFIC NORTHWEST

CHAPTER I

INTRODUCTION

The phenomenal growth of the titanium metal industry is attributed to the metal's unusual properties of lightness, strength, and resistance to corrosion. Because of these properties, the government has provided financial aid in the development of the titanium metal industry for defense applications. Mr. N. E. Promisel, speaking from his experience with the Navy Department Bureau of Aeronautics, said, "Although interest in titanium was, in part, generated by (its) corrosion resistance, lack of magnetic properties, high electrical resistivity, low thermal expansion and so on, the major excitement and enthusiastic anticipation for the use of titanium has resulted from its high physical properties, or better stated, strength-weight ratios" (55, p.242).

In view of this rapid growth and industrial interest in titanium metal, this study is undertaken to survey the possibilities of the Pacific Northwest as a basis for a potential titanium industry.

The method of approach to this study is directed at the historical technological background, its method of production, and the geography of the present industry, in order to determine the present titanium metal plant location factors. These location factors were then used to determine the possibilities of the Pacific Northwest for a titanium metal industry.

Factual information was obtained from the following sources: Questionnaires sent to firms now engaged in titanium metal production (see Appendix No. 1); published reports and articles; personal interviews with staff members of the Bureau of Mines regional office at Albany, Oregon; and Mr. Stephen Shelton, former regional director of the Bureau of Mines at Albany, Oregon, who is now head of the Oregon Metallurgical Corporation at Albany, Oregon.

CHAPTER II

OVERVIEW OF TITANIUM METAL

History of Titanium

The history of titanium dates back to 1789 when the Reverend William McGregor, an amateur mineralogist, was engaged in an investigation of a peculiar mineral found in the black sand of Menachan in Cornwall, England (33, p.13). McGregor called the black sand "menachanite" after the locality in which he found it. During his analysis of menachanite, he discovered a new element which he called "menachite". Approximately five years later, in 1794, an Austrian chemist by the name of M. H. Klaproth was investigating the composition of the mineral "rutile" from which he discovered a new element (1, p.3). He gave it the name "titanium" after the Titans of Ancient Greek mythology, because of the strength of the chemical combination in which it was held. It was not until 1797 that Klaproth discovered, while in a subsequent investigation of the mineral "ilmenite", that menachite, as reported by McGregor, was identical to titanium (33, p.13). It was the name titanium that was adopted universally; due, perhaps, to the trend of scientists to name new discoveries after characters of ancient mythology.

Early attempts by chemists and metallurgists to isolate the new element were made by a number of investigators. Due to its high fusion point and strong affinities for oxygen, nitrogen, and carbon, these earlier attempts resulted in the production of nitrides or carbides; which, because of their metallic lustre, were mistaken for the metal itself.

The first titanium metal was produced in 1887 by a young Swedish chemist Axel Hamberg (1, p.3), but it was badly contaminated. His investigations were reported by L. F. Nilsen and O. Petterson, who were also working with Hamberg. They conducted a chemical determination of the oxygen content of Hamberg's product and found the results were 95 per cent titanium, 5 per cent oxygen, nearly free of iron, and only small traces of nitrogen. The method used by Hamberg was the reduction of titanium tetrachloride by using metallic sodium inside a small autoclave of wrought steel.

In 1895 a Frenchman, H. Moissan (1, p.3), fused titanium dioxide with carbon at extremely high temperatures in an electric furnace and reported to have obtained a final product free from nitrogen and silicon. The product, however, contained 2 per cent carbon and some oxygen. It was, therefore, far from being pure titanium.

In 1910 M. A. Hunter (58, p.4), working first in the General Electric Laboratory and later in Rensselaer Polytechnic Institute at Troy, New York, repeated many of the reported experiments of Hamberg and Moissan. He found Hamberg's experiment to be best suited for the production of Metallic titanium. Hunter used a larger steel bomb, capable of withstanding high pressures, and obtained up to 120 grams of titanium in a single reaction. The metal was readily forgeable but remained brittle at room temperatures. The oxygen content of Hunter's product was 1.5 per cent.

It was not until 1925 that the first high purity titanium metal was produced by A. E. Van Arkel and J. H. De Boer in Eindhoven, Netherlands, using their now famous iodide process (64, p.60). In this process crude titanium is placed between a perforated molybdenum retainer and a glass bulb. The bulb is evacuated, outgassed, and iodine added into the bulb. The bulb is sealed from the pump and then heated to 350°F which results in the formation of titanium tetraiodide in the bulb. After approximately ten hours, the tungsten filament, which was sealed into the bulb, is heated to approximately 2400°F and held at this temperature by current control. The titanium tetraiodide is then decomposed to titanium, which builds up on the filament and to free iodine vapor that reacts with more crude titanium. This process continues until the filament becomes $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter or until the increasing current required to maintain the temperature becomes economically impractical (1, pp.7-8). The output of high quality titanium metal by the iodide process is used mainly for research where high purity titanium metal is required. Because of the high cost of production, the "iodide process" has not been developed for commercial titanium production.

In 1937 Dr. Wilhelm J. Kroll, working in his private research laboratory in Luxembourg, developed what is now called the "Kroll Process." Dr. Kroll came to the United States in 1939 to escape working for the Nazi Government. He was later employed as a consulting metallurgist by the U. S. Bureau of Mines in 1944 (6, p.5). He reported his method of making ductile titanium in 1940 (U.S. Patent No. 2,205,854). His method involved the reduction of titanium tetrachoride with pure magnesium in a molybdenum-lined electrically heated crucible under argon gas at normal pressure at a temperature of about 1,000^{o}C. Following this was the separation of the metal from magnesium salts by leaching and acid treatment (59, p.4). This produces a spongy titanium metal that must be compressed into bars, melted in an induction or an electric-arc furnace, where it is again under a protective blanket of inert gas. The resulting ingots can then be rolled into sheets or other forms for commercial use.

The U. S. Bureau of Mines pioneered in development of the Kroll process that is now used in producing ductile titanium metal on a commercial scale. There are other processes under development that are based on the electrolysis of a fused electrolyte and offer the advantages for a continuous process. Extensive investigations are presently being conducted on this new process; but, in any event, the major proportion of the world's commercial titanium metal produced today and in the near future, at least, will be obtained by modifications of the Kroll-Bureau of Mines process (11, p.6).

Technology of Titanium Metal

Titanium is very difficult to reduce to a pure form from its basic compounds, because it is an extremely reactive metal at high temperatures. The most harmful impurities in titanium metal are oxygen and nitrogen. The production steps involved are essentially chemical ones, and the production on a commercial scale has depended largely on the application of chemical engineering techniques and principles.

A recent report by the Bureau of Mines during the operation of its Boulder City, Nevada plant indicates the difficulties involved in titanium sponge production (60, p.1).

> "A few hundredths per cent of nitrogen and less than two-tenths per cent of oxygen will make titanium too hard for many purposes where maximum ductility is essential. A microscopic crack or pinhole, a poor valve packing or the slightest inattention of an operator can allow enough air to diffuse into a batch to ruin it."

Commercial plant operations, using the Kroll-Bureau of Mines method, are divided into three independent processes: (1) the production of crude titanium tetrachloride from the basic ore; (2) the production of titanium sponge from titanium tetrachloride; (3) the production of titanium ingots from the titanium sponge. See Figure 1. The following summarizes each of the three steps:

The Production of Titanium Tetrachloride

Titanium tetrachloride is produced by chlorinating titanium ores, rutile and ilmenite. Ilmenite is the most plentiful and is widely used in the titanium dioxide pigment industry. Rutile is less plentiful but has a much higher titanium dioxide content.

Table 1 gives the chemical compositions of rutile from Australia, ilmenite from India, ilmenite from the McIntyre Mines at Tahawus, New York, and titanium slag made from Canadian ilmenite.

The use of ilmenite involves difficult economic and engineering problems in separating iron chlorides produced in the production of titanium tetrachloride. At the present

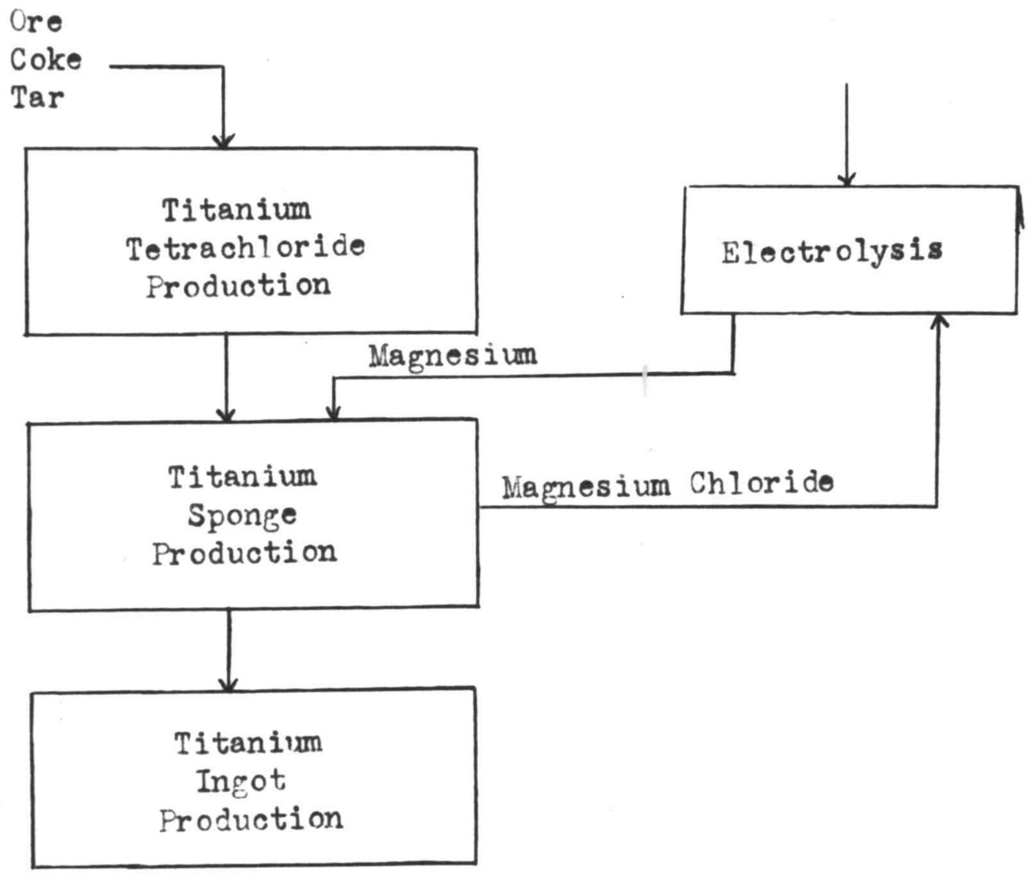


Figure 1

Steps in Producing Titanium Metal

time most of the major producing firms are using rutile because of its higher TiO_2 content. It is generally believed, however, that in time the greatest tonnage of titanium metal will be processed from ilmenite ore (49, p.8).

TABLE 1

Ore Analysis

	AUSTRALIAN RUTILE	ILMENITE INDIAN	ILMENITE McINTYRE	Q.I.T. SLAG
TiO_2	96.2	59.1	44.9	77.2
Total Fe	0.8	26.4	33.9	9.6
SiO_2	0.6	0.7	3.8	5.5
Al2O3	0.9	1.3	2.1	8.7
CaOMgO	1.4	1.0	4.0	5.4

Source: (30, p.578)

Chlorination of Titanium Ore

Measured amounts of ore, ground coke, and coal tar are fed into a steam-heated pug mill and then dumped into the moving table of a circular kiln. See Figure 2. The table carries the mix into the heated zones of the kiln, where controlled heat is supplied by burners both above and below the table. The last section of the kiln is unheated and serves as a cooling zone. The finished sinter is plowed off the table, broken into fragments to form briquettes (30, p.578).

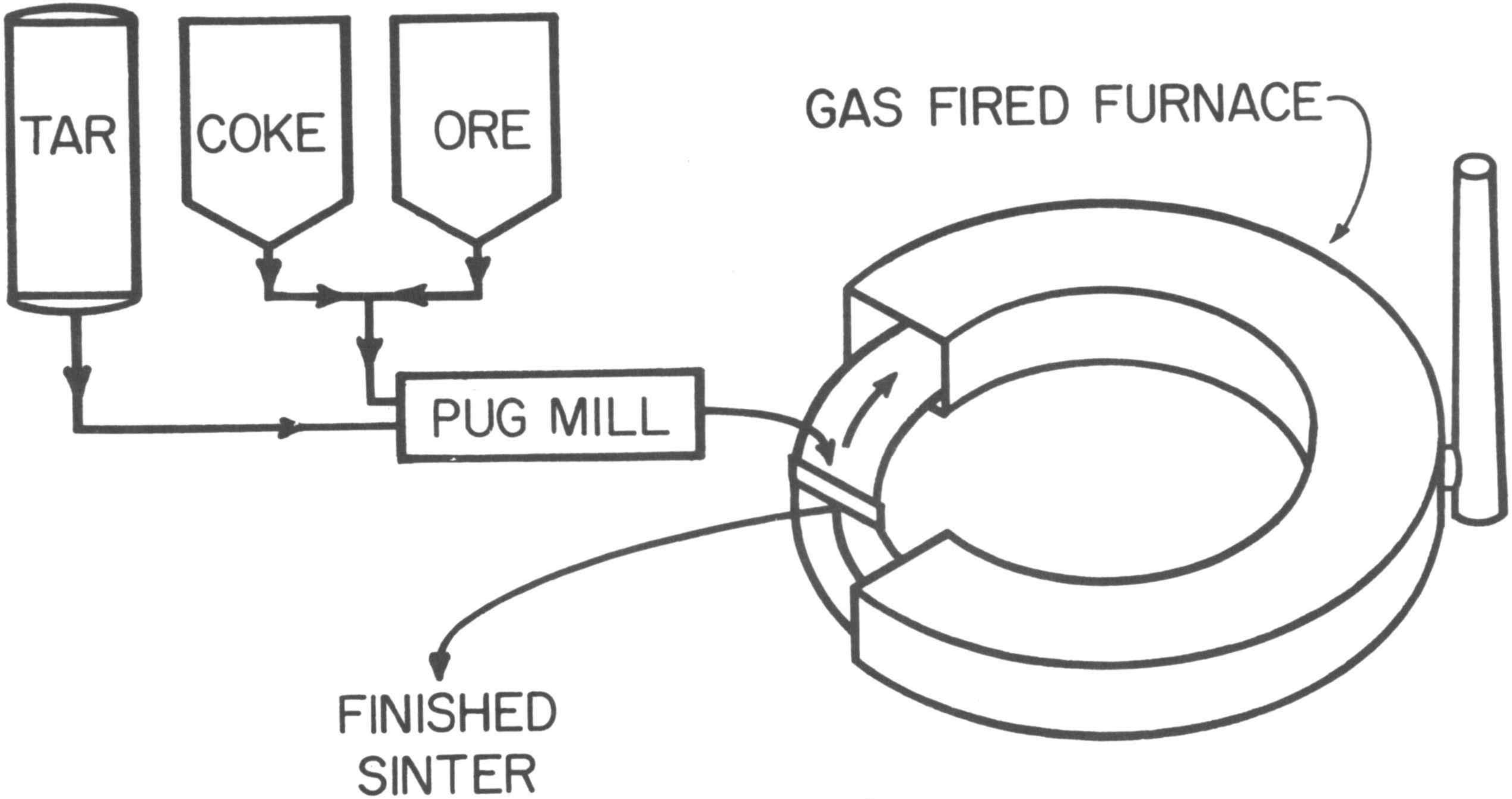


Figure 2

Preparation of Titanium Ore

The type of equipment used for chlorination of the sintered material is illustrated in Figure 3. The furnace is maintained at a temperature of 800°C or higher, partially by means of power supplied through carbon resister blocks in the bottom and partially by the heat of reaction generated during the chlorination.

The product gasses from the chlorinator pass through dust collectors to remove suspended solids and then into the vertical condenser towers in which liquid titanium tetrachloride is sprayed in order to condense these gases. The condensed titanium tetrachloride is pumped to settling tanks for the removal of insoluble matter and sludge. It is then ready for purification (26, p.735).

The Production of Titanium Sponge

The operation begins with crude titanium tetrachloride and commercial pig magnesium and finishes with titanium sponge metal. See Figure 4. Titanium tetrachloride is used, because it is one of the easiest and cheapest of all titanium compounds to purify and reduce (60, p.5).

Crude titanium contains many impurities which are removed by chemical treatment and fractional distillation. The magnesium ingots used must be free of any oxide, therefore, they are pickled in a muriatic acid solution

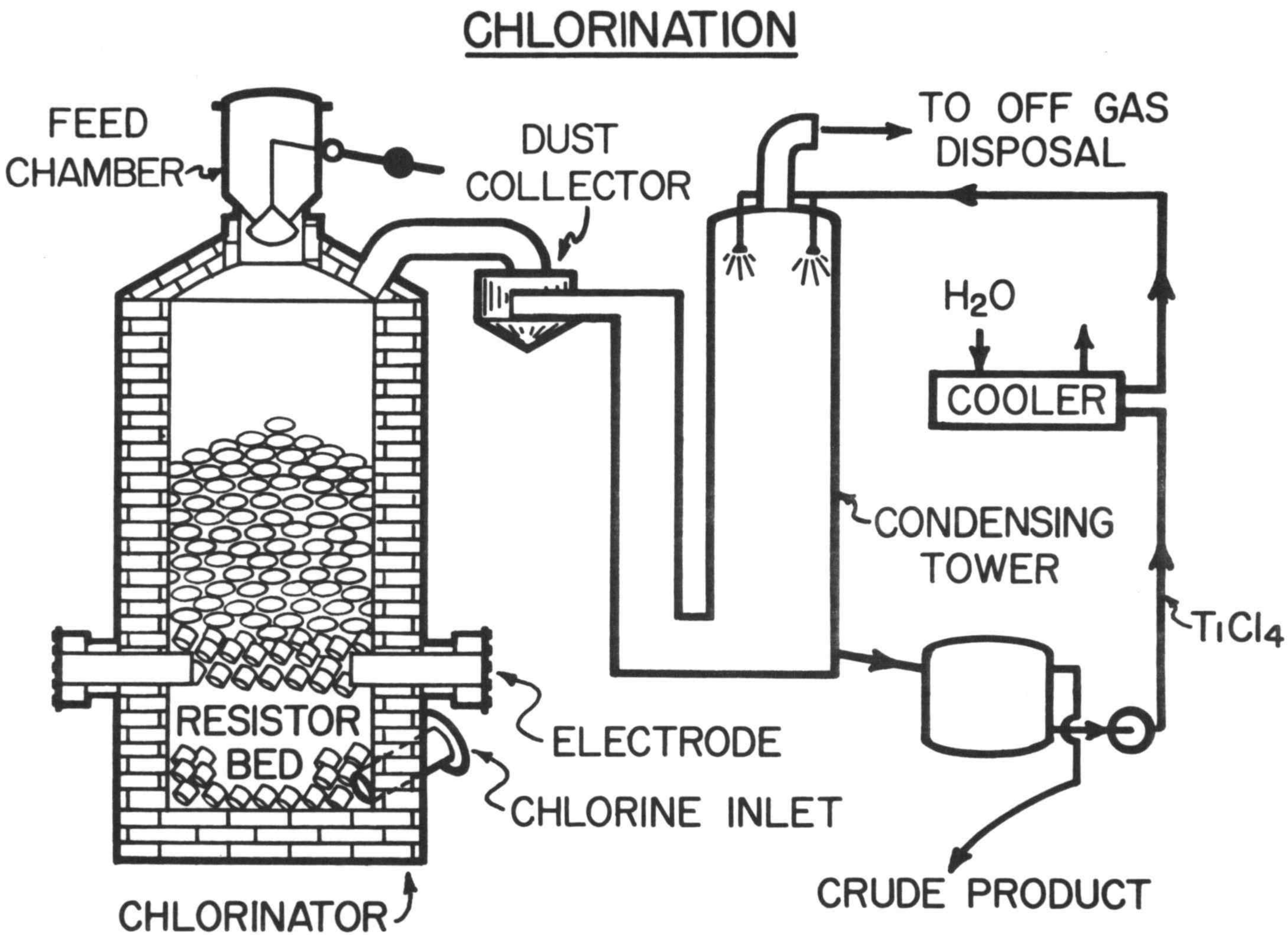


Figure 3

Chlorination furnace for producing Titanium Tetrachloride

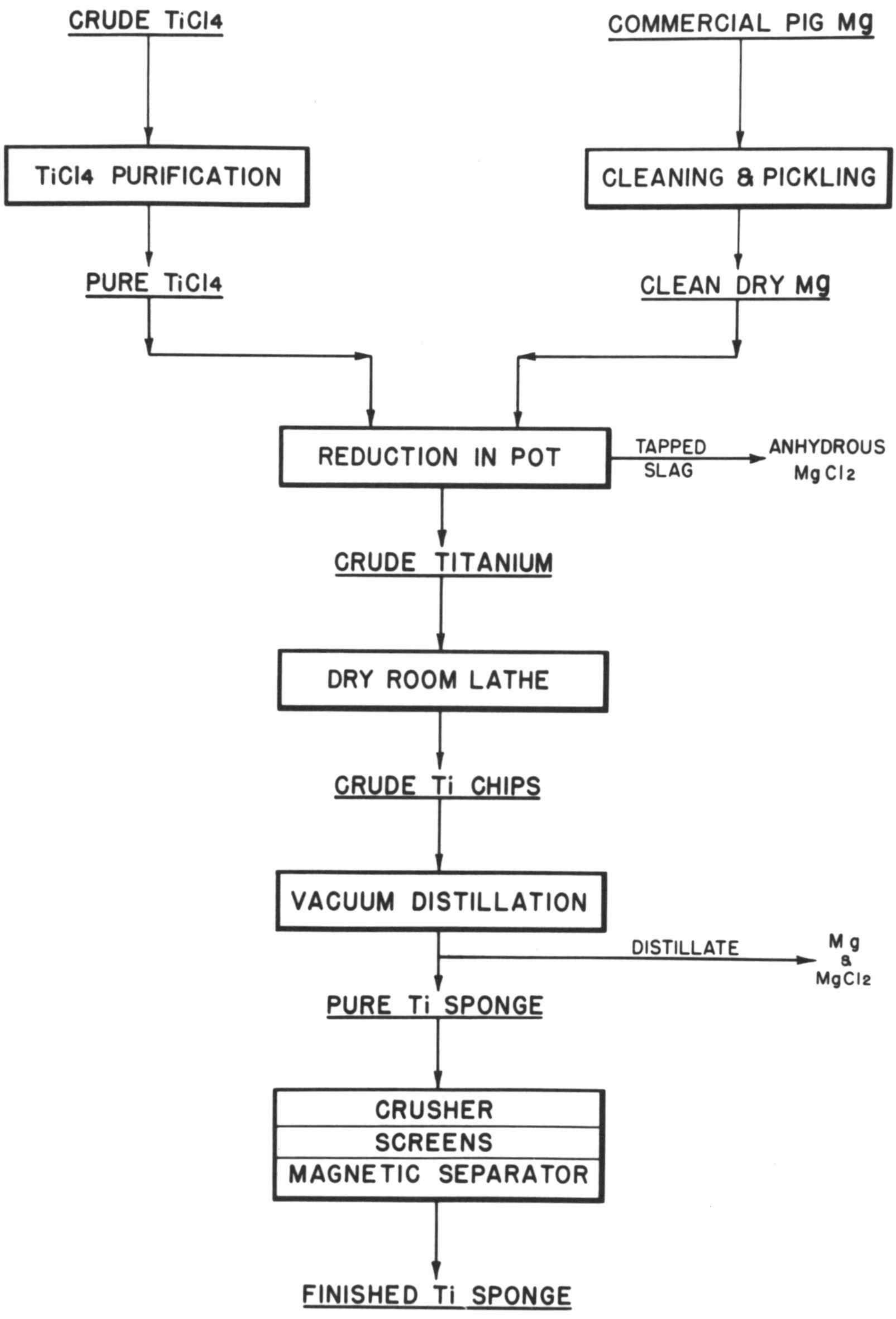


Figure 4

Titanium-production Flowsheet

followed by a thorough washing and drying.

The reactor is a steel pot with a flanged cover. The magnesium ingots are loaded into the reactor pot, and the lid is tightly welded on. This operation is carried out in a dry room to prevent any pickup of moisture. The "dry room" is a room maintained at a humidity equivalent to a dew point of -15° to -45°F.

After the pot has been checked for leaks, it is evacuated and pressurized with helium or argon and then lowered into a gas fired reduction furnace. The furnace burners are then started, and the temperature set at 750°C. Then, the titanium tetrachloride feed is started. During the reaction, magnesium chloride is periodically tapped from the pot. A final tap is made after the completion of the reaction and one hour cooking period. The pot is then removed from the furnace and allowed to cool until it is at room temperature. It is transferred to the dry room, where the lid is removed and the contents are bored out. The resultant chips, which still contain a small quantity of magnesium and magnesium chloride, are purified by heating in a vacuum furnace; thereby distilling the residual impurities away from the sponge titanium. After cooling, the sponge is crushed and transferred to shipping drums equipped with air tight lids (60, p.63).

The Production of Titanium Ingots

The consolidation of titanium sponge chips is accomplished in double-melting vacuum arc furnaces with the resultant ingots weighing from one to two tons each (26, p.736).

The first step in converting titanium sponge into ingots is the compression of the sponge into long electrodes. Each electrode, if required, contains alloying elements. The melting furnaces are of special design and contain a water cooled copper crucible into which the electrodes are arc melted, forming a solid ingot.

The first stage ingot is then used as an electrode in a second melting operation, yielding a final homogenious ingot.

The ingots are turned on a lathe to remove surface imperfections and shipped to fabrication mills for conversion to bar, open die forgings, wire and flat rolled products (47, p.102).

Properties of Titanium Metal

Titanium metal has many attractive physical and mechanical properties that have enhanced the widespread interest of industry. This interest is based upon three outstanding characteristics: strength, weight, and corrosion resistance (58, p.12). When minimum weight and service in the temperature range of 300 to 800 degrees F is required, titanium does not have a close competitor.

Titanium weighs .16 pounds per cubic inch as compared to stainless steel which is .28 pounds and .10 pounds for aluminum. On a percentage basis titanium weighs forty per cent less than stainless steel and sixty per cent more than aluminum (18, p.30).

Physical Properties

The physical properties of titanium are, in most cases, intermediate between stainless steel and aluminum. In Table 2, for the purpose of comparison, the physical properties of commercial pure titanium are listed along with three other structural metals which compete with titanium in many applications.

The high melting point of titanium metal has caused much speculation that the metal could be used at high temperatures; but, due to the change in crystal structure that takes place at approximately 885°C (1615°), this could not be substantiated. The high temperature properties are intermediate between those of aluminum and steel. The upper temperature of titanium is limited to 800°F where useful engineering properties still exist. The limiting features of temperature are its poor oxidation

Table 2. Comparison of Physical Properties of Titanium and Other Structural Materials

Property	Com. Pure Titanium	Al Alloy 75-ST-6	Mg Alloy AZ-31X	Stain. Steel AISI 302
Melting Range				
°C	1670	476-638	565-632	1425-1470
°F	3040	890-1180	1050-1170	2600-2680
Density				
gm/cm^3	4.5	2.80	1.78	7.93
$lbs./in.^3$	0.163	0.101	0.064	0.286
Atomic Number	22	13(Al)	12(Mg)	26(Fe)
Atomic Weight	47.90	26.97(Al)	24.32(Mg)	55.84(Fe)
Thermal Conductivity				
$Cal/cm^2/sec/^oC/cm$	0.0425	0.29	0.23	0.039
$BTU/ft^2/hr/^oF/ft$	10.3	845	672	9.4
Thermal Expansion				
$Cm/cm/^oC$ (20/100C)	$9.0x10^{-6}$	$23.6x10^{-6}$	$26.0x10^{-6}$	$17.3x10^{-6}$
$In./in./^oF$ (32/212F)	$5.0x10^{-6}$	$13.1x10^{-6}$	$14.5x10^{-6}$	$9.6x10^{-6}$
Electrical Resistivity (20^oC)				
Micro ohm . cm	55	5.75	9.3	72
Tensile Modulus of Elasticity ($x10^6$ psi)	15.5	10.4	6.5	28

Source: (18,p.III-1-2)

resistance and embrittling effects of oxygen and nitrogen above 800°F (15, p.143).

Titanium has a very low electrical and thermal conductivity. It is only 3.1 per cent as efficient as copper in resistance and similar to stainless steel in thermal conductivity. Its low coefficient of thermal expansion reduces thermal stresses, when close tolerances are required over a considerable temperature range. This is lower than stainless steel.

Tensile modulus for titanium is intermediate between aluminum alloys and that of stainless steel; hence, titanium is a good structural material.

Mechanical Properties

The mechanical properties of high purity iodide titanium puts it into the same strength and ductility range as some of the annealed copper alloys, although titanium is harder. The effects of small additions of carbon, nitrogen, and iron in commercially pure titanium doubles the strength but reduces the ductility by approximately one-half (11, p.22).

Commercial titanium, as produced today, varies considerably in composition and properties. Producers have developed specifications for their own products, but standardization among industry is not universally employed (11, p.35). Table 3 lists some of the mechanical properties of alloyed grades that are produced today. Tensile strength is the amount of load that can be applied before the metal breaks or ruptures, and yield strength is the minimum load that will produce a permanent stretch or deformation when the load is removed.

Table 3

Mechanical Properties of Commercial Titanium Alloy Grades

Grade	Min. Yield Strength PSI.0.2% Offset	Min. Tensile Strength PSI	Elongation In 2",%
RC-55	55,000	65,000	20
RC-70	70,000	80,000	15
Ti-75A	70,000	80,000	20
Ti-100A	90,000	100,000	15
C-110M	110,000	120,000	10
C-120AM	120,000	130,000	10
C-120AV	120,000	130,000	10
C-130AM	130,000	140,000	10
A-110AT	110,000	115,000	10
RS-55	55,000	60,000	20
RS-70	70,000	80,000	18
RS-110A	110,000	120,000	10
RS-110BX	110,000	120,000	12
RS-130	130,000	140,000	10
RS-140X	140,000	150,000	10
MST III	72,000	80,000	25
MST IV	85,000	100,000	18
MST-3AL-5Cr	145,000[1]	155,000[1]	13.5[1]
MST-6AL-4V	120,000	130,000	10
MST-4AL-4Mn	130,000	140,000	10

[1]Average Properties

Source: (43, p.4)(11, p.39)

The comparison of the two competitive metals, aluminum and stainless steel, is shown in Table 4, using Republic Steel's RS-110A titanium.

Table 4

Comparison of Strength and Ductility

	Titanium RS-110A	Aluminum 75S-T6	Stainless Steel T302
Min. Tensile Strength (Psi) 0.2% offset	120,000	75,000	80,000
Min. Yield Strength (Psi) 0.2% offset	110,000	65,000	30,000
Per cent Elongation (2" Gauge)	10	10	50

Source: (6, p.12)

Titanium alloy research is underway for a grade that will have tensile strengths in excess of 200,000 Psi that will replace many of the high strength alloys of stainless steel on a strength/weight basis (15). The high strength of titanium alloys and moderate weight results in a high strength-to-weight-ratio (SWR). Aluminum is lighter but lower in strength, therefore it has only a moderate SWR. Steels are heavier though stronger, hence have only a moderate SWR. Titanium is superior in SWR to both, with the exception of a few super strength steels (21, p.83).

Corrosion Properties

J. B. Sutton of E. I. du Pont de Nemours and Company reports, "In a peacetime economy, perhaps the largest market for titanium will be found in the field of corrosion resistance. It is completely inert to all types of marine environments including sea water, brakish river water, and marine atmosphere. Excellent resistance is shown toward inorganic chlorides, chlorinated hydrocarbons, moist chlorine gas, nitric acid, and many organic acids."

The most outstanding characteristic of titanium's corrosion behavior is its resistance to attack by hot chloride environments which severely affects other structural metal (51, p.17). Corrosion resistance data of commercially pure titanium is published by E. I. du Pont de Nemours and Company, Technical Information Bulletin #1 on titanium (45).

The basis for titanium's corrosion resistance is considered to be the formation of a protective surface film, promoted by the presence of oxygen or oxidizing agents (11, p.50).

Machinability of the Metal

Machinability of titanium metal closely resembles that of stainless steel but galling and seizing have been major problems. The development of lubricants and surface treatment technique will eliminate these problems.

Welding Characteristics

Care must be exercised to prevent hydrogen, oxygen, and nitrogen from coming in contact with hot titanium while it is being seam-welded, or a brittle weld will result. Thus, it is necessary to use special welding apparatus so that the weld can be made under an inert gas-shield.

Flash and spot welding of commercially pure titanium is accomplished using conventional equipment.

The welding of titanium to other materials is not possible, but extensive research is being conducted to overcome this difficulty (43, pp.6-7).

Casting Possibilities

The casting of titanium metal by the skull melting technique has been developed with some success. The problem of casting is difficult, because the metal is extremely reactive in the molten condition (11, p.111) (6, p.32).

Grinding of the Metal

The metal tends to smear and load the abrasive grains of the grinding wheel. The use of wheels such as aluminum oxide and silicon carbide, that have a soft bond, has been successful. Special precautions must be taken while grinding because the dust is inflammable.

Forging

Titanium can be forged at temperatures between 1450°F and 1800°F without excessive contamination with conventional forging equipment.

Rolling of Titanium

Hot rolling can be done at 1350°-1500°F, provided the temperature is not allowed to fall below 900°F during the operation. The hot mill scale on the titanium can be removed by a sodium hydride bath or Virgo salt bath. Shot and sand blast could also be used but results in a rougher finish (43, pp.5-6).

Cold rolling can be accomplished by conventional equipment and methods but becomes more difficult as alloying elements are increased.

Present Cost of Titanium and Titanium Alloys

The price of titanium sponge has been reduced from a high of \$5.00 a pound in 1953 to \$3.45 per pound in 1956. This downward trend is expected to continue in the future due to improvements in manufacturing processes and broadening of commercial markets. Current titanium prices are listed in Table 5.

Table 5

Titanium Metal Prices - January 1956

Form	Commercially Pure Price per pound	Alloyed Price per pound
Sheet	\$13.10-\$13.60	\$15.25-\$15.75
Plate	10.50- 11.00	11.50- 12.00
Wire	9.50- 11.50	11.50
Bar	7.90- 8.15	7.90- 8.10

(10,000 pounds base FOB mill)

Sponge A-1 Grade 125 BHN \$3.45 per pound
Sponge A-2 Grade 170 BHN \$3.15 per pound

(min. 100 pounds FOB)

BHN (Brinell Hardness Number) is used by metallurgical industry to measure ductility and purity of a metal.

Source: (53, p.120)

Uses of Titanium and Titanium Alloys

The present uses of titanium metal and titanium alloys are related very closely to the cost factor and availability.

At the present time ninety per cent of the titanium mill products are being utilized by the Government for defense production items, while the remaining ten per cent has been released for civilian and industrial users (29, p.53) (9, p.21).

The greatest advantages in the use of titanium are gained when it is used in structures requiring minimum weight, corrosion resistance, and/or used at elevated temperatures (21, p.83).

The air craft industry is the largest user of titanium today; and, it is predicted, that it will be the primary large scale user in the future. The Air Force has pointed out that a one pound weight reduction in a jet engine would result in eight to ten pound reduction in the over-all weight of an air frame. In a large heavy bomber, by using titanium in eight of its jet engines, a weight savings of 500 pounds each would reduce the over-all weight by 40,000 pounds (52, p.69). The aircraft industries "two rules of thumb" are: (1) for every one pound cut from the weight of an aircraft part, ten pounds can be cut from the over-all weight, (2) for every one pound cut from the over-all weight, $40 can be saved in building and operating cost (38, p.186). Thus, the commercial aircraft companies are willing to pay $20 to $40 a pound for reduced weight and increased payload (2, p.7).

Applications of titanium alloy items used in aircraft are: engine fire walls, fuselage skins, baffles, ductwork, brackets, fittings adjacent to the engine and exhaust system, leading edges of wings and fins in supersonic aircraft and missiles, propeller blades, landing gear, bolts, and many other items where high strength-to-weight ratios are basic in design.

High corrosion resistance, prolonged useful life, lightness and strength are of primary importance to the manufacturers of marine products. Applications are: seats and disk trims in salt water valves, tubing for condenser systems, heat exchangers, wet exhaust mufflers for submarine diesel engines, turbine blades for low temperature steam turbines, salt water pump shafts, snorkel tubes, hull material for small craft such as PT boats, water lubricated bearings, antenna wires, and outboard shafting.

The U. S. Army considers that titanium has extensive possibilities. The Ordnance Corps, Research and Development Division, has been working on military applications since 1947. Suggested applications are: the 81 milimeter mortor base plates (now under production, and reduces weight from 47 pounds to 24 pounds) gun carriages, structural components of vehicles, portable military bridges, armor plate for tanks and trucks, guided missiles, rockets, large-caliber weapon firing tubes, sheels, strong light-weight airborne equipment and perhaps many others.

The use of titanium alloys for armor plate is still in experimental stage, but sufficient progress has been made to suggest its use in lieu of steel on an equal thickness basis with a weight saving up to forty per cent (29).

Perhaps the largest tonnage of titanium metal used in non-defense applications will be where corrosion is of uppermost importance (43, p.8). The Chemical and Process Industries are very interested in titanium with one company constructing operational units such as: piping systems, containers for strong oxidizing solutions, steam jet diffusers, and jet aftercondensers. Some of the potential civilian uses are: surgical instruments, textile spindles, portable machine tools, oil and gas drilling equipment, railroad cars, racing sailboats for fittings above the keel, oil refining equipment, pulp and paper manufacturing equipment, and food processing equipment. The major expansion problem for future civilian use of titanium at the present time is COST.

Role of the Government in Titanium Metal

The Bureau of Mines in 1946 published its significant papers on the preparation, fabrication, physical and mechanical properties of ductile titanium (59). This came as a result of many years of intensified research at its Tucson, Arizona, Salt Lake City, Utah, Boulder City, Neva and College Park Maryland experiment stations. These papers aroused considerable interest among engineers, metallurgists, and fabricators of light-weight materials. Even before 1946, however, the Army, Navy and other defense agencies were testing samples of the metal supplied by the Bureau of Mines for various strategic applications. As a result, Armed Services leaders foresaw that titanium could be used to make weapons of superior performance, if it were available in quantity and at reasonable price.

The first limited commercial production began in 1948 using the Kroll-Bureau of Mines process on a pilot plant basis by the E. I. du Pont de Nemours and Company, Inc. Even so, private enterprise was reluctant to enter the titanium metal field because of the imminent danger of equipment obsolesence from newer processes and the uncertain future of the metal. The government, therefore, through the General Services Administration, established a program to provide government financing of sponge manufacturing facilities. This program provided guaranteed loans and accelerated tax amortization.

In 1951 the government established a purchase and resale program for titanium sponge to maintain maximum capacity during the development of military applications. By the end of 1955 this revolving fund stockpile amounted to 6,446 tons.

A Titanium Advisory Committee with Dr. Herbert H. Kellogg, Columbia University, School of Engineering, as chairman, was established on February 17, 1954, by the Office of Defense Mobilization (Defense Mobilization Order V-2) to facilitate coordination of Federal policies and programs with respect to titanium supply and to serve as a point for collection and dissemination of technical information to industry.

On July 16, 1954, titanium sponge-metal was placed on the list of strategic and critical materials.

Under the government expansion program, many contracts pertaining to research and the production of titanium metal were signed by GSA (representing the Government) and industry.

Government assistance for additional titanium sponge production was suspended by the Office of Defense Mobilization (ODM Press Release No. 428) on September 12, 1955, but the programs are to be kept under continuous review. This action was taken because the supply of titanium sponge exceeded the consumption. Senator Stuart Symington and Senator James Duff pointed out that government subsidized facilities for titanium will be able to produce 22,500 tons annually, but the consumption amounted to only 1,500 tons in 1954 and totaled only 1,700 tons in 1955 (35, p.16). ODM, however, recommended that the Defense Department continue to expand titanium metal use in military equipment on a production basis, despite its present high cost (57, p.2).

It can be seen by this short summary that the U. S. Government, through its defense agencies, has been responsible for the rapid growth of the present Titanium Industry.

CHAPTER III

GEOGRAPHY OF THE TITANIUM METAL INDUSTRY

The basis for the location of the various plant production operations in the United States are to be discussed in this chapter. These plant location factors will then be used to study the possibilities of the Pacific Northwest as a basis for a potential titanium industry in Chapter IV.

Raw Material

The development of the titanium metal industry is based upon three groups of titanium ores: rutile (TiO_2) which usually occurs in sand deposits; concentratable ilmenite ($FeTiO_2$) which occurs in sand as well as in rock deposits; and non-concentratable, ferruginous ilmenite (an extremely fine intergrowth of ilmenite with magnetite or hematite) which occurs in rock deposits. The North American Continent is endowed with all three forms in significant deposits to make mining economical. The most plentiful are the two ilmenites. See Table 1 for ore analysis.

The color of ilmenite is usually iron black, but it may vary from red to brown. Rutile usually varies in color from red to brown but is sometimes yellow, blue, black, or even green. It may also be found to be transparent or opaque and has a submetallic lustre (58, p.6).

Today, rutile is the most preferred raw material for titanium metal manufacture. The Kroll Process requires that the ore be converted into titanium tetrachloride, made by the chlorination process previously discussed in Chapter II. The presence of iron, contained in ilmenite ores, results in the conversion to ferric chlorides that must be subsequently separated from the titanium tetrachloride and complicates the over-all process. Thus, the use of rutile permits the simplest technology and lowest cost in the production of titanium tetrachloride.

There are two important factors in favor of ilmenite for future expansion. They are high cost and relative scarcity of rutile compared to ilmenite. See Table 6 and 7 for comparison of cost and production. It should be pointed out that the large production of ilmenite shown in Table 7 is used mainly in the pigment industry and in titanium compounds used in steel making.

Table 6

Raw Material Prices

	Price Per lb.	Price Per lb. Ti Content
Ilmenite concentrate (55%, TiO_2)	\$0.009	\$0.027
Titanium slag (70%, TiO_2)	0.018	0.043
Rutile concentrate (94%, TiO_2)	0.06	0.106
Titanium Tetrachloride	0.40	1.58
Titanium Oxide, pigment grade	0.24	0.40

Source: (21, p.75)

Table 7

Production of titanium concentrates from domestic ores in the United States, 1945-49 (average) and 1950-55, short tons.

Type Ore	Production (Gross Weight)
Ilmenite: 1/	
1945-49 (average)	343,711
1950	468,320
1951	535,835
1952	528,588
1953	513,696
1954	547,711
1955	584,100
Rutile:	
1945-49 (average)	7,516
1950	7,535
1951	7,189
1952	7,125
1953	6,825
1954	7,411
1955	8,400

1/ Includes a mixed product containing altered ilmenite, rutile, and leucoxene.

Source: (57, p.5)

The location of deposits of ilmenite and rutile in the United States are shown in Figure 5. Not all of the United States deposits shown are presently economical but are potential resources for the future expansion of the industry. Figure 6 shows the location of the deposits that are now being exploited. The New York deposits

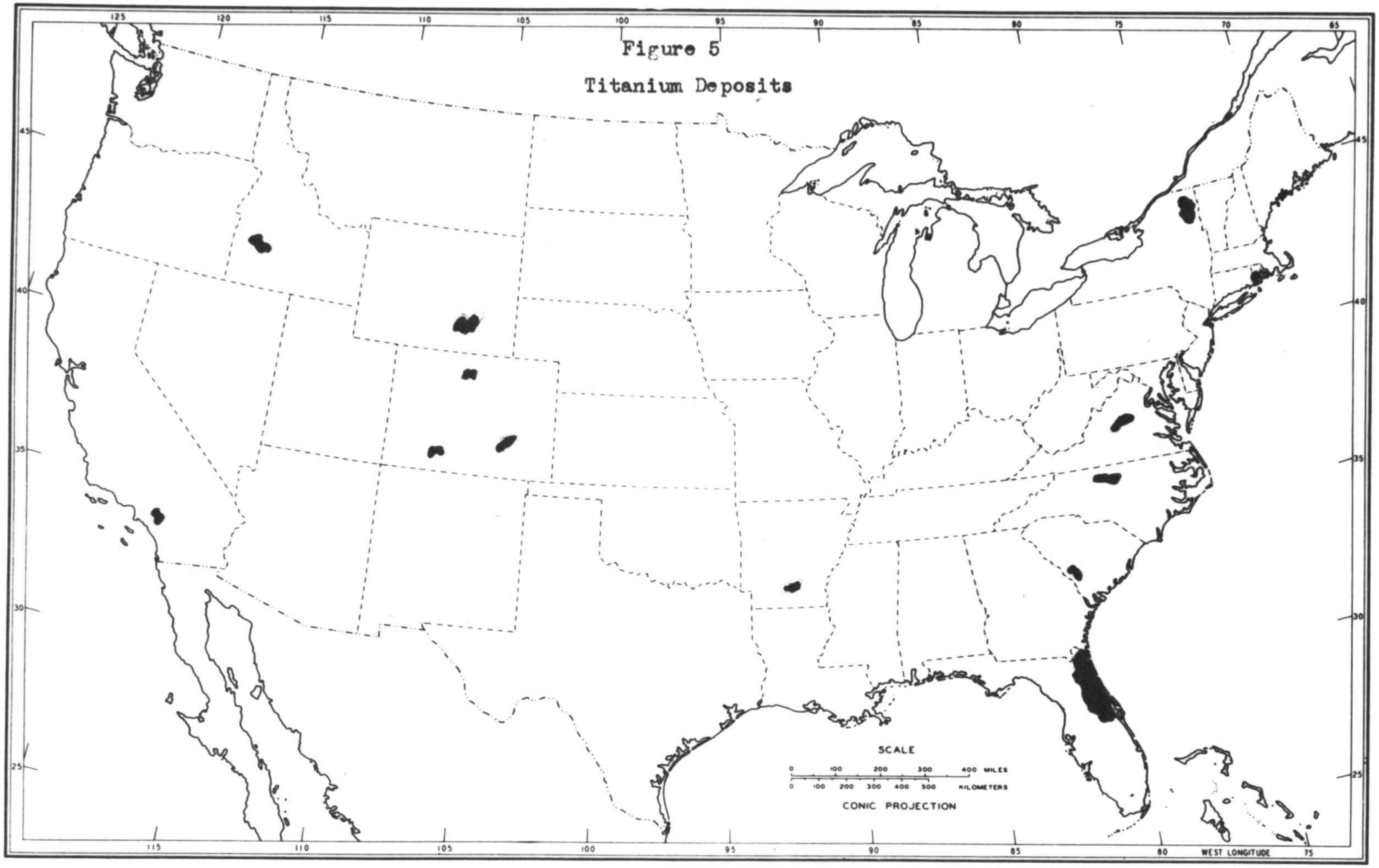
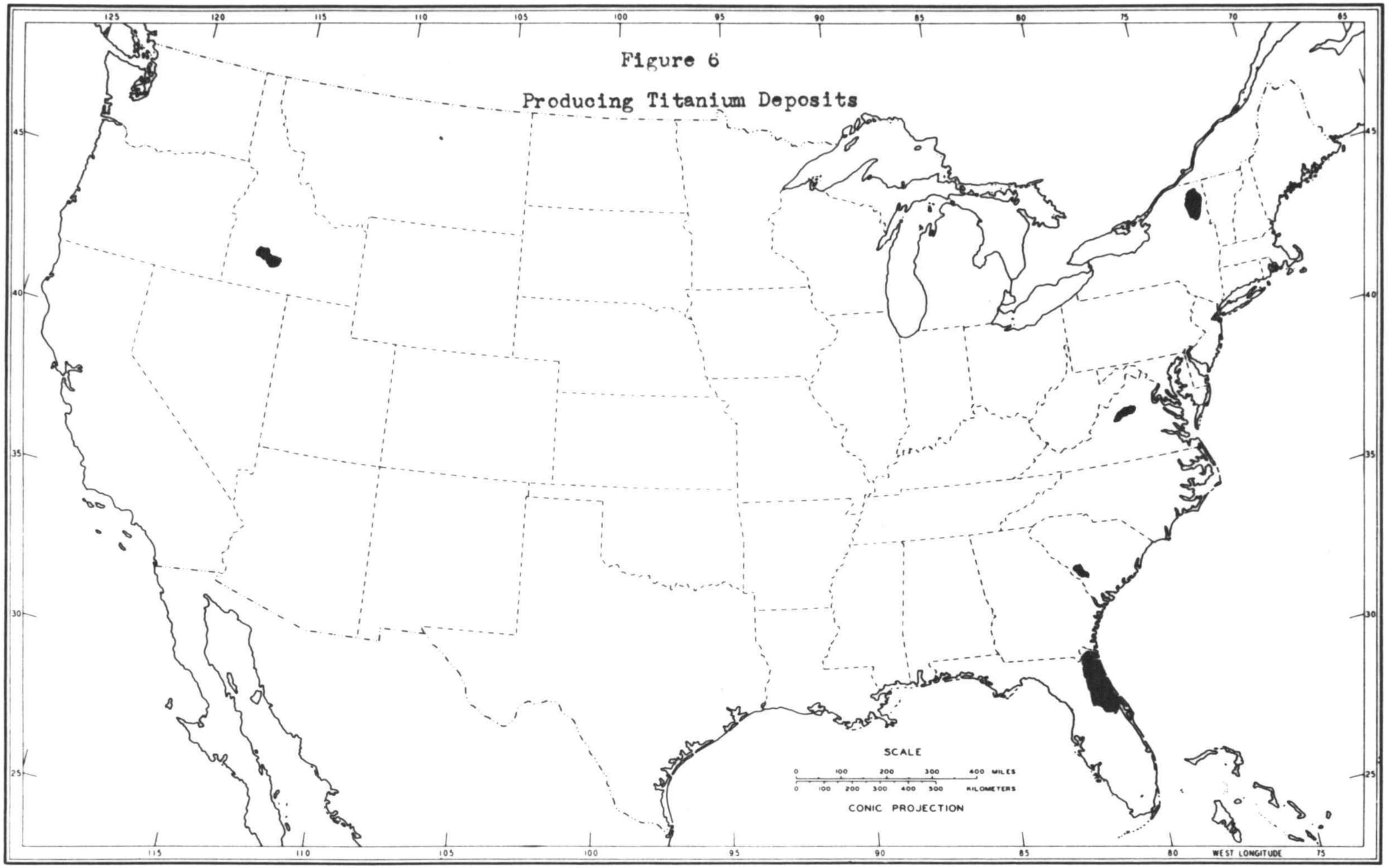


Figure 5

Titanium Deposits

Figure 6

Producing Titanium Deposits



supplies one-half the total production of ilmenite, Florida, one-third, and the remainder from deposits in South Carolina and Virginia. Most of the United States rutile production comes from deposits in Florida with small amounts from South Carolina.

Huge deposits of ferruginous ilmenite are located near Laramie, Wyoming in an area approximately 250 square miles surrounding Iron Mountain. The Union Pacific Railroad owns or controls about sixty per cent of this land. William Reinhardt, vice president of the railroad, reported that the ore contains 46 per cent iron, 19 per cent titanium, and about 1 per cent vanadium. The deposits amount to over 228 million tons lying near the surface that can be mined by the open-pit method (27).

United States Ilmenite Producers

Ilmenite is being produced by the American Cyanamid Company, Piney River, Virginia; E. I. du Pont de Nemours and Company, Inc., Starke, Florida; Florida Ore Processing Company, Melbourne, Florida; Hobart Bros. Corporation, Winter Beach, Florida; Marine Minerals, Inc., Aiken, South Carolina; National Lead Company, Tahawus, New York; Rutile Mining Company of Florida, Jacksonville, Florida; and the Titanium Alloy Manufacturing Company, Division of the National Lead Company, Jacksonville, Florida. The Baumhoff-Marshall, Incorporated and Idaho-Canadian Dredging Company of Boise, Idaho recovered ilmenite from monazite but discontinued operations in August, 1955, reportedly for lack of a market (57, p.4).

The largest ilmenite mine in the United States is the National Lead Company's open-pit operation at Tahawus, New York. At the present time the mine yields 5,000 tons of ilmenite-magnetite ore daily. The company's mill at the same location produces 2,000 tons of magnetite concentrates and 1,000 tons of ilmenite concentrates daily (20, p.83). The reserves in the Tahawus, New York deposits are estimated to be about 150 million tons.

Humphreys Gold Corporation, Denver, Colorado operates mining facilities for E. I. du Pont de Nemours and Company that produces approximately 200,000 tons yearly from its Lawtey and Trail Ridge, Florida ilmenite plants in north central Florida. The operation uses a dredge floating on a "traveling lake" which mines the Florida's white sands to get out coal-black ilmenite. The dredge and separators, floating on the lake, pick up the sand in front, takes out the black ore, and pours the sand back in again behind them. The separation of the ore from the sand is done by a system of spirals in a "wet mill," then the ore is piped to a "dry mill" on land; where it is further concentrated by electro-magnetic and electro-static separators. For every 100 tons of sand that is dug out, approximately two tons of ilmenite is recovered.

United States Rutile Producers

Rutile is being produced by the Florida Ore Processing Company, Melbourne, Florida; The Hobart Bros. Corporation, Winter Beach, Florida; Marine Minerals, Incorporated in Aiken, South Carolina; Rutile Mining Company of Florida, Jacksonville, Florida; and Titanium Alloy Manufacturing Company, Division of the National Lead Company, Jacksonville, Florida.

The rutile production is on the increase in the United States with an expansion goal set by the Office of Defense Mobilization for 35,000 tons. Even with this increased expansion, it is doubtful that the production will be enough for the increased need of the titanium industry (57, p.5). Rutile is the only titanium mineral included in the National Stockpile List of Strategic and Critical Materials. No other titanium minerals have been purchased by the government for stockpiling purposes (9, p.11).

United States Imports of Titanium Ore

The imports to the United States from the world market by countries is shown in Table 8.

Table 8

Titanium Concentrates Imported for Consumption in the United States 1950-55 by Countries in Short Tons

Country	1950	1951	1952	1953	1954	1955
Ilmenite						
Canada 1/	1,357	3,776	38,451	139,585	107,521	111,589
Norway	27,155	---	---	---	---	---
India	187,834	184,145	145,562	147,005	167,484	168,275
Australia	112	100	---	54	---	---
Rutile						
Australia	3,427	11,023	19,394	16,098	14,965	16,256
Grand Total	199,885	199,044	203,407	302,742	289,970	296,120

1/ Canada chiefly all titanium slag averaging about 70% TiO_2.

Source: (56, p.12)(57, p.6)

The comparison between foreign and domestic production is shown in Table 9. This indicates that the United States is depending on foreign imports for approximately 30 per cent of ilmenite consumption and 66 per cent of rutile consumption for all titanium uses. The increase in titanium metal production in the United States will undoubtedly result in an increased amount of import, unless technological developments result in more economical production techniques for lower grade domestic ores. There is no tariff on titanium concentrates.

United States, India, Norway, Canada and Australia supplies most of the world's ilmenite production, with Spain, Egypt, Portugal, and Brazil providing minor tonnage. The ilmenite from India comes from the beaches of Travancore and are expected to continue production on a large scale for many years. Australia is, at the present time, the world's largest producer of rutile with the United States, French Cameroon, India, and Norway producing the remainder.

The discovery of an estimated 25 million tons of rutile near Oazaca, Mexico by the Republic Steel Corporation of Cleveland, Ohio was announced in 1954. The deposit is located 26 miles from the nearest shipping port, Puerto Angel on the Pacific Coast. The ore that was mined in 1954 was stockpiled for concentration. The

Table 9

Comparison of Domestic Production of Titanium Concentrates with Foreign Imports
1950-55 short tons

	1950	1951	1952	1953	1954	1955
Ilmenite						
Domestic production	468,320	535,835	528,588	513,696	547,711	584,100
Foreign imports	196,458	188,021	184,013	286,644	275,005	179,866
Total U.S.	664,778	723,856	712,591	800,340	822,716	763,966
Import % of Total	29.6	26.0	25.8	35.8	33.3	23.5
Rutile						
Domestic production	7,535	7,189	7,125	6,825	7,411	8,400
Foreign imports	3,427	11,023	19,394	16,098	14,965	16,256
Total U.S.	10,962	18,212	26,519	22,923	22,376	24,656
Import % of Total	31.3	61.0	73.2	70.5	67.0	66.0

Source: (56, p.12)(57, pp.5-6)

company has plans for a monthly export to the United States of 2,000 tons of rutile concentrates, averaging 95 per cent titanium dioxide. No shipments have been reported to date, however (56, p.5).

The world's largest developed ilmenite deposit is located at Allard Lake in Eastern Quebec, Canada. It is estimated to contain 300 million tons of 26-40 per cent iron and approximately 32 per cent titanium oxide. The ore is shipped south to the St. Lawrence River to Sorel, where it is concentrated by electric arc furnaces to form pig iron and titanium slag (70-75 per cent TiO_2). Two-thirds of it is owned by Kennecott Copper Corporation and the remaining one-third by New Jersey Zinc (6, p.23).

Present Plant Locations

In Figure 7 is shown the locations of all titanium sponge producing plants, and those that are under construction or proposed. The planned annual production capacity under existing Government contracts call for an annual output of 21,600 short tons in 1957. E. I. du Pont de Nemours and Co., Inc., Newport, Delaware, and Titanium Metals Corporation of America, Henderson, Nevada, are the major producers.

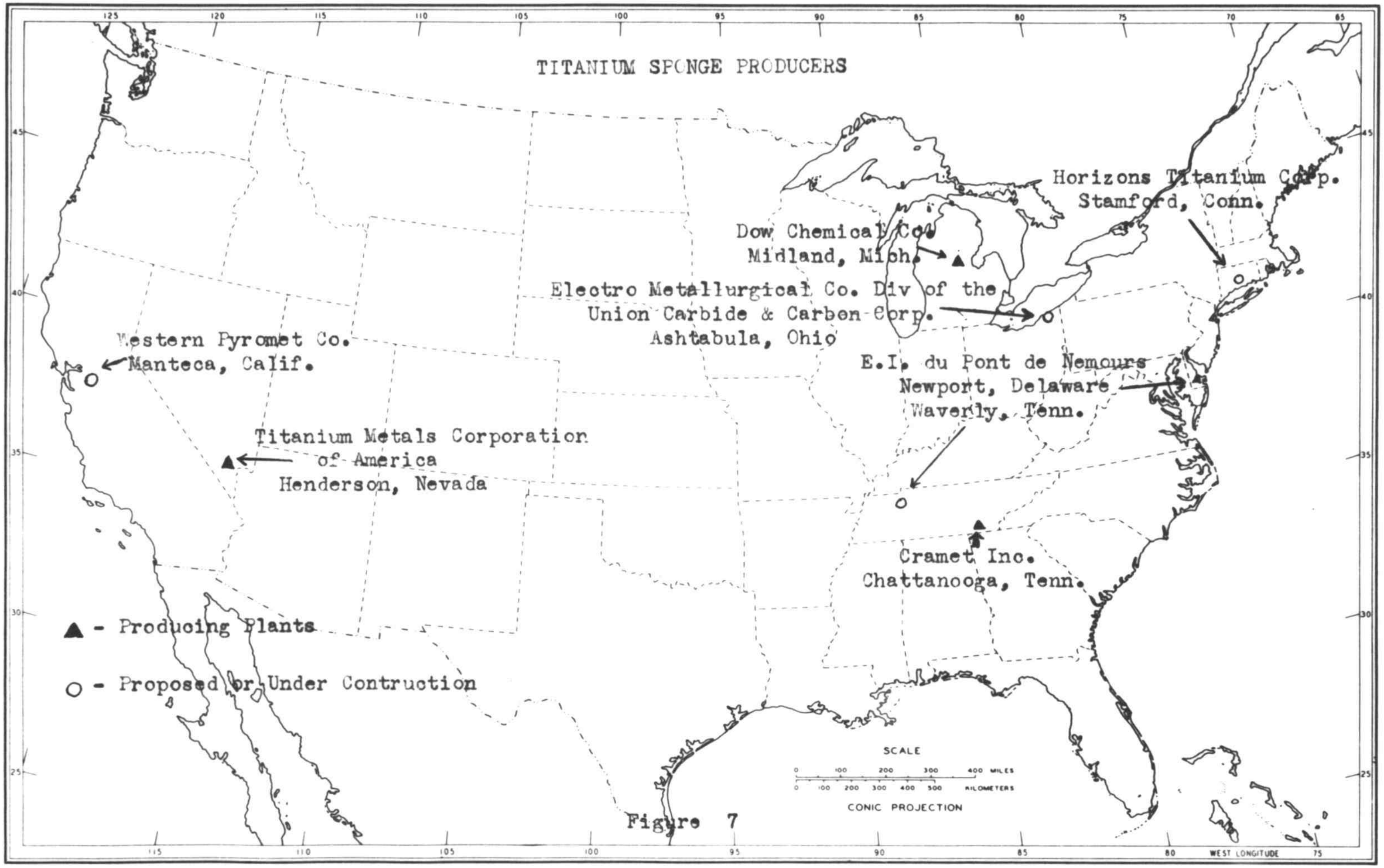

TITANIUM SPONGE PRODUCERS
Horizons Titanium Corp.
Stamford, Conn.
Dow Chemical Co.
Midland, Mich.
Electro Metallurgical Co. Div of the
Union Carbide & Carbon Corp.
Ashtabula, Ohio
Western Pyromet Co.
Manteca, Calif.
E.I. du Pont de Nemours
Newport, Delaware
Waverly, Tenn.
Titanium Metals Corporation
of America
Henderson, Nevada
Cramet Inc.
Chattanooga, Tenn.
▲ - Producing Plants
○ - Proposed or Under Contruction
SCALE
0 100 200 300 400 MILES
0 100 200 300 400 500 KILOMETERS
CONIC PROJECTION
WEST LONGITUDE

Figure 7

In Figure 8 the plant locations of present ingot producers and those under construction are shown. The major producers of ingots and mill products in the United States are: Titanium Metals Corporation of America, Henderson, Nevada; Rem-Cru Titanium, Inc., Midland, Pennsylvania; Mallory-Sharon Titanium Corporation, Niles, Ohio; and Republic Steel Corporation, Cleveland, Ohio.

Review of the Titanium Metal Industry

The E. I. du Pont de Nemours and Company, Inc., Newport, Delaware, was the first United States producer of commercial titanium sponge. The present plant is now producing 10 tons of titanium sponge daily (maximum of 3,600 tons per year) using a modified Kroll Process of Magnesium reduction of titanium tetrachloride. The chief factor for the selection of this site was the existence of facilities already owned by the company. At the present time the company is only engaged in sponge manufacture from its own ore deposits in Florida. This ore is shipped to the plant by railroad.

An expansion goal under a Government contract signed July 24, 1952, calls for an annual production of 13,500 tons, in addition to its own private facilities of 14,500 tons. The expansion is to take a five-year period beginning when additional facilities are producing approximately

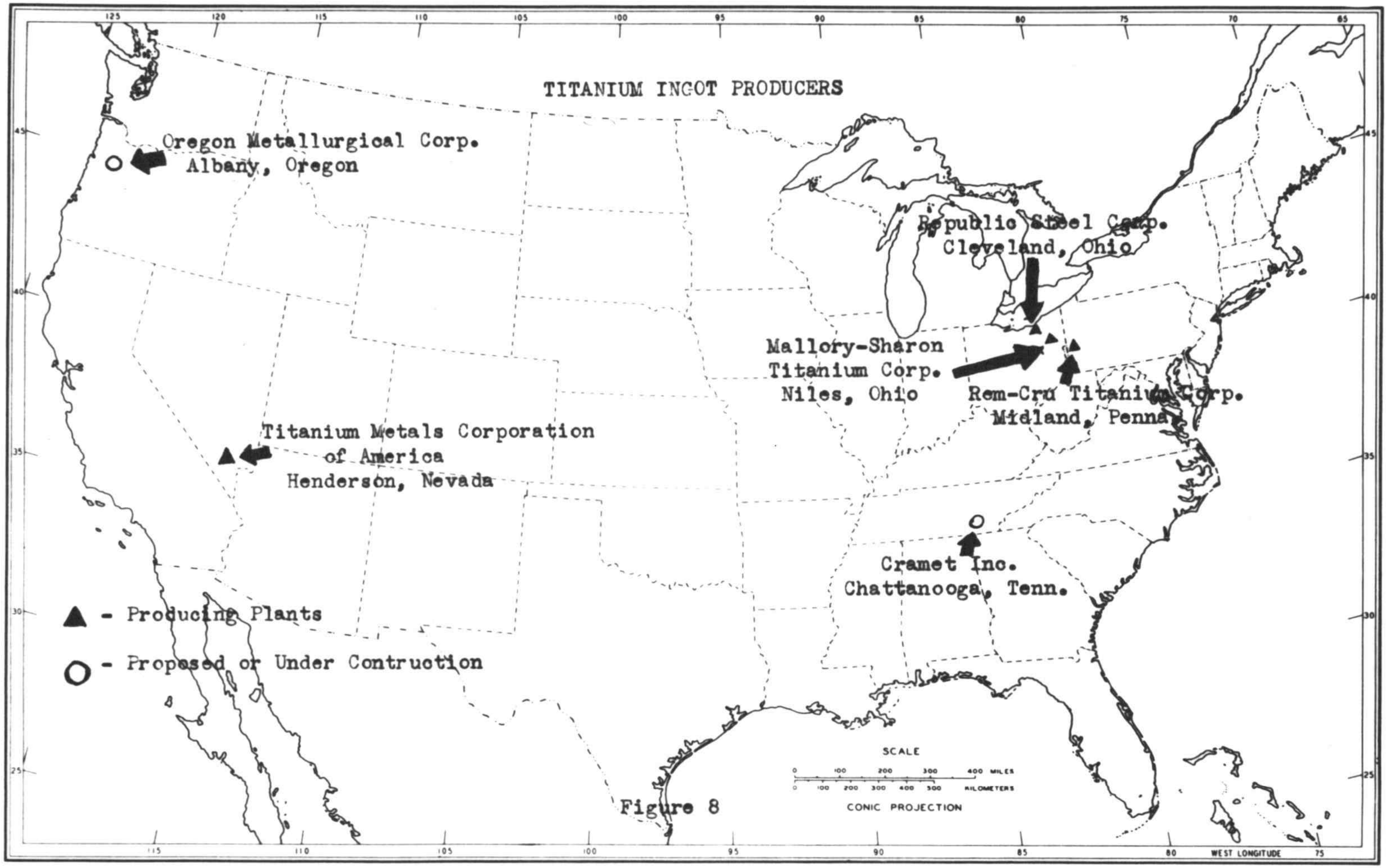

TITANIUM INGOT PRODUCERS
Oregon Metallurgical Corp.
Albany, Oregon
Republic Steel Corp.
Cleveland, Ohio
Mallory-Sharon
Titanium Corp.
Niles, Ohio
Rem-Cru Titanium Corp.
Midland, Penna.
Titanium Metals Corporation
of America
Henderson, Nevada
Cramet Inc.
Chattanooga, Tenn.
▲ - Producing Plants
O - Proposed or Under Contruction
SCALE
CONIC PROJECTION
WEST LONGITUDE

Figure 8

1,350 tons and termination no later than June 30, 1962. Plans are now underway for new plant facilities at Waverly, Tennessee.

Titanium Metals Corporation of America, Henderson, Nevada, is owned by National Lead Company and Allegheny Ludlum Steel Corporation and is the world's largest integrated plant with facilities for chloridation of titanium ore and recovery of magnesium and chlorine by electrolysis of magnesium chloride. The present site was the former Basic Magnesium, Inc. plant built by the government during World War II and was taken over on an agreement with the government on August 1, 1951 (9, p.17). Major components of the plant were leased from the State of Nevada.

The company began commercial production in October, 1951 and now has an annual capacity of 3600 tons of sponge.

The company imports its basic raw material "rutile" from Australia. Magnesium and chlorine are purchased from Stauffer Chemical Company, nearby.

Recycling of magnesium and chlorine requires a high power consumption. Electric power is allocated from Hoover and Davis Dams by the Colorado River Commission up to a maximum of 151 million kw-hr (9, p.18).

Sponge is converted into ingots using the double melting of a consumable electrode in a vacuum arc furnace method. The ingots are shipped to Allegheny Ludlum Mills at Brackenridge, Pennsylvania; West Leechburg, Pennsylvania; Dunkirk, New York; Detroit, Michigan and Los Angeles, California (66, p.35).

Titanium Corporation of America is spending large sums of money on titanium research.

The Dow Chemical Company, Midland, Michigan, is producing sponge by magnesium and titanium tetrachloride reduction (modified Kroll Process), under a government contract signed July 8, 1954, by which the company agrees to maintain a minimum production of five tons per day (9, p.19), (a maximum capacity of 1800 tons per year). The company expects to be in full production sometime during 1956. Mr. Ralph M. Hunter, staff coordinator of electrochemical activities for the company, reported "the chief factors for selecting this plant site at Midland, Michigan, was the availability of personnel and company possession of chlorine and magnesium."

The plant uses rutile imported from Australia and plans to use rutile from Mexico and later ilmenite slag from Sorel, Canada.

Electric power for plant operation is generated by the company.

Cramet Incorporated, Chattanooga, Tennessee, a subsidiary of the Crane Company, signed a contract with the government on July 31, 1953, for the construction and operation of a plant with a capacity of 6,000 short tons of titanium sponge annually. A modified Kroll reduction process of magnesium and titanium tetrachloride is used. The basic raw material rutile is obtained from Australia, but the company expects to use ore from Florida and South Carolina. They are planning to melt some of their sponge and sell some. Full production is expected in late 1956 or early 1957.

The Electro Metallurgical Company, a division of the Union Carbide and Carbon Corporation, signed a government contract on September 10, 1954, for a titanium plant at Ashtabula, Ohio, with an annual production of 7500 short tons of titanium sponge. The initial production is expected to start during 1956.

They will use sodium reduction of titanium tetrachloride rather than magnesium as used in the Kroll Process. This new process is the first commercial facility to use a process other than the modified Kroll process. The company has spent over two million dollars researching this new process over a five-year period.

Sodium and chlorine will be obtained from National Distillers with plans being made to recycle the byproduct sodium chloride.

Horizons Titanium Corporation signed a contract with the government on July 1, 1954, to install a pilot plant using a company electrolytic process at Stamford, Connecticut. The process is the electrolysis of potassium titanium fluoride. No other details are available from this company at the present time.

Western Pyromet Company received a government contract on August 31, 1954, for the lease of the government-owned magnesium plant at Manteca, California (seventy miles southeast of San Francisco) for a period of nine to twelve months with an option for a ten-year lease. B. D. Hardin, president of the company, estimates the production will be 6,000 tons annually. They are using a modified Kroll process and buying their raw materials on the open market. Mr. Hardin reports that the company owns ilmenite properties in Nevada but does not anticipate development for at least five years. It is estimated that the conversion of the plant will be approximately one-fourth the cost of a new plant (46, p.54)(9, p.20).

Rem-Cru Titanium Corporation, Midland, Pennsylvania, jointly owned by Remington Arms Company and Crucible Steel Corporation, produces ingots from sponge and processes them down into sheet, bar, billet, wire, plate, tubing and other mill products. Mill processing is done in a number of different Crucible Steel Company plants, all located in the eastern part of the United States. The chief factor in the selection of the Midland site as reported by Mr. A. G. Caterson, Sales Engineer for the company, was its proximity to available rolling mills. The principal supplier of sponge is the E. I. du Pont de Nemours and Company, Inc., at Newport, Delaware. Generally, motor truck transportation is used from the sponge source. Mr. Caterson stated that it is impractical, at this time, to give an indication of the number of Kilowatt-hours of electricity per pound of ingot produced, since the methods of titanium melting are under constant study and revision. A figure, given today, would be misleading in the near future. The company's source of electric power is the Duquesne Power and Light Company. The future capacity of the plant is contingent on the potential demand of military aircraft and the chemical process field.

Mallory-Sharon Titanium Corporation, Niles, Ohio, was founded in 1951 jointly by P. R. Mallory and Company, in Indianapolis, Indiana and Sharon Steel Corporation, Sharon, Pennsylvania. It includes a titanium melting plant, research laboratory, rolling mill, engineering, and administration building, occupying twenty-two acres. The main reason for the Niles location was the existence of rolling facilities (formerly Nibs Rolling Mill) and sufficient land for future expansion. Truck transportation is used to deliver sponge from E. I. du Pont Company at Newport, Delaware. Mallory-Sharon Company was the originator of the double-melting process called "Method S," which improves quality and predictable properties. "Method S" is the consumable electrode arc, melting in a vacuum process. Electric power is obtained from the Ohio Edison Company.

Republic Steel Corporation, Cleveland, Ohio. Production of Republic Steel Corporation consists of sponge melting, rolling, and fabricating of titanium and titanium alloys. It purchases sponge mainly from E. I. du Pont de Nemours Company, Inc. Extensive knowledge of Republic's activity is not available, but experts believe they are potential leaders in the industry because of their extensive reputation in Metallurgical Research and in the steel industry. They own rutile mining properties in Oazaca, Mexico, and have reported they expect to ship rutile concentrates to the United States in the near future.

Republic Steel also has integrated titanium melting and rolling at its Massillon and Niles, Ohio steel plants.

Foote Mineral Company, Philadelphia, Pennsylvania. This company's only interest in titanium consists of the manufacture of approximately 100 to 200 pounds per year of high purity iodide titanium crystal bars, which are sold to various laboratories for doing basic titanium alloy research.

Metal Hydrides, Inc. at Beverly, Massachusetts, is interested, solely, in the production of titanium in powder form by their patented process using TiO_2 and CaH_2. They are not contemplating going into the manufacture of titanium metal products. The company's main effort is in research.

Oregon Metallurgical Corporation, Albany, Oregon, is building melting and fabrication facilities. This firm plans to use the double melting vacuum arc method for producing titanium ingots from sponge obtained on the open market. Some mill rolling is also planned.

The Federal Bureau of Mines at Boulder City, Nevada, built a pilot plant for researching of the Kroll Process early in 1944. This plant, in agreement with other government agency, on April 30, 1953, was to produce titanium sponge to supplement, but not compete with private production. It produced 246 tons of sponge before operation ceased September 7, 1954. The Bureau of Mines, from this operation, was able to obtain accurate cost valuation of titanium production processes to facilitate their research program in the titanium metal field.

Recently, the Bureau of Mines, at its regional headquarters at Albany, Oregon, completed research on producing a highly concentrated TiO_2 slag (90% TiO_2) from ferruginous ilmenite. This development is very significant, because the highest concentrate previously obtained commercially was only approximately 70% TiO_2. The process uses one to one ratio of ore and hog fuel (wood chips) in an open furnace (4).

The following companies are engaged in various stages of research: Anaconda Copper Mining Company, Bohn Aluminum and Brass Corporation, Eagle-Picher Company, Glidden Company, Kaiser Aluminum and Chemical Corporation, National Distillers Products Corporation, Monsanto Chemical Company, and National Research Corporation. Harvey Machine Company is seeking a government contract for sponge production.

Current Problems of the Titanium Industry

There are five major problems of the titanium industry today, all of which are equally important: (1) Inadequate knowledge of the location, quality and grade of domestic titanium minerals; (2) methods for economical recovery of titanium; (3) the high cost of producing titanium metal and titanium metal products; (4) additional information is needed on the properties and uses of titanium metal; (5) development of practices for processing titanium scrap is needed.

Factors of Plant Location

The locations of present titanium metal plants have been based mainly on the availability of facilities suitable for conversion to titanium metal production. The availability of electric power in sufficient amounts to support plant operation was also a major consideration. It is estimated by experts that the over-all power requirement to produce one pound of titanium metal from its basic ore to titanium ingot to be approximately 40-50 KW-hours. The location of the necessary raw materials and potential markets affected plant locations to a lesser extent.

The factors of lower cost production in relation to plant locations are: cost of electric power; location of raw materials; labor resource; and location of the major consumers. It would be practically impossible to satisfy all of these requirements, but the most important would be availability and cost of electric power, plus the location of the necessary raw materials.

Expanded titanium metal production will require the shifting of plants to locations that will effect the lowest possible production costs in order for titanium metal to be used in applications where cost is equally as important as its superior properties.

Future Outlook of the Industry

When the industry reaches maturity, it is anticipated by some experts that the production and consumption of titanium metal will be about 200,000 tons annually (21, p.72). This prediction assumes peacetime utilization and the maintenance of powerful armed forces.

Domestic supply of titaniferous minerals are available in considerable supply to meet the demands of the increased titanium industry through recent technological improvements in smelting titaniferous iron ores. Rutile cannot be considered the major material for titanium metal production, because it does not occur in sufficient quantities; therefore, the titanium metal industry in the future will be based upon the use of ilmenite or a high-titania slag (9, p.22).

Technological improvements in alloy qualities, uses, and utilization of scrap are necessary in order to be certain of the demand and lower cost. The planned annual production now totals 22,500 tons, which is expected in 1957. If lower cost production methods are developed and the price declines to the level of stainless steel, the demand would be greatly expanded, resulting in a large and profitable industry of the future.

CHAPTER IV

THE PACIFIC NORTHWEST AND THE TITANIUM INDUSTRY

The plant location factors previously discussed in Chapter III are the basis for determining the possibilities of a titanium industry in the Pacific Northwest. These factors are: (1) availability and cost of electric power; (2) location of raw materials; (3) labor resources, and (4) location of major consumers. These factors, as they are applied to the Pacific Northwest, are discussed below.

Availability and Cost of Electric Power

The exact amount of electric power required for the production of titanium metal is not known at the present time because of the variations and changes in production techniques. Mr. Stephen Shelton of the Oregon Metallurgical Corporation at Albany, Oregon, in an interview with the writer, estimated that the power requirements for an integrated titanium metal plant (production from the basic ore to the finished ingot) would probably be 40-50 KW-hours per pound of titanium. Dr. H. H. Kellogg (21) estimated the requirements for sponge production to be 14 KW-hours per pound and ingot production 2.2 KW/hr/lb. Mr. Lloyd Banning of the U. S. Bureau of Mines, Albany, Oregon, in a personal interview said that he would estimate the power required to produce 90 per cent titanium slag from ilmenite (4) to be 4,000 KW-hours per ton. Therefore, it can be assumed that power availability is a prerequisite to titanium metal production.

Power systems in the Pacific Northwest are interconnected in one large network of generating stations and transmission lines, known as the Northwest Power Pool (16, p.79). The Power Pool is divided into East and West Groups as follows:

West Groups	Location
U. S. Columbia River Power System	Oregon, Washington Idaho, Montana
Seattle, City of	Washington
Tacoma, City of	Washington
Puget Sound Power & Light Co.	Washington
Washington Water Power Co.	Washington, Idaho Montana
Pacific Power & Light Co.	Oregon, Washington
Portland General Electric Co.	Oregon
East Groups	
Idaho Power Co.	Oregon, Idaho
Montana Power Co.	Montana
Utah Power & Light Co.	Idaho, Utah
British Columbia Electric Co.	British Columbia

Source: (63, p.9)

This Power Pool provides the region with the following benefits: (1) major utility companies can coordinate their operations including both hydro (which is the major source) and stream generation, to provide the most economical use of total energy resources; (2) continuity of service and lower cost to the utility companies because of economic transfers by a large number of inter-connections; (3) a savings in the amount of standby capacity needed to meet emergencies is effected; (4) operation permits more firm power than if each system is on an isolated basis (63, p.10). See Table 10 for generating capacity of the Pool.

The historical analysis of the region shows that in the past decade barely enough development of electric power resources has been done to keep pace with its expanding economy. However, the Pacific Northwest is endowed with 37 per cent (35 million KW) of the nation's "hydro" electric power potential and only 13 per cent of it is now developed (12, p.18). Controversies over whether development of this hydro-potential should be done through public or private finances has occupied a large amount of time and has delayed considerably the future development of this resource. Electric power requirements by major classes of consumers in the west group area of the Northwest power pool is shown in Table 11 along with estimated future requirements. Table 12 indicates the future loads and resources with power deficit shown after 1960.

GENERATING CAPACITY
PACIFIC NORTHWEST POWER POOL AREA IN THE UNITED STATES
Nameplate Rating in Kilowatts

	Existing December 31, 1950			Existing June 30, 1955		
	Hydro	Thermal	Total	Hydro	Thermal	Total
West Group of Northwest Power Pool						
U. S. Columbia River Power System	2,138,400	0	2,138,400	3,588,800	0	3,588,800
Seattle, City of	219,260	30,000	249,260	549,260	53,000	602,260
Tacoma, City of	207,500	34,000	241,500	238,000	59,000	297,000
Northwestern Electric Co. 1/	0	0	0	0	0	0
Pacific Power & Light Co. 1/	122,480	53,500	175,980	236,420	82,720	319,140
Portland General Electric Co.	106,410	88,000	194,410	121,820	88,000	209,820
Puget Sound Power & Light Co.	203,250	93,000	296,250	206,500	70,000	276,500
Washington Water Power Co.	203,210	0	203,210	354,650	0	354,650
Total West Group Utilities	3,200,510	298,500	3,499,010	5,295,450	352,720	5,648,170
East Group of Northwest Power Pool						
Idaho Power Co.	267,930	1,500	269,430	350,730	1,500	352,230
Montana Power Co.	364,840	0	364,840	421,940	60,000	481,940
Utah Power & Light Co.	176,080	96,250	272,330	175,830	366,000	541,830
Total Power Pool Utilities in U. S.	4,009,360	396,250	4,405,610	6,243,950	780,220	7,024,170
Other Utilities in and Adjacent to Northwest Power Pool Area						
Bureau of Reclamation	40,300	0	40,300	103,800	0	103,800
Bonners Ferry, City of	2,380	240	2,620	2,380	240	2,620
Centralia, City of.	4,000	0	4,000	9,000	0	9,000
Chelan County PUD	2,450	0	2,450	185,450	0	185,450
Clallam County PUD	0	650	650	0	990	990
Cowlitz County PUD	0	26,640	26,640	0	26,640	26,640
Ellensburg, City of	2,100	500	2,600	0	0	0
Eugene, City of	21,500	25,000	46,500	21,500	25,000	46,500
Grays Harbor County PUD	0	16,900	16,900	0	15,500	15,500
Idaho Falls, City of	7,400	2,840	10,240	7,400	2,840	10,240
Lower Valley Power & Light, Inc.	1,600	700	2,300	2,600	700	3,300
McMinnville, City of	200	2,740	2,940	200	2,740	2,940
Milton-Freewater, City of.	1,360	420	1,780	1,360	420	1,780
Okanogan County PUD	3,200	0	3,200	3,200	0	3,200
Orcas Power & Light Coop.	0	2,550	2,550	0	2,550	2,550
Pacific County PUD	0	1,500	1,500	0	500	500
Pend Oreille County PUD	0	0	0	15,560	0	15,560
California Oregon Power Co.	142,220	15,880	158,100	223,670	1,030	224,700
California-Pacific Utilities Co.	3,580	2,580	6,160	2,900	1,450	4,350
Montana Light & Power Co.	4,500	0	4,500	4,500	0	4,500
Mountain States Power Co. 1/	6,050	16,580	22,630	0	0	0
Star Valley Power & Light Co.	980	150	1,130	980	150	1,130
Teton Valley Power & Milling Co.	1,870	0	1,870	1,870	0	1,870
Total All Utilities	4,255,050	512,120	4,767,170	6,830,320	860,970	7,691,290

1/ Capacity of Pacific Power & Light Co. increased on May 31, 1947 by merger with Northwestern Electric Co. and on May 21, 1954 by merger with Mountain States Power Co.

Table 10

ELECTRIC POWER REQUIREMENTS BY MAJOR CLASSES OF CONSUMERS
WEST GROUP AREA OF NORTHWEST POWER POOL
Millions of Kilowatt-Hours

Year	Domestic, Urban and Rural	Commercial and Small Industrial	Large Industrial 1/	Irrigation Pumping	Other	Losses	Total Annual Energy Requirements
Actual							
1940.	1,065	881	2,186	22	177	1,029	5,360
1941.	1,279	950	3,558	20	190	1,198	7,195
1942.	1,552	1,018	5,526	21	246	1,492	9,855
1943.	1,830	1,114	8,204	23	427	1,563	13,161
1944.	2,007	1,196	9,181	24	564	1,938	14,910
1945.	2,304	1,334	7,575	39	602	1,890	13,744
1946.	2,780	1,507	6,203	44	552	2,055	13,141
1947.	3,409	1,777	8,430	49	554	2,463	16,682
1948.	4,144	2,154	9,446	50	523	2,990	19,307
1949.	4,834	2,214	9,772	66	480	3,019	20,385
1950.	5,469	2,354	11,187	101	500	3,128	22,739
1951.	5,940	2,499	12,672	369	505	3,630	25,615
1952.	6,722	2,686	12,601 2/	391	563	3,268	26,231
1953.	7,272	2,827	15,182	473	541	3,801	30,096
1954 3/	8,160	2,958	16,348	784	542	4,108	32,900
Estimated							
1955.	9,197	3,147	18,362	832	572	4,587	36,697
1956.	10,272	3,376	21,326	879	609	5,212	41,674
1957.	11,388	3,613	23,554	975	626	5,389	45,545
1958.	12,546	3,876	24,093	1,098	638	5,651	47,902
1959.	13,743	4,148	24,441	1,168	649	5,983	50,132
1960.	14,988	4,446	24,801	1,283	660	6,097	52,275
1961.	16,277	4,756	25,173	1,373	671	6,290	54,540
1962.	17,472	5,096	25,557	1,474	683	6,669	56,951
1963.	18,707	5,466	25,953	1,582	695	7,107	59,510
1964.	19,986	5,850	26,518	1,689	707	7,466	62,216
1965.	21,309	6,266	27,194	1,802	719	7,812	65,102

1/ Exclusive of any new large electroprocess plants after 1957.
2/ Decrease from previous year due to curtailment of large industrial loads and other voluntary curtailment.
3/ Partially estimated.

Table 11

LOADS AND RESOURCES
WEST GROUP AREA OF NORTHWEST POWER POOL
Thousands of Kilowatts

	1955-56	1956-57	1957-58	1958-59	1959-60	1960-61	1961-62	1962-63	1963-64	1964-65	1965-66
	Critical Year (1936-37) Hydroelectric Conditions										
Winter Peak											
Firm Loads 1/	6,020	6,566	7,050	7,522	7,939	8,351	8,748	9,225	9,730	10,270	10,852
Area Capabilities 2/.	6,865	7,546	8,036	8,942	9,363	10,202	10,215	10,215	10,215	10,215	10,215
Surplus or (Deficit)	845	980	986	1,420	1,424	1,851	1,467	990	485	(55)	(637)
Interruptible Loads Not Included . .	574	678	665	614	614	625	684	684	684	684	684
Average Energy During Storage Drawdown Period											
Firm Loads 1/.	4,133	4,483	4,817	5,138	5,387	5,637	5,852	6,142	6,449	6,779	7,133
Area Capabilities 2/.	4,524	4,818	5,129	5,515	5,621	5,734	5,797	5,798	5,798	5,798	5,798
Surplus or (Deficit)	391	335	312	377	234	97	(55)	(344)	(651)	(981)	(1,335)
Interruptible Loads Not Included . .	538	627	654	602	602	613	672	672	672	672	672
	Median Month Year Hydroelectric Conditions										
Winter Peak											
Firm Loads 1/	6,089	6,629	7,123	7,617	8,041	8,443	8,840	9,320	9,825	10,365	10,948
Area Capabilities 2/.	7,008	7,694	8,137	9,109	9,504	10,335	10,348	10,348	10,348	10,348	10,348
Surplus or (Deficit)	919	1,065	1,014	1,492	1,463	1,892	1,508	1,028	523	(17)	(600)
Interruptible Loads Not Included . .	576	680	667	616	616	627	686	686	686	686	686
Average Energy During Storage Drawdown Period											
Firm Loads 1/.	4,144	4,494	4,838	5,165	5,424	5,676	5,892	6,179	6,485	6,813	7,165
Area Capabilities 2/	5,205	5,501	5,916	6,381	6,639	6,732	6,814	6,804	6,787	6,769	6,762
Surplus or (Deficit).	1,061	1,007	1,078	1,216	1,215	1,174	922	625	302	(44)	(403)
Interruptible Loads Not Included . .	525	615	648	597	597	608	667	667	667	667	667

1/ Includes transmission losses.

2/ Capabilities include 100 per cent use of all generating facilities in the area plus all available surplus supplies imported from British Columbia and Montana.

Table 12

A study of these tables reveals the fact that it is doubtful that there will be power available for a large titanium metal industry in the Pacific Northwest now or in the future.

Dr. Kellogg (21) has estimated the future cost for producing titanium sponge, based on a plant with an annual capacity of 30,000 tons, as follows:

		Cost Per Lb. Ti	Per Cent of Cost
Raw Materials	$11,170,000	18.6	25.7
Electric Power (7 mils/Kw-hr)	5,880,000	9.8	13.5
Fuel and Water	900,000	1.5	2.1
Labor	7,300,000	12.2	16.8
Maintenance	9,500,000	15.8	21.8
Non-processing cost	8,790,000	14.6	20.1
Total Production Cost	$43,540,000	72.5	100.0

The power required for a plant of this size is approximately 840,000,000 kilowatts-hours per year.

The cost of Federal generated power direct from the Bonneville Power Administration averages 2.14 mils per kilowatt-hour, which is the kilowatt-year rate for firm power delivered anywhere from the U. S. Columbia River Transmission System (64, p.22).

The power cost in Dr. Kellogg's future estimate above, based on 2.14 mils per kilowatt-hour, would be $1,800,000 (3.0 cents per pound titanium). A savings of

$4,080,000 (6.8 cents per pound titanium) would result annually. With all other factors remaining the same, the cost for producing one pound of titanium sponge could be reduced from 72.6 cents to 65.8 cents, using the lower cost power or an annual savings of 9 per cent in over-all production costs.

<u>Location of Raw Materials</u>

The only economical occurrence of titanium ore in the Pacific Northwest is found in Idaho, where ilmenite is recovered from monazite. Ilmenite also occurs in the coastal sands but is not economical to recover.

The ilmenite in Idaho was recovered by dredging operations conducted by Baumhoff-Marshall, Inc. and Idaho Canadian Dredging Company in Valley County (57, p.6). They recovered and stockpiled approximately 80,000 tons of ilmenite which is now being shipped to St. Louis for the pigment industry. The Idaho dredging operation ceased in August of 1955. (It is very doubtful that the Idaho deposits could provide ilmenite in sufficient amounts to support a large industry in the Pacific Northwest).

The large titaniferrous ore deposits at Iron Mountain in Wyoming is significant to the Pacific Northwest because of the recent development by the Bureau of

Mines in producing a high titanium slag concentrate (4). This method requires hog fuel (wood chips), of which the Northwest has a large resource due to its forest industry. This ore could be shipped by railroad to the Pacific Northwest for smelting into titanium slag and its by-product, pig iron.

The Ports of the Puget Sound and Lower Columbia River are important for shipping ilmenite from other domestic sources as well as from foreign sources.

Chlorine can be obtained from two concerns in the region: Hooker Electrochemical Corporation of Tacoma, Washington, and Pennsalt Manufacturing Company of Portland, Oregon. This chlorine is used in the chlorination of the titanium slag to produce titanium tetrachloride. Four tons of the chlorine are required to produce one ton of titanium tetrachloride. The cost of chlorine in the Pacific Northwest is $56 a ton as compared to $67 a ton from eastern sources.

The magnesium required in the reduction process is obtained from the Dow Chemical Company, Valasco, Texas, which is the largest source in the United States.

Labor Resources

The availability of labor does not weigh heavily in titanium metal plant location because the key experienced personnel would be recruited from outside sources. An inexperienced labor force is available as indicated in Table 13 below:

Table 13

LABOR FORCE - WASHINGTON AND OREGON
1950

	Washington	Oregon
Total labor force	957,611	619,595
Civilian labor force	900,746	616,733
Unemployment	60,684	40,223
Employment	840,062	576,510

Source: Bureau of the Census, 1950 Census of the Population, Volume II, "Characteristics of the Population." Cross reference Employment 111-B.

Location of Major Consumers

The largest present consumer of titanium metal products is the aircraft industry. This fact would seem to be advantageous to the Pacific Northwest because the largest percentage of aircraft production in the United States is west of Denver, Colorado. California has 40 per cent of the nation's non-military production, while Washington has 11 per cent.

Titanium metal supplied to this market from the Pacific Northwest would have an important advantage in lower transportation charges over metal shipped from eastern producers. According to the Southern Pacific Railroad freight agent in Corvallis, Oregon, the rail rates on titanium sheet from the Pacific Northwest to Southern California markets probably would be 65 per cent less than the rates from eastern Ohio titanium producers. This means that the Pacific Northwest has a rail freight advantage of about 1.3 cents per pound of sheet. However since sheet now sells at $15.00 per pound this advantage is not critical. Even if selling price for sheet should reduce to about $2.50 the freight advantage is still a small consideration.

CHAPTER V

CONCLUSION

The low cost hydro-electric potentials of the Pacific Northwest would seem advantageous to titanium production. However, under the present hydro-electric power development program of the Pacific Northwest, indications are that electric power is not available for large-scale titanium production.

Power for small scale ingot and fabrication production is available. An example is the Oregon Metallurgical Corporation, which is being built in Albany, Oregon, for sponge melting, casting, and so forth. The Pacific Power and Light Company will provide up to 3,000 kilowatts for this operation. There is also a possibility of smelting ilmenite ore in the Pacific Northwest, using the Bureau of Mines recently-developed smelting process, which uses hog fuel (wood chips) to produce high concentrate titanium slag. The region has an abundance of hog fuel due to its forest industry. The ilmenite could be supplied from deposits in Idaho and Wyoming. This smelting operation would require about 200 million kwh of electric power annually for its electric arc furnaces for an annual production of 50,000 tons of titanium slag, based on 4,000 kwh per ton. The slag could either be shipped to sponge producers or chlorinated into titanium tetrachloride before shipment.

At present, evidence suggests that the Pacific Northwest does not offer sufficient inducements in available low cost energy, resources, or markets for the support of a large scale titanium industry. In confirmation with this conclusion, the questionnaires received from companies presently engaged in the titanium industry indicate total lack of interest in the Pacific Northwest as an area for future expansion.

Unless the development of the Pacific Northwest hydro-electric potential is accelerated to provide large blocks of firm electric power for industrial purpose, the titanium industry in the region will not develop except on a small scale basis.

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A P P E N D I X

QUESTIONNAIRE SUBMITTED TO, AND RECEIVED FROM, THE FOLLOWING COMPANIES

Dow Chemical Company

E. I. du Pont de Nemours and Company

Mallory-Sharon

Titanium Metals Corporation of America

Rem-Cru Titanium, Inc.

Electro Metallurgical Co.

Metal Hydrides, Inc.

Foote Mineral Company

GEOGRAPHY OF THE UNITED STATES TITANIUM INDUSTRY
QUESTIONNAIRE

I. Name of Company: ______________________________

Location: ______________________________

II. Type of Titanium Production.

A. Sponge. Yes _____ No _____

1. Type of process used _________________

2. Location of plant (or plants) _________

____

3. What were the chief factors leading to selection of this site? (Raw material etc.) ______________________________

____

____

4. Production in tons/year. 1954 _______

1955_______

Future _________ Max capacity ________

5. Principal raw materials required and source of supply.

____

____

____

6. Transportation used to assemble raw material.

Railway ____ Truck ____ Other _________

7. Kw hrs of electric power required per pound __________

8. Source of electric power (company)

____

B. Titanium ingots. Yes _____ No _____

1. Process used __________________________

2. Location of plant (or plants) ________

____

3. What were the chief factors leading to selection of this site? (Raw material, etc.) _______________________________

____

____

4. Production in tons per year. 1954 ____

1955 ____ Future ___________________

Max. capacity ______________________

5. Source of sponge (Company and location)

____

____

Type transportation from source ______

____

6. Kw hrs of electric power required per/pound ___________________________

7. Source of electric power (company)

____

III. Do you have plans for production plants in the Pacific Northwest? _______ If so what type of operation? ________________________________

____

____

IV. In your opinion what is the future of Titanium Metal in the next 10 years? For example: What expanded or new uses do you envision? What quantity of expansion do you envision? What price reduction do you envision?