BEFORE THE

WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION

WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION Complainant, v. NORTHWEST NATURAL GAS COMPANY, Respondent.	DOCKET UG-18___

NORTHWEST NATURAL GAS COMPANY

Direct Testimony of Andrew C. Middleton

ENVIROMENTAL MITIGATION HISTORY

EXH. ACM-1T

December 31, 2018

DIRECT TESTIMONY OF ANDREW C. MIDDLETON

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I. INTRODUCTION AND SUMMARY

Q. Please state your name and position.

A. My name is Andrew C. Middleton. I am President of Corporate Environmental Solutions LLC.

Q. On whose behalf are you appearing in this proceeding?

A. I am appearing on behalf of Northwest Natural Gas Company (“NW Natural” or the “Company”).

Q. Please describe your educational and professional background.

A. I hold a Bachelor of Science degree in Civil Engineering from Virginia Polytechnic Institute and State University (awarded 1971), a Master of Science degree in Sanitary Engineering from Virginia Polytechnic Institute and State University (awarded 1972), and a Ph.D. in Environmental Engineering from Cornell University (awarded 1975). Since 1975, I have taught environmental engineering at universities, worked for industry on environmental matters, and worked as an environmental consultant.

My industrial experience included a large number of environmental projects on facilities involving the production, processing, and handling of tar and tar chemicals, including ones on industrial wastewater treatment and industrial site investigation and remediation. As an environmental consultant, I have worked on at least 300 manufactured gas plant ("MGP") sites, including visits to at least 145 sites. My scope of work on the vast majority of the 300 sites included a review of historical information about them. In the course of my research concerning these 300 MGPs and the manufactured gas industry in general, I have also seen and reviewed information concerning numerous other plants. I have testified on eight occasions before public utility commissions regarding manufactured gas plants. I have also testified about MGPs in a number of lawsuits across the United States in depositions and affidavits, as well as twice in court where the courts recognized me as an expert on manufactured gas plants.

At *Exhibit ACM-2* is my curriculum vitae describing my background in more detail.

Q. Please summarize your testimony.

A. In my testimony, I:

- Review the history and evolution of the manufactured gas industry in the U.S.—how and why it developed, its general characteristics, and why it declined;
- Identify the major gas manufacturing processes and the residual streams generated in gas manufacture;
- Describe the demolition and dismantling practices of gas plant equipment and vessels; and
- Describe the state of gas industry knowledge regarding the potential environmental consequences, as understood today, of:
    - the operation of manufactured gas plants;
    - the disposition of residuals from gas manufacture; and
    - the demolition and dismantling of manufactured gas plants.

Second, my purpose is to:

- Review the history of gas manufacture in Portland at the MGP located in Linnton now connected with NW Natural ("GASCO MGP") as this MGP provided almost all, if not all, of manufactured gas to Vancouver, Washington, beginning around 1913;

- Identify the residual streams generated by the GASCO MGP and the disposition of those streams;
- Describe the demolition and dismantling of the gas manufacturing and storage facilities at the GASCO MGP; and
- Compare these to the practices of the gas industry during the comparable time frames.

II. HISTORY OF THE MANUFACTURED GAS INDUSTRY

Q. Please provide an overview of the history of gas manufacture in the United States.

A. Although "gas" was first named in 1609, the first gas company was not founded until over 200 years later in London in 1812. The first U.S. gas company was founded in Baltimore in 1816. A century later, by 1920, the U.S. had over 1,000 manufactured gas companies. However, by 1970, utility-owned or operated manufactured gas plants were almost non-existent, with manufactured gas having been replaced by natural gas across the U.S. The 150-year period from 1816 until the mid-1960s defines the era of manufactured gas ("MGP Era").

During the MGP Era, the U.S. manufactured gas industry began, matured, and ended. Various gas-making processes, gas storage vessels, and gas purification equipment were developed and modified throughout much of the MGP Era.

Q. How was gas manufactured?

A. Three types of gas-making processes generally dominated the manufacture of gas in the United States during the MGP Era: coal gas, carburetted water gas (also known as just “water gas”) and oil gas. Coal gas manufacture, which began in 1816, had two primary process configurations: retorts and byproduct coke ovens. In either case, bituminous coal was heated to a high temperature in a closed vessel in the absence of air. This resulted in the volatile portion of the coal being driven off as hot gas which was cooled and purified through various processes. Retorts were smaller vessels more widely used by the gas industry than the larger coke ovens. The purified gas was stored in gas holders prior to its distribution. The remaining part of the coal was coke, which was a high carbon material used as fuel, in metallurgical processes, or as feedstock to the carburetted water gas process. Coal gas was manufactured in retorts at two earlier Portland MGPs.

Carburetted water gas manufacture, which began in the 1870s, made gas from coal or coke and oil in three cylindrical vessels. The process was cyclical alternating in vessel heating and in making gas. By the early 1900s, the carburetted water gas process was widely used in the gas industry. As with coal gas, the hot carburetted water gas was cooled and purified before storage. Carburetted water gas was manufactured at one earlier Portland MGP.

Oil gas manufacture had three general process configurations: small-scale oil gas, West Coast oil gas and high-Btu oil gas.[1] These processes made gas from oil or a fraction of oil often in conjunction with the use of steam. There were many equipment configurations for the small scale oil gas process, which was used predominantly in the

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[1] It should be noted that in this document “Btu” stands for British thermal unit, which is a measure of heat content. As used here, “Btu” generally means the heat content of the gas per cubic foot of gas. For example, a reference to “530 Btu gas” means that the heat content of the gas was 530 British thermal units per cubic foot of gas, which was generally the approximate Btu value of manufactured gas. Natural gas has a Btu value of around 1000. High-Btu oil gas had a Btu value around 1000 to be compatible with natural gas.

1800s, but not at Portland MGP Sites. The West Coast oil gas ("Oil Gas") process was used in major installations beginning around 1900 on the West Coast and continuing throughout the MGP Era. This process relied on one or two vessels operated in alternate heating and gas making cycles. The hot oil gas was cooled and purified before storage. The other major oil gas process was the high Btu oil gas process used later in the MGP Era. This process relied on Oil Gas equipment or modified carburetted water gas equipment. It operated similarly to the Oil Gas process, but the feedstocks were manipulated to produce a heat content of around 1000 Btu so that it could be mixed with natural gas in contrast to the other major processes, which produced gas with a heat content in the range of 500-600 Btu. The Oil Gas process was used at the GASCO MGP Site along with a high Btu oil gas process in later years. The Oil Gas process had also been used at one earlier Portland MGP.

More detailed descriptions of Oil Gas are provided below in regard to the types of processes that were used at the GASCO MGP Site.

In addition, there were at times other gas-making processes used less frequently than those discussed above (*e.g.*, refinery gas reforming, small-scale oil gas manufacture, petroleum coking, or rosin gas manufacture). Petroleum coking was used at the GASCO MGP and is described below in regard to that site.

Q. What was generated by gas manufacture in addition to the gas itself?

A. In addition to gas, the gas-making processes also generated solid and liquid residuals. Depending on the particular gas-making process, these residuals included tar, lampblack, light oil, petroleum coke, ash, clinker, residuals from sulfur removal, and/or wastewater.

Q. **How was manufactured gas purified?**

A. After its manufacture by one of the above processes, gas was purified to recover byproducts and to remove residuals not suitable to be distributed with the gas. *Exhibit ACM-3* is a general overview of a typical gas manufacture process diagram showing purification steps. As described above, the first step in purification of the hot gas was its quenching (*e.g.*, hydraulic main for coal gas and wash box for carburetted water gas and Oil Gas). Further removal of tar not removed in the quench step was accomplished generally by the use of condensers and scrubbers. Additional equipment, such as tar extractors or Cottrell precipitators, was used at some plants as it became commercially available. At coal gas plants, ammonia removal, typically through water absorption, was the next step. At some coal gas plants, absorption of ammonia into sulfuric acid was used. Depending on the process and scale of operation, light oil and naphthalene may have also been removed typically by oil scrubbing.

The most common last step before gas storage was hydrogen sulfide removal. Prior to the 1880s, lime absorption was the typical process. In the 1880s and afterwards, iron-oxide beds became the dominant process. Around 1920 and afterwards, some larger plants used liquid sulfur removal. In the case of coal gas and Oil Gas plants using crude oil, hydrogen sulfide removal also accomplished cyanide removal from the gas.

After hydrogen sulfide removal, the gas went into storage prior to its distribution.

Q. **How was gas stored?**

A. There were three general types of gas holders used to store gas: 1) low-pressure, water-seal; 2) waterless, low-pressure; and 3) high-pressure.

The low-pressure, water-seal gas holder consisted of a water tank, the holder itself, which could have had multiple telescoping lifts, and structural components and piping equipment. *Exhibit ACM-4* is a picture of a low-pressure, water-seal holder with an above-ground steel water tank at the GASCO MGP. The water tank was filled with water which sealed the gas within the holder. The holder itself moved up and down within its superstructure as gas was added or removed from it.

The waterless, low-pressure holder consisted of a very large, vertical tank with a disk floating on the gas inside. The purpose of the disk was to contain and pressurize the gas. The disk moved up and down in the interior of the tank as gas was added and removed, respectively. The seal between the perimeter of the disk and the inside of the holder was typically wetted with recirculating tar.

High pressure holders were either spherical (*e.g.*, the Hortonsphere), horizontal cylinders (a.k.a. “bullet tanks” like current propane storage cylinders) or vertical cylinders. These tanks received gas from compressors and stored the gas at higher pressures (*e.g.*, 30-60 pounds per square inch) than the low-pressure holders. These were mechanically sealed, pressurized tanks in contrast to the low pressure, water-seal holders.

Gas holders ranged in size from small (*e.g.*, 25,000 cubic feet in an early low-pressure water seal) up to very large (*e.g.*, 20 million cubic feet for waterless holders of the 1920s and afterwards).

Q. What was the general disposition of residuals from gas manufacture?

A. The gas-making processes produced various residuals in addition to manufactured gas. Residuals included both byproducts and wastes. Byproducts were materials that could be sold or beneficially used at the MGP. Wastes were the converse—materials that could not be sold or used beneficially. There were three general methods for disposition of these residuals:

- <u>Sale or Use as Byproducts:</u> Various markets existed at different times for byproducts. These markets changed according to external factors. Byproducts could also be used by a gas company directly or as feedstocks to other manufacturing processes to create more valuable byproducts.
- <u>Use as Fuel</u>: If residuals had sufficient energy content and had physical and chemical characteristics that could reasonably facilitate use as fuel, they could be burned to generate heat for the gas manufacturing process or in the boiler house to generate steam.
- <u>Disposal:</u> If residuals could not be sold or used as byproducts or fuel, they became wastes for disposal.

The viability of byproduct recovery was dependent on several factors, including: economical technologies had to be available to recover byproducts that would meet market specifications; sufficient quantities of material had to be produced to warrant recovery; and, there had to be a market for the byproducts. The principal motivation for byproduct recovery was to generate added revenue, reducing the cost of gas to the consumer, thereby making manufactured gas less costly. As part of their oversight role on behalf of the gas consumer, public service commissions often received reports on the recovery and sale or use of byproducts from manufactured gas companies within their respective jurisdictions.

Q. **What was the typical disposition of coke?**

A. Coke from coal carbonization was a high-carbon content byproduct sold for use as fuel or in metallurgical processes or used as fuel at the MGP or at the MGP as feedstock to the carburetted water gas process. Petroleum coke was high-carbon with lower ash content than coal coke. It typically was sold, for example, to be used in the manufacture of aluminum.

Q. **What was the typical disposition of tar?**

A. Tar from any of the processes was a byproduct sold for use in making commercial products (*e.g.*, road tar and tar chemicals), used as fuel at the MGP, or used as a feedstock for producing commercial products at the MGP (*e.g.*, road tar and tar chemicals). As necessary, tar was dehydrated where practical, with the resulting tar sold or burned as fuel. Various dehydration processes were available to generate lower water content tar, including heating and centrifugation methods. None, however, proved to be completely practical on every high water content tar. If a high water content tar could not be reasonably treated or the tar could not be sold or burned, it was typically stored in tanks, gas holders, or onsite ponds, or was disposed of as a waste.

Q. **What were commercial uses of tar?**

A. Tar is a complex mixture of hundreds of organic chemical compounds, including many polycyclic aromatic hydrocarbons. It had and still has many beneficial uses. Various companies outside of the gas industry purchased tar during the MGP Era to refine it into commercial products. The primary refining process for tar was distillation into different fractions. The commercial products included creosote as a preservative for railroad ties and utility poles, road tar, bitumen used for tar roofs, tar coatings, and tar pitch used in the manufacture of aluminum. Some gas companies refined the tar at the MGP and sold the resulting commercial products directly to end users such as state or county road departments.

Substantial volumes of tar were put on the ground in paving roads and streets or for dust suppression on roads and streets. For example, application rates were up to two gallons of tar binder per square yard of road. On a 20-foot wide road, this would be 23,000 gallons of tar per mile of road. In 1913, the Barrett Company stated that its product, Tarvia, had been used successfully on over 50 million yards of roadways and pavements in this country. For a 20-foot wide road, this quantity in square yards would equate to over 4,000 miles of roads and streets. At an application rate of two gallons per square yard, this would equate to 100 million gallons of tar placed on roads and streets.

Currently, coal tar (there is no current U.S. production of carburetted water gas or Oil Gas tar) remains a commercial product used for a variety of purposes, including production of creosote, roofing bitumen, tar pitch for the aluminum industry, and driveway sealer. In addition, certain shampoos (*e.g.*, Westwood-Squibb Sebutone® tar shampoo) contain a USP-grade of coal tar.

Q. What was the typical disposition of lampblack?

A. Lampblack was very fine carbon particles with low ash content. Lampblack from the Oil Gas process was typically used at the MGP as fuel or sold as fuel or a feedstock to certain manufacturing processes. As discussed in further detail below, the GASCO

MGP made briquettes from the produced lampblack, which was then sold as fuel. If sale or use was not practical, lampblack could have been disposed onsite at the MGP or offsite at a waste disposal site.

Q. What was the typical disposition of light oil?

A. In the manufactured gas industry, "light oil" was a liquid recovered from the gas-making process that was made up primarily of volatile aromatic hydrocarbons (*e.g.*, benzene and toluene). Light oil was less dense than, and therefore floated on, water. Without being refined into other chemicals, light oil could be used as fuel or sold as commercial product for use as a feedstock to chemical manufacture. It could be refined into motor fuel that could be mixed with gasoline or that could be used by itself. It could also be distilled into its different fractions, thereby serving as a source for commercial chemicals such as benzene. Light oil recovered from the gas of any of the processes was typically sold as a commercial product, used at the MGP as fuel or processed at the MGP into other commercial products (*e.g.*, motor fuel).

Q. What was the typical disposition of materials from sulfur removal?

A. There were two general types of material mixtures resulting from sulfur removal: spent lime primarily in the 1800s and spent iron oxides from the 1880s until the end of the MGP Era. In addition, there was elemental sulfur recovered from certain liquid sulfur removal processes from the 1920s until the end of the MGP Era. The typical disposition of these materials was as follows:

Spent Lime

Spent lime was a mixture of wet lime that had reacted with hydrogen sulfide (and in the case of coal gas, hydrogen cyanide) to form chemical compounds of sulfide (and cyanide in the case of coal gas). Its use was predominantly before the 1880s when iron oxide sulfur removal was developed; however, its use afterwards continued at some MGPs. It was sold or given away as a soil conditioner or disposed of as a waste.

Spent Iron Oxides

Spent iron oxide was a mixture of iron compounds, sulfur compounds, and elemental sulfur, and the medium on which the iron oxide had originally been fixed. This medium was often wood chips or wood shavings, but it could have been other materials (*e.g.*, corn cobs) depending on the materials available to the MGP. The purpose of the medium was to provide porosity together with a surface for the iron oxide so that the hydrogen sulfide containing gas could flow through a bed of the material and have the sulfide react with the iron. In the case of coal gas and of Oil Gas using crude oil, the spent iron oxide also contained iron cyanides, as the iron would react with the hydrogen cyanide present in these manufactured gases. Iron cyanides typically converted to Prussian blue or ferric ferrocyanide ("FFC"), which is a stable compound. Commercially, Prussian blue is used as a blue pigment.

The sulfide removal capacity of the iron oxide could be regenerated several times (known as revivification in the gas industry). Revivification was accomplished either by removing the iron oxides and placing them on the MGP site for exposure to air or by adding air to the gas entering the purification process. However, at some point no further revivification could be attained and they became "spent."

The spent oxides were typically used as fill materials, disposed of as a waste, or sold or used as sources of chemicals. An example of this market is the appearance in the 1910s in Brown's Directory of gas companies of advertisements seeking to purchase spent oxide.

Elemental Sulfur

Liquid sulfur purifiers were developed in the 1920s for use at larger scale MGPs. The purification process was to scrub the gas with a solution that would absorb the hydrogen sulfide and then treat the scrubber solution to remove the sulfide so the solution could be recycled to the scrubber. In certain of these processes, elemental sulfur was recovered.

Elemental sulfur from liquid sulfur purifiers was typically sold as a commercial product or disposed of as a waste if it was not saleable.

Q What was the typical disposition of ash and clinker?

A. Ash resulted from heating the retort coal gas process by burning coke or the burning of coal or coke in the boiler house to generate steam. It consisted of the chemical compounds in coal which did not combust. Clinker was a residual of the carburetted water gas process, being the remnants of the coal or coke that did not burn or react with steam in the cyclical process in the generator vessel. It consisted of the non-combustible compounds in coal or coke along with unreacted carbon. Clinker had a slag-like appearance.

Ash and clinker were not generally marketable in the U.S. Sometimes, ash was used in building materials and clinker was used in sports running tracks. The majority of ash and clinker was used as fill, or disposed of as a waste.

Q What was the typical disposition of wastewater?

A. Wastewater was the excess water from the gas-making and purifying processes not recycled to the process. Substantial amounts of water were recirculated for hot gas quenching, gas scrubbing, and gas cooling. Typically, the excess water (*i.e.*, wastewater) became an effluent discharged to surface waters, to local municipal sewerage systems, or to the MGP site itself, where its fate depended on the local site hydrologic conditions.

Q. What happened if residuals from an MGP had no market or economic use during some time period in which the MGP operated?

A. If there was no market or economic use for any of the residuals produced, they became wastes for disposition by the means contemporary to the situation at the time.

Q. What general waste disposal practices did the manufactured gas industry employ?

A. In the manufactured gas industry, as in other industries during the MGP Era, when residuals could not be recovered and sold or used as fuel or byproducts, they became wastes for disposal. Wastewaters were typically discharged as effluents to surface waters, municipal sewerage systems, or the MGP site itself. Solids were generally disposed of on land. For example, unusable tar was sometimes disposed of in ponds or low-lying areas onsite or offsite. These disposal methods were widely practiced during the MGP Era by MGPs, other types of industry, and municipalities, and were considered to be acceptable and proper. Indeed, due to the state of the technology at that time, there were no other feasible means of disposal.

Q. How were MGP residuals released at MGP sites?

A. In addition to waste disposal practices, there were several activities related to the storage and transfer of liquids at an MGP that sometimes resulted in releases of residuals to an MGP site. As liquid byproducts, such as tar, were produced, they were pumped around the plant through piping networks to above and below-grade processing and storage vessels. Accidental leaks and spills from pipes, pump seals and valves occurred. These incidents resulted in releases of liquids to the site. In addition, leaks and spills of liquids from above- and below-ground tanks, pits, and other vessels, such as gas holders, sometimes also occurred, causing liquids to reach the surface or enter the subsurface of the site.

The revivification process for iron oxides from gas purification was also a means through which residuals or their chemical constituents could have reached the surface of the site. One means to revivify oxide was by spreading it in thin layers on the ground so that air could oxidize the iron sulfide to iron oxide, its reactive state, and sulfur (*i.e.*, *ex situ* revivification). When the oxides could no longer be revivified, they were often removed from the purifier boxes and placed on the ground. Depending on the circumstances, the oxide might be stored on the ground at the MGP for extended periods of time. Eventually, if the oxides could not be sold or used as the source of saleable chemicals, they might be used as fill or disposed of on other parts of the site or in offsite landfills.

Related to iron oxide handling, in the late 1800s and into the 1900s, there were newspaper articles about people bringing their children to gas plants when the purifying boxes were being opened to change out the media. According to these articles, breathing the vapors from the spent oxide boxes brought relief to those suffering from croup, colds, and whooping cough.

Q. How were MGPs demolished and dismantled?

A. MGPs were taken out of service throughout the MGP Era for various reasons. Some plants reached the end of their useful lives and were not replaced. Some were closed when gas could be more economically provided by other larger plants on a regional basis. Many were closed when the introduction of natural gas made them obsolete, as was the case for the GASCO MGP. Some carburetted water gas plants were converted to high-Btu oil gas plants for peak shaving during the 1940s and thereafter before being closed permanently. Peak-shaving equipment operated intermittently for short periods of time to provide gas during a period of high demand (*e.g.*, very cold winter days).

Once taken out of service, the plants were dismantled in whole or in part for various reasons. One purpose was to reduce their assessed value for tax purposes. Another was to allow for reuse or redevelopment of the land.

The procedures for taking a plant out of service generally entailed dismantling and demolishing all of the above-ground structures and leveling the site, except where certain buildings were left for future use. Below-ground tanks were often filled with building debris or other material to bring them to ground level. Bulk liquids removed from tanks were disposed of either onsite or offsite and sludge layers were often left behind in tanks that were not completely removed (*e.g.*, below grade water tanks of gas holders or below grade tar separators). Below-grade pipes were left in place along with the liquids they might contain. Salvageable materials, such as steel from tanks, were recovered. Solid wastes from above-ground vessels, such as iron oxides, were used as fill or disposed of either onsite or offsite.

Q. How did current environmental impacts result from historical MGP activities and practices?

A. Typical operating, disposal, and demolition-dismantling practices during the MGP Era at former MGP sites resulted in environmental contamination of soil, groundwater, or stream sediments as it is defined today (*i.e.*, in 2018), which may require remediation under current state or federal laws and regulations. Additionally, post-MGP activities sometimes also resulted in releases of chemicals or spreading of chemicals left behind at the cessation of MGP activities.

Beginning around the 1970s, analytical technologies became commercially available to measure relatively low concentrations of chemical constituents in water, soil, and sediments which provided a basis to begin assessing impacts. A number of organic or inorganic chemicals may possibly be present in now measurable concentrations in soils, groundwater and sediments at or near a former MGP site as a result of historic gas plant activities. Organic chemical compounds include the following groups: volatile aromatics (*e.g.*, BTEX), phenolics, and polycyclic aromatic hydrocarbons (*i.e.*, PAHs). It should be noted that these groups of compounds generally represent the chemicals possibly present at MGP sites, but they may not represent what actually will be discovered at any specific location. Current testing at a specific MGP site may or may not find any or all of these chemical compounds.

Q. How did consideration of the environment change after the end of the MGP Era?

A. The MGP Era had ended by the first Earth Day in 1970, the year that began the modern era of environmentalism ("Environmental Era"). From 1970 onward, the U.S. Congress enacted a series of laws revolutionizing the U.S. approach to environmental regulation and management of air quality, water quality, solid waste, industrial sites, and historical disposal facilities. A national understanding of the impact of historical industrial operating and disposal activities on soil and groundwater quality evolved in the 1970s, resulting in the passage of the "Superfund" Act in December 1980. Laws, regulations and guidance issued under Superfund and state counterparts formed the foundations of the then new environmental field of site remediation. Application of the site remediation process to MGP sites generally began in the 1980s and continues through the present as a significant post-MGP Era effort by those held responsible for MGP sites.

Q. During the MGP Era, what was the gas industry's knowledge of environmental impacts as they are understood currently (2018)?

A. Manufactured gas plants' operating, waste disposal, and demolition-dismantling practices were consistent with the practices of other industries, governments, and individuals throughout the U.S. During the MGP Era and prior to the Environmental Era, these practices throughout industry and society as a whole were generally regulated by the principle of nuisance control (*e.g.*, controlling offenses to the senses, such as smoke and odors in the air, objectionable tastes in the water, or soot deposition). Nuisances were considered temporary problems and were dealt with as discrete and separate situations in a manner so as to eliminate the immediate offensive condition.

From 1816 through the present, surface water has been accepted as a proper receptor of wastewaters. Discharge of wastewater to surface waters (*e.g.*, rivers) was common for industries and municipalities during the MGP Era and continues to be so today. However, the required degree of pre-discharge treatment of wastewaters throughout this time period has changed significantly, especially during the Environmental Era after passage of the amendments to the Clean Water Act in 1972. In 1972, regulations promulgated under the Clean Water Act mandated controls on wastewater discharges across the U.S. based on best practical treatment and subsequently best available treatment. Since 1972, there has been increasing limitations placed on wastewater discharges based on current understandings of impacts to rivers with respect to present water quality standards. These Environmental Era requirements have also extended to stormwater discharges and runoff from agricultural lands. Present-day regulation of wastewater discharges contrasts greatly to the situation during the MGP Era.

From 1816 until the 1970s, land was accepted as the final receptor for many kinds of wastes. Solid and liquid wastes from industries and municipalities were disposed of in open dumps either onsite or offsite, and/or in low-lying areas onsite. In the 1970s, the requirements for land disposal of waste began to change significantly.

There are several significant examples of industries, other than the manufactured gas industry, that also followed these disposal practices prior to the 1980s. In the iron and steel industry, solid wastes from byproduct coke plants were disposed of on land, either onsite or offsite. These wastes consisted primarily of ash, sludges from cleaning of process tanks and vessels, and spent oxides or other gas cleaning solids (*e.g.*, off-specification sulfur). Additionally, in the petroleum refining industry, oily sludges were disposed of on land. In the wood-treating industry, waste liquids were disposed of in onsite ponds. Additionally, sludges from cleaning of tanks and vessels were disposed of in onsite dump areas. All these practices continued until the 1980s, when regulations promulgated under the 1976 Resource Conservation and Recovery Act ("RCRA") mandated controls on land disposal of wastes across the U.S. These Environmental Era regulations have also required for treatment of certain wastes prior to land disposal and for incineration of certain wastes.

Municipal garbage, trash, and sludges from sewage treatment plants were disposed of in open dumps. These practices remained in effect in the U.S. until the 1970s and 1980s, when regulations began to systematically phase them out, in favor of sanitary landfills or controlled land application, in the case of sewage sludges.

Q. What do you consider to be the definition of a reasonable industry practice with respect to the operation of an industrial facility like an MGP and to the disposition of residuals from such a facility?

A. I consider an activity to be a reasonable practice if the activity was one which a reasonable business person, given the context of the legal standards and state of knowledge at the time of the activity, would have engaged in.

III. GAS MANUFACTURE AT THE GASCO MGP SITE

Q. Please describe the history of gas manufacture at the GASCO MGP Site?

A. As an overview, gas manufacture began in 1913 and continued until the fall of 1956. Gas manufacturing processes used Oil Gas and petroleum coking. During the fall of 1956, Portland Gas & Coke Company ("PGCC") converted to natural gas distribution.

Afterwards, the Oil Gas equipment was converted to high Btu oil gas and maintained for standby and peak shaving until 1958.

In 1910, the American Power & Light Company formed PGCC, acquiring the gas business from Portland Gas Company. In 1912-13, PGCC constructed a new Oil Gas plant at Linnton (*i.e.*, the GASCO MGP) on the west bank of the Willamette River, several miles northwest of downtown Portland. In 1913, operations began at this new plant, negating the need to operate the former downtown MGP.

E.L. Hall of PGCC, in a 1916 paper, attached as *Exhibit ACM-5*,[2] described the rationale for building a new gas plant as follows:

> Due to the phenomenal growth since the Lewis and Clark Exposition in 1905, the old site of the gas works at Front and Everett Streets, consisting of a few city blocks on the water front, became inadequate to take care of the continuous additions to plant and machinery, while the business center drawing its cordon tighter around the manufacturing activities, brought about increased complaints against the smoke and odor in connection with manufacturing operations. Growing inefficiency and inadequacy of the old machinery, most of which had been in use for many years, called for a reconstruction of the plant. It was, therefore, decided in 1910 that the time had come to move the manufacturing plant to the outskirts of the city.[3]

In the citation above, Hall's mention of complaints against smoke and odor provide an example of nuisance issues related to manufactured gas operations. Hall closed this paper with a conclusion about "Operating Efficiencies:"

> The new plant effects a saving over the old plant approximating $45,000.00 per annum, or practically 15 per cent, accounted for principally in fuel and labor.[4]

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[2] Hall, E.L., *New Oil Gas Plant—Portland, Oregon, in The Publication Committee (eds.)*, Proceedings of the American Gas Institute, Eleventh Annual Meeting, Chicago, IL, pp 355-418 (October, 1916) [hereinafter Hall Paper, Exh. ACM-5].

[3] Hall Paper, Exh. ACM-5 at 2.

[4] *Id.* at 64.

The new plant also manufactured lampblack briquettes on a significant scale for sale as fuel in the Portland area. This planned briquette manufacture was a significant aspect of the economics of the new plant. The plant also stored tar recovered from the Oil Gas process, which it then either sold or used as fuel at the plant. In the 1920s, the plant installed equipment to recover light oil and process it into motor fuel and to process tar into a variety of products. These tar products included road tar used across Oregon, including in Multnomah County. In 1941, PGCC installed petroleum coke ovens to generate gas and petroleum coke. Petroleum coke was in demand by aluminum smelting plants, particularly those located in Vancouver, Washington. Aluminum manufacture was a primary industry in support of the war effort of World War II. Production of gas, petroleum coke, and also of pitch from tar at this plant provided significant support of the war effort.

PGCC manufactured gas and commercial byproducts at this location until 1956, when natural gas pipelines reached Portland. At that time, the Oil Gas plant at the GASCO MGP was placed on standby for a time to be available for peak shaving and the location became a distribution operation for natural gas, which continues today.

In the 1960s, demolition and dismantling of the gas plant began in order to make way for the installation of the liquefied natural gas (LNG) tank, which began operation in 1969. Renovation of the surface of the GASCO MGP continued until 1980 to bring it more or less to its present general topographical condition. Today, there are no surface structures left from the original GASCO MGP.

Finally, around 1913, PGCC began supplying Vancouver, Washington with manufactured gas, acquiring the Vancouver gas business in the 1920s and continuing to supply gas to Vancouver through the present (2018).

Exhibit ACM-5, pages 10, 21, 26, 42, 54, 58 and 61 includes pictures from Mr. Hall's 1916 paper of the new 1913 gas plant at the GASCO MGP. *Exhibit ACM-5*, page 6 is a drawing from a 1916 paper showing the layout of the 1913 GASCO MGP.

Q. When and where was the Oil Gas process used?

A. As background, in 1906, carburetted water gas manufacture at the downtown Portland MGP was discontinued due to the price of coal used in the generator. The carburetted water gas equipment was modified to produce Oil Gas from crude oil. Oil Gas was made from 1906 until the downtown Portland MGP ceased operations with the startup of the new GASCO MGP in 1913.

On October 27, 1913, the new GASCO Oil Gas plant began operation. This plant used a single shell Oil Gas process with five gas machines installed at that time. Each Oil Gas set (*i.e.*, single Oil Gas machine) had a gas production capacity of two million cubic feet per day. Subsequently, additional Oil Gas machines were added to further increase the capacity of the plant. The operation of the Oil Gas machines was modified at times as necessary to respond to changing conditions. For example, in 1935, the single-shell generators were cross-connected in pairs to enable the plant to use a high-carbon fuel oil available at lower cost, as described by William Q. Hull and W.A. Kohlhoff in a 1952 paper in Industrial and Engineering Chemistry[5] , attached as

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[5] Hull, W.Q. and Kohlhoff, W.A., *Oil Gas Manufacture*, Industrial & Engineering Chemistry, 44 (5), pp 936–948 (May 1952) [hereinafter Hull paper, Exh. ACM-6].

Exhibit ACM-6. In the fall of 1956, PGCC converted to natural gas, thereby ending base load manufacture of gas. Afterwards, the Oil Gas equipment was converted to high Btu oil gas and maintained for standby and peak shaving until 1958. In 1958, the GASCO MGP was mothballed for future emergency use.

The GASCO plant was one of the larger gas manufacturing plants in the U.S. *Exhibit ACM-7* is a graph of the annual production at the GASCO MGP from 1914 through 1953. Annual gas production during this time period ranged from a low of 1.5 billion cubic feet in 1915 up to a high of 10.5 billion cubic feet in 1948. The 1949-50 edition of Brown's Directory of American Gas Companies listed manufactured gas production for calendar year 1948, from which examples can be taken. The listed 1948 annual production amounts of the western cities of Seattle and Honolulu, which were producing Oil Gas at the time, were 3.6 and 2.4 billion cubic feet, respectively. There was also 0.8 billion cubic feet of carburetted water gas production listed for Seattle in that year bringing the total to 4.4 billion cubic feet. Contrastingly, the listed 1948 annual production for a smaller eastern city, Holyoke, Massachusetts, was 0.4 billion cubic feet of carburetted water gas. The 1948 GASCO MGP production of 10.5 billion cubic feet was multiples of these example cities.

Q. Please describe Oil Gas manufacture.

A. Oil gas manufacture was with the large scale oil gas process (*i.e.*, Oil Gas) and the high-Btu oil gas process.

The Oil Gas processes, also known as Pacific Coast oil gas, were first developed in the 1890s with the first major oil gas plant beginning operation in 1902 in Oakland, California. Oil Gas manufacture was economically beneficial in situations where crude oil was more readily available and less costly than coal, such as on the West Coast of the U.S. in the 1900s. Oil Gas manufacture occurred at the GASCO MGP from 1913 until 1956 using single shell oil gas equipment modified at times during this period to accommodate changes in feedstocks and situations.

Exhibit ACM-8 is a schematic diagram of the Oil Gas process. The process was cyclical and it relied on one (single-shell Oil Gas) or two vessels (two-shell Oil Gas) filled with firebrick arranged in a manner to create gas passageways. In the first cycle, oil was burned in the vessels to heat the firebrick to a high temperature. In the second cycle, manufacture of Oil Gas occurred by injection of steam and additional oil into the hot vessels which caused a reaction to form gas.

The hot gas exited the vessel into a wash box, in which it was quenched with water. This quenching caused, depending on the process, lampblack and/or Oil Gas tar to separate from the gas. The relative proportions of lampblack and tar in the hot gas depended on the operational conditions of the Oil Gas process. For example, the Oil Gas process could be configured and operated to produce more lampblack and less tar. Also, depending on the configuration and operation of the wash box, the degree of separation of lampblack and tar could be affected. For example, primary removal of lampblack from the gas could be accomplished in the wash box with tar removal in subsequent purification steps by the design and operation of the wash box. The resulting lampblack and water mixture or Oil Gas tar and-water mixture flowed to quiescent basins or other processes for separation of the water and recovery of the lampblack and tar.

Following the wash box, gas was further purified to remove remaining tar and sulfur. In the case of Oil Gas plants using crude oil as a feedstock, purification downstream of the wash box would also have removed some cyanide.

The Oil Gas process generally produced the residuals oil gas tar, lampblack, materials from sulfur removal, and wastewater. At some Oil Gas plants, additional residuals (*e.g.*, light oil) were recovered.

After conversion to natural gas in 1956, PGCC used the high Btu oil gas process until 1958 for peak shaving. The high-Btu oil gas process was generally developed for application when gas companies were switching from manufactured gas to natural gas. High Btu oil gas was a modification of Oil Gas manufacture that resulted in the manufactured gas having a heat content of around 1000 Btu per cubic foot, thus allowing it to be compatibly mixed with natural gas. Typically, the role of this process was to be on standby such that during periods of peak demands (*e.g.*, colder winter times), it could be activated to supplement natural gas supplies. This process was typically used just a few days a year. The high Btu oil gas process could be developed either by modifying a carburetted water gas process or a regular Oil Gas process. Its operation was similar to that of the Oil Gas process, as were the residuals it produced.

Q. When and where was the petroleum coking process used?

A. In 1941, four petroleum coke ovens (Knowles Coke Ovens) were added at the GASCO MGP to produce gas and petroleum coke. The high Btu content (around 1000 Btu) of the gas from these ovens was reformed downward to meet required Btu content of 570 Btu. These ovens operated until 1953, after which they were dismantled.

Q. What was petroleum coking?

A. The process of petroleum coking is analogous to that of coking coal (*i.e.*, coal gas manufacture), except that petroleum or petroleum fractions were subjected to high temperature heating in the absence of air instead of coal. This resulted in the production of gas and residuals. The coking apparatus was constructed to facilitate the treatment of liquids rather than solids as in the case of coal gas manufacture. The gas was purified for removal of tar and sulfur. The main residuals from petroleum coking were petroleum coke, tar, materials from sulfur removal, and wastewater.

Q. What residuals were generated by gas manufacture at the GASCO MGP and what was the disposition of those residuals?

A. I will first discuss the residuals generated by the respective gas manufacturing processes used at the GASCO MGP. The next topic will be the fate of any of the residuals not usable or saleable. Finally, since wastewater was a residual common to all of the processes, its consideration will be made separately at the end.

As discussed above, typically, the primary residuals of oil gas manufacture were lampblack, oil gas tar, and spent purifier materials. In addition, this MGP recovered light oil from the gas. Records regarding the disposition of these residuals have been found. Based on these records, the disposition of the Oil Gas residuals was as follows:

- <u>Lampblack</u>: predominantly pressed into briquettes for sale as fuel, but some sales occurred in bulk for use as a chemical feedstock; lampblack not pressed into briquettes was stored on site and eventually sold in the late 1940s and early 1950s in bulk to local industry as well as elsewhere;

- <u>Oil Gas Tar</u>: separately recovered from the lampblack and initially used as fuel in the boiler with some sold; and, subsequently processed into commercial products at the MGP (*e.g.*, road tar, pitch) which were sold;
- <u>Light Oil</u>: processed into commercial products at the MGP (*e.g.*, motor fuel, chemicals) which were sold, including some sales of motor fuel at company-owned filling stations for a period of time; and
- <u>Spent Purifier Materials</u>: spent iron oxides placed on the MGP site until its demolition and dismantling in the 1960s and 1970s; some recovery of yellow prussiate of soda was done during World War I; some sulfur recovery was done in the time frame of the late 1930s.

Exhibit *ACM-9* is a good summary of this plant's operation, given in 1939 by Bliss G. Sinclair, who at the time was Assistant Chief Engineer, Department of Public Service, State of Washington. The paper was entitled, "The Gas Industry in State of Washington,"[6] and presented at the 17th Annual Conference of State Utility Engineers in Washington, DC.

Mr. Sinclair first commented on the Seattle Gas Company oil gas process: "Although Washington produced considerable quantities of coal, there are only two or three deposits of coking coal and these are comparably high in ash ... not economically adaptable to the production of coke oven gas. Consequently, the Seattle Gas Company decided to install an oil gas unit similar to the one used in Portland, which permits the

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[6] Sinclair, B.G., *The Gas Industry in State of Washington*, Paper presented at the 17th Annual Conference of State Utility Engineers, Washington, DC (May, 1939) [hereinafter Sinclair paper, Exh. ACM-9].

recovery of a number of valuable by-products. This interesting process will be described later in detail."[7]

He noted about manufactured gas in Portland: "The city of Portland, Oregon, and the surrounding territory have enjoyed the use of manufactured gas for a period of 79 years. This utility is, therefore, one of the oldest on the Pacific Coast. The company is justly proud of the progress made."[8]

His paper includes a section entitled, "A Brief Description of the Oil Gas Plant of the Portland Gas & Coke Company,"[9] which makes up about half of the whole paper. His description begins, "The Portland Gas & Coke Company's plant is the only one of its kind in the country. A unit somewhat similar is being placed into operation in Seattle at the present time. The interesting part of this method is the use of an oil residuum from raw materials and also the yield of a large number of by-products." ... "In 1936 a change was made in the gas generators, which for the first time in the history of the gas industry made it possible to use for raw material a very low gravity residuum obtained from gasoline refineries. The use of such material for gas making had never before been attempted because excessive carbon deposits would accumulate in the generators. By cross connecting the generators in pairs this excess carbon could be burned out during the heating cycle, the carbon itself serving as fuel for heating instead of oil as formerly." ... [10]

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[7] Sinclair paper, Exh. ACM-9 at 7.
[8] *Id.* at 9.
[9] *Id.* at 9-15.
[10] *Id.* at 9.

"Virtually all of the tar now finds a ready market in the construction of non-skid surfacing roads. Last year the sales of tar amounted to over 1,600,000 gallons."[11] "The second kind of by-product that is recovered is carbon or lampblack. ... Last year the briquette sales were nearly 52,000 tons."[12] "The third by-product is the recovery of light oil ... the annual output being over 2,000,000 gallons. ... there are other by-products, one of which is sulphur."[13]

"There has been a great deal of original engineering and chemical research in order to develop such a plant as this. In 1937 the company constructed a 'pilot plant' which is a miniature gas plant complete in all essential details. This makes it possible for research to be carried on and special tests to be made ..."[14] "During the period from 1906 to 1930 the quality of oil available to Portland Gas & Coke Company at a reasonable price went down from 22° A.P.I. to 8° A.P.I., accompanied, nevertheless, by a moderate increase in price. However, the development of by-products by this company has more than kept pace with the decreasing quality and increasing cost of oil, so that manufacturing costs have not tended to rise appreciably, if one neglects the flurries in oil prices during the war-time [World War I] period. ... The heavier residuums are, however, a preferred source of gas manufacture when it is desired to produce maximum amounts of carbon for the production of briquettes. By reason of the local market for solid fuel, the Gas Company can carry on the processing oil from where the oil refiner leaves off, to produce gas with a maximum yield of by-products."[15]

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[11] Sinclair paper, Exh. ACM-9 at 11.
[12] *Id.* at 12.
[13] *Id.* at 12.
[14] *Id.* at 13.
[15] *Id.* at 14-15.

As discussed above, from 1941 until 1953, the GASCO MGP also used the petroleum coking process. Typically, the primary residuals of petroleum coking were petroleum coke, tar, light oil, and spent purifier materials. Records regarding the disposition of these residuals have been found. Based on these records, the disposition of these residuals was as follows:

  - <u>Petroleum Coke</u>: sold to aluminum smelters for electrode manufacture;
  - <u>Tar:</u> as for Oil Gas tar, processed into commercial products at the MGP, which were sold;
  - <u>Light Oil</u>: as for Oil Gas light oil, processed into commercial products at the MGP, which were sold; and
  - <u>Spent Purifier Materials</u>: the gas from petroleum coking was purified of sulfur after consolidation with oil gas; see the discussion above for the disposition of the spent purifier materials.

- **<u>Unusable, Unsalable Residuals</u>:** If, because of market conditions, any of the residuals discussed above, which were typically commercial byproducts or beneficially used, could not be sold or used, they became waste for disposal by the means contemporary to the situation at the time. In addition, if there were other residuals such as sludge from tanks or from residuals processing, which were unusable and unsalable, these were waste for disposal by the means contemporary to the situation at the time. These means contemporary to the operation of the GASCO MGP included disposal on land onsite at the MGP or offsite.

- **<u>Wastewater</u>:** Manufactured gas plants used water for quenching, condensing, and scrubbing of the gas in the purification process, quenching of hot coke, cooling, and for boiler water. Such water use, in part, resulted in tar-water and lampblack-water mixtures. A plant would typically attempt to separate tar and lampblack from these mixtures using quiescent basins or filters. A substantive amount of the water recovered by such separation was typically recycled to the quenching and scrubbing processes. Excess water became a wastewater effluent for disposition. Initially, the GASCO MGP effluent was discharged to plant sewers that went to the Willamette River or to drainage channels connected to the Willamette River. In its later years, some of the effluent passed through settling lagoons prior to discharge to the Willamette River.

Q. What are examples of technical efforts made by PGCC to improve gas manufacture or residuals processing?

A. Examples of technical efforts made by PGCC to improve gas manufacture or residuals processing include the following:

- In 1916, E. L. Hall of PGCC described the rationale for the GASCO oil gas plant as one that produced substantial amounts of byproducts. He presented general ways to accomplish the goal of producing "the greatest number of B.t.u.'s per dollar." First was by "elimination of all by-products, *i.e.*, by conversion of all the raw material into gas." The second was "by production simultaneously with the gas of the largest amount of merchantable by-products on the theory that weight for weight the latter are worth more than the raw material." He went on to say that the first method had been developed by E. C.

Jones in San Francisco, but it had not yet been able to completely eliminate lampblack generation. He characterized the second method as more universal and exemplified in Los Angeles, San Diego, Oakland, and, notably, Portland, in so far as byproducts are marketed. He went on to say, “Nearly all other oil gas plants produce lampblack, but have not sufficient volume to briquette. . . . Where there is a good fuel market and oil is cheap, it will unquestionably pay to produce by-products.” The technical effort by PGCC in planning the new GASCO MGP resulted in the specific configuration of the overall plant including the intentional production of lampblack as the dominant byproduct with its disposition to be sale of briquettes as fuel in the Portland market in pursuit of the goal of producing “the greatest number of B.t.u.’s per dollar.”

- In 1924, Russell Ripley and Sigmund Schwarz applied for a patent entitled “Process for the Recovery of Gas Tars from Their Emulsions with Water,” and this patent was granted in 1929. Their invention was the means to recover salable tar from the “heavy viscous hydrocarbon emulsions with water which are byproducts in the manufacture of city gas from crude petroleum. . . .” Generally, the process involved addition of sodium hydroxide to the emulsion, followed by heating under pressure. This process prepared oil gas tar made at the GASCO MGP for further processing into higher value commercial byproducts such as road tar, thereby decreasing the cost of gas generation. Prior to this, the higher water content tar had been burned in the boiler as a primary means of disposition.

- In 1925, Professor S.H. Graf of Oregon Agricultural College ("OAC", the predecessor to Oregon State University) investigated the use of 620 BTU gas tar primarily for use as a road binder and issued a report on this date. He concluded that the tar was suitable for this use and described its preparation to attain ASTM standards on road tar. He also concluded that this tar appeared "wonderfully adapted to painting concrete for damp proofing." Subsequent to this, Professor Graf followed up with reports on the treatment of macadam road surfaces with tar from the GASCO MGP. One of the road surfaces was at the MGP itself. The basis of his reports included interviews with municipal staff.

Q. How did the environmental conditions presently under investigation and remediation at these MGP sites result from past manufacture of gas?

A. The environmental conditions that at present (2018) require investigation include the presence in soil, groundwater, surface water, and river sediments of certain chemicals (*e.g.*, benzene, naphthalene, polycyclic aromatic hydrocarbons, cyanide) or materials (*e.g.*, oil, tar, lampblack). Where concentrations exist that pose unacceptable risks by present standards, remediation of soil, groundwater, and river sediments will likely be required. The means by which these chemicals reached their present locations at the MGP sites include leaks or spills of MGP residuals, placement of MGP residuals directly onto the site, migration of these chemicals from where they first reached the site, and the reworking of site soils in redevelopment activities. In the case of river sediments, the means included discharges or spills to the river, transport of the chemicals from the uplands to the river or through reworking of river sediments by natural water flow, or by dredging activities. It is also important to understand that other parties are likely possible sources of some of these same chemicals, especially in the river sediments as numerous industrial and municipal wastewaters were discharged to the Willamette River throughout the time period that gas was manufactured in Portland.

Q. How would you characterize the residuals handling and disposition practices of the GASCO MGP?

A. Based on my review of the history of gas manufacture at the GASCO MGP, I believe the practices at the GASCO MGP for handling and disposition of residuals from gas manufacture were fully consistent with those of other MGPs, other industries, and municipalities in the Portland area and across the country during the MGP Era, and were reasonable and prudent in view of the circumstances and information available at the time.

Q. How would you characterize the demolition and dismantling practices of the GASCO MGP?

A. Based on my review of the history of the GASCO MGP, I believe the GASCO MGP practices for demolition and dismantling practices were fully consistent with those of other MGPs and other industries in the Portland area and across the country during the MGP Era, and were reasonable and prudent in view of the circumstances and information available at the time.

Q. On what did you rely to answer the questions about gas manufacture in Portland?

A. I relied on my training as a civil, sanitary, and environmental engineer; experience with manufactured gas, byproduct coke oven and tar distillation plants, sites or projects; and my more than 40 years of experience as a consulting engineer, an industrial environmental engineer, an industrial environmental manager and executive, and a university professor and researcher, in addition to historical documents that provide information on manufactured gas in Portland.

Q. Does this conclude your direct testimony?

A. Yes, it does.

IV. LIST OF EXHIBITS

Exh. ACM-2	Curriculum Vitae of Andrew C. Middleton
Exh. ACM-3	General Overview of a Typical Gas Manufacture Process Diagram
Exh. ACM-4	Picture of a Low-Pressure, Water-Seal Holder with an Above-Ground Steel Water Tank At The GASCO MGP
Exh. ACM-5	Hall, E.L., *New Oil Gas Plant—Portland, Oregon, in The Publication Committee (eds.)*, Proceedings of the American Gas Institute, Eleventh Annual Meeting, Chicago, IL, pp 355-418 (October, 1916)
Exh. ACM-6	Hull, W.Q. and Kohlhoff, W.A., *Oil Gas Manufacture,* Industrial & Engineering Chemistry, 44 (5), pp 936–948 (May 1952)
Exh. ACM-7	Graph of the Annual Production at the GASCO MGP from 1914 through 1953
Exh. ACM-8	Schematic Diagram of the Oil Gas process
Exh. ACM-9	Sinclair, B.G., *The Gas Industry in State of Washington*, Paper presented at the 17th Annual Conference of State Utility Engineers, Washington, DC (May, 1939)