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Geoenvironmental protocol for site and waste characterization of former manufactured gas plants; worldwide remediation challenge in semi-volatile organic wastes☆

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Abstract

The most common and difficult of all hazardous waste sites are those that historically produced artificial (manufactured) gas; for gas-making was international in scope and at the very core of the industrial revolution. With former manufactured gas plants (FMGPs), virtually no geologic region in the industrialized or urbanized world or its trade centers and ports escaped the gas industry. These plants applied pyrolysis of organic matter (roasting to drive off volatiles in the form of useful gases) to illuminate the world and to fuel all manner of progress. Gas was and is the universal fuel. Its prominence stemmed from the omnipresence of organic matter and the universal process for the extraction of its volatile contents to manufacture useful gas. Furthermore, for most of the century and a half-long history of manufactured gas, natural gas was unavailable to slow or daunt the production of man-made gas and the universal creation of its toxic tar residues and other harmful waste residuals. Today we face the presence of toxic organic gas manufacturing residuals as a unique threat to both the health and welfare of contemporary society, as well as being a long-term threat to the environment that is dominantly geologic in character. Most of these tar residuals are highly resistant to natural degradation or attenuation in the environment and their lives, therefore, they are measured in geologic time. Given its environmental persistence, potential problems associated with tar may exist centuries to thousands of years. Engineering geologists and geological engineers are, by training and experience, particularly well equipped to plan, manage and conduct site and waste characterization efforts for FMGPs and related coal-tar sites. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Site and waste characterization; Former manufactured gas plants; Semi-volatile organic wastes

1. Introduction

Derelict industrial waste sites are among the greatest environmental problems worldwide. "Uncontrolled hazardous waste sites" (UHWS) have been noticed as a major societal threat for about the last quarter century.

With these sites we face a vast spectrum of compounds comprising the waste and an infinite variety of complex geological materials/waste settings. The variable relationships between geologic conditions and the fate of hazardous waste is the most difficult of all site characterization challenges for those working in the applied earth sciences.

The very presence, design layout, management and operation of each gas works was wholly influenced by geologic site features and accessibility to natural and man-made resources. Likewise, historically, the

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management options for toxic waste by-products (i.e. sell, use, discard) were often governed by the location of the gas works or their geologic setting, including proximity to surface water bodies, wetlands, and unoccupied land. Economics also played a large role in the operations of the gas plant, from the selection of feedstock to the management of by-products and wastes.

Most of the broad advances made in dealing with toxic and persistent groundwater contaminants have been concentrated on and successful in dealing with halogenated (chlorinated), specialty chemical compounds created since 1928 to serve as solvents, pesticides and heat-dissipation oils. These solvents are volatile organic compounds (VOCs) and their nature and geologic affinities and associations are very different from the predominant semi-volatile organic compounds (SVOCs) associated with the processes of manufacturing gas, as well as the halogenated pesticides and heat-dissipation compounds.

This paper deals with the associations between geologic conditions and the nature and ultimate face of the tar residuals and oils generated by the manufacture of gas and coke, and by the processing of the tar and oil by-products of the industry. Tar residuals and gas oil are composed of complex mixtures of hundreds of aliphatic and aromatic organic hydrocarbons. The constituents of tar and oil that are of specific interest for investigation and remediation at former manufactured gas plant (FMGP) sites are the polycyclic aromatic hydrocarbons (PAHs). Many of these compounds are of particular concern because they are suspected human carcinogens. Sixteen of the PAHs found in tar are on the U.S. Environmental Protection Agency (USEPA) list of priority pollutants. Also of grave concern are the known and emerging carcinogenicity of the PAHs and the toxic threats of associated cyanides, heavy metals, and sulfur compounds.

2. Historic background of manufactured gas

Prior to 1792, inhabited portions of the earth were lit at night by various types of tallow candles and oil lamps. The streets of most cities were unlit and on moonless nights thieves abounded so that no citizen was safe. Likewise, commerce was restricted to daylight hours and nighttime deliberations of government were carried on under the feeble light of whale oil and candle. Factories worked on single 12-h shifts when possible.

The complacency of this world was shattered by a discovery by Scotsman William Murdoch (now known as Murdock) in 1792. Murdock was a brilliant self-educated mechanical engineer who was employed as an erection engineer by Boulton & Watt of Birmingham, England. While on assignment in Cornwall, to install a steam (pumping) engine at a local mine, Murdock fashioned the world's first gas manufacturing and house lighting system, in his spare time, at his home at Redruth. The rest truly is history.

Murdock returned soon to Birmingham and, by 1798, had built institutional gas plants for double-shift lighting factories in England's industrial "Black Country" northwest of Birmingham and raised the specter of gas lighting. By the turn of the 19th century, awareness of artificial gas and gas lighting had awakened in Moravia (now Czech Republic), Belgium and France. This knowledge came to be focused by the German Moravian Friedrich Albrecht Winzler, at London, around the year 1804.

Murdock went on to pursue other important works in practical engineering and Winzler, anglicized as Winsor, created the world-pioneering Chartered Gas Light and Coke of London (1812), sometimes known as the London and Westminster Gas Light and Coke Company. The world took note and the British Empire, upon whose flag the "sun never set," cheerfully began to light its nighttime world. The first experimentation with gas lighting in the United States was in 1796 at Philadelphia (the Italian fireworks manufacturers, the Brothers Ambroise) and around 1810 at Newport, RI, by David Melville. America's first commercial gas lighting occurred in Baltimore in 1816.

A complete treatment of the historic technical aspects of the subject is contained in *Remediation of Former Manufactured Gas Plants and Other Coal-Tar Sites* (Hatheway, in press (a)).

3. The chemical–geologic connection of manufactured gas

Gas manufacturing and gas lighting were of the highest order of technologies at the turn of the 19th

Table 1
De facto geologic siting conditions for manufactured gas plants

Geologic/related anthropogenic factors	Application	Rationale
Proximity to central business district	Optimal gas distribution at minimal cost	Saves in cost and effort toward placing gas mains for distribution of plant gas to the city.
Size of site	Half hectare minimum; generally much larger	Based on premise that city would grow and that more and more gas could be sold, hence the need to expand the plant; a few to tens of ha. of space most desirable.
Sited on transportation route	Rail, river or canal ideally accessible to the plant site by spur or slip. Vehicle transport rarely available during the era of manufactured gas.	Incoming feedstock such as coal, coke, and oils, as well as replacement supplies and parts for the making machines. Export of such salable residuals as must go off-site, such as coke, tar, light oils, ammonia, sulfur and cyanides.
Plant elevation lower than distribution zone	Illuminating and fuel gas is lighter than air	Designed to rise from the plant throughout the gas distribution area.
Entrance "Fluids" at the highest elevated portion of the works	Fluids able to move through plant from process start to finish	Facilitates movement of process water and fluids by gravity, without requiring pump energy.
Source of process water	On-site well or adjacent water body (lake, river, stream)	High demand for water; to generate steam and to clarify gas; water used to gather and manage tar residuals and to produce tar for possible use or sale.
Stable foundation for works structure	Retort benches and other gas-manufacturing machines, as well as clarification, purification, and storage structures have heavy foundation loads	Entire function of gas manufacturing, treatment and storage is sensitive to stress fracturing as well as gas and fluid leakage from foundation settlement on poor or over-stressed foundation earth materials.
Located on inferior site of rail tracks	Gas works were considered nuisances by the public	Resulted in devaluation of surrounding properties.
Site drainage	From gate to lower end of the site.	Most operators took effort to see that the working surface of the gas yard was trafficable in all weather.
Off-site drainage	Effluents could not be stored on the plant site	Required consideration of some form of off-site removal of liquids from the plant site.
Above frequent flood levels	Gas machines highly susceptible to thermal and silting damage from floodwaters	Gas was considered essential once the supply was initiated and coal-gas retorts could not be shut down without thermal damage.
Plant "Upsets"; explosions and other emergency situations	Floods, explosions, hurricanes, unseated gas holders, frozen valves	May have resulted in direct discharges of process residuals and wastes to the ground, to include surface waters. Also flood erosion and transport of residuals and wastes. Search for contemporary newspaper accounts of impact on FMGP.
Waste disposal area(s)	Plant generated significant amounts of solid and liquid waste that could not be accommodated on the plant site	Typically solids assigned to plant dump, mostly as broken bricks and ceramic retort fragments, along with purification wastes. Dumps typically had high voids ratios and were a tempting disposal for toxic liquids and sludges.
	Large and sometimes deep tar ponds have been encountered at Duquoin, IL, Larium and Pontiac, MI, and Carondelet Coke Works, St. Louis, MO; the latter measured in hectare of area and meters of depth	Contemporary swamps, sloughs and lowlands were favorite dumpsite candidates. Adjacent low land was often selected for use as typically unlined tar ponds and tar lagoons, as a waste disposal option when tar quality fell below sales or during bad-market conditions.

century. Science and trade journals eagerly carried news of its developments and applications. Likewise, technical books began to appear, in English as early as 1815 (Accum, 1815). All that was needed to create gas and to have gas lighting was feedstock (coal), an iron monger (i.e. blacksmith) and some ready financing.

At its beginning and for several decades thereafter, manufactured gas could be generated anywhere, given the two essential ingredients, but it required a local means of storage. This was solved immediately by invention of the *gasometer*—or *gas holder*. The technical impracticalities of its transmission prevented its distribution beyond a few miles of each gas works. Reliable, high-pressure metal pipelines were to be a thing of the future, a problem not wholly solved until 1928.

Initially, the gas engineer was faced with physical decisions related to the actual siting and layout of the gas works. Once the financing was raised (about £6,000 or US$30,000), the rest of the equation was based on geologic and anthropogenic factors (Table 1), the latter not directly recognized at the time.

4. Generic process of gas-making

It is imperative that the remedial site manager tasked with investigation and remediation of an FMGP have knowledge of the general gas manufacturing processes and the specific processes, equipment, and operational practices of the plant being investigated.

Basically, an organic feedstock (e.g. coal or oil) was pyrolytically roasted (in the absence of oxygen) to release volatile constituents in the form of raw gas. For manufacture of coal gas roasting was a batch process of a few hours' duration. For production of gas from oil (i.e. water gas, carburetted water gas, oil-enriched water gas, and the various types of oil gas), roasting was a continuous process conducted in sequential cycles of a few minutes each.

Once created, the gas always contained tar and other microscopic impurities inimical to the purpose of the gas, which was for illumination, heating, or used as an industrial fuel. Removal of these impurities was performed in two sequential efforts. The first effort, which occurred immediately after the gas was

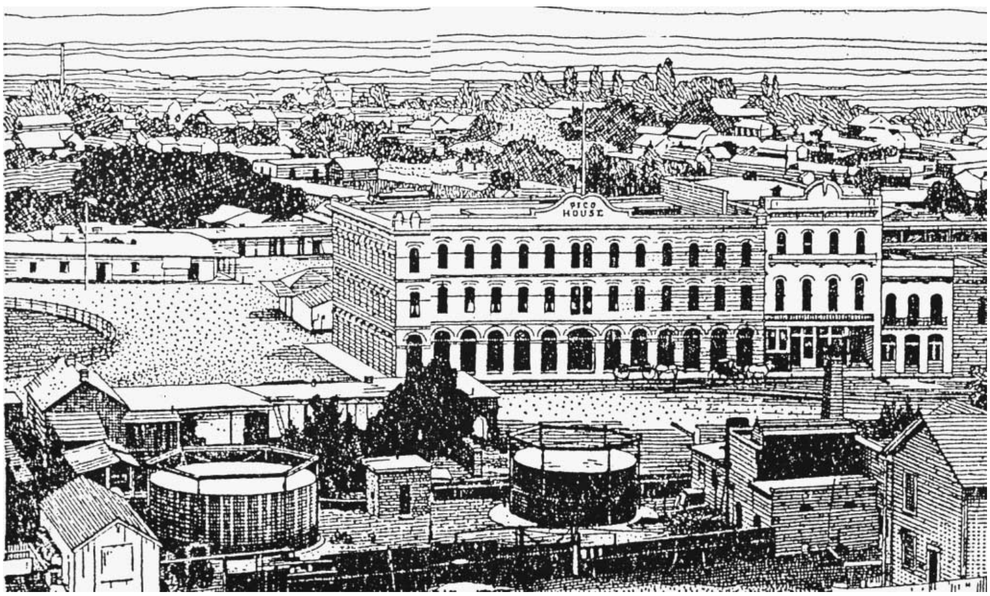

Fig. 1. Los Angeles Gas Company works off Aliso Street at today's historic Olvera Street Plaza. This was a coal-gas plant employing feedstock sent from Australia and from Britain as return cargoes for California grains. The works fronted Governor Pio Pico's hotel and it sported gas lights. Note the two gas holders already present at the 3-year-old plant. In the center is the lime house, storing purification media (from Newcomen Society of America, 1966).

generated and released from the retort (coal gas) or the generator (water gas, carburetted water gas [CWG], oil-enriched water gas and oil gas), never had a simplistic name and was conducted in devices named condensers, washers and scrubbers and in combinations of those devices. For this overall process, I use the generic term of *clarification*. The subsequent and finishing process of treatment always was termed *purification*.

Most of the gas treatment was involved in clarification. Purification, however, was essentially the same process for all forms of manufactured gas. Purifiers came in a wide variety of shapes, mainly right-circular cylinders and square-sided paralellapipeds. Known generically as ''boxes,'' these devices produced ''box wastes'' that demanded strict attention toward their management as solid wastes. In the past 2 years, a rash of discoveries of derelict box wastes has brought their fate and today's threats, mainly from forms of cyanide, to the forefront of our national remediation attention.

4.1. Generic layout for a manufactured gas plant

After examining the layout evidence for hundreds of former plants, I have concluded that there never was a consensus physical arrangement employed by the manufactured gas industry. Gas works were designed

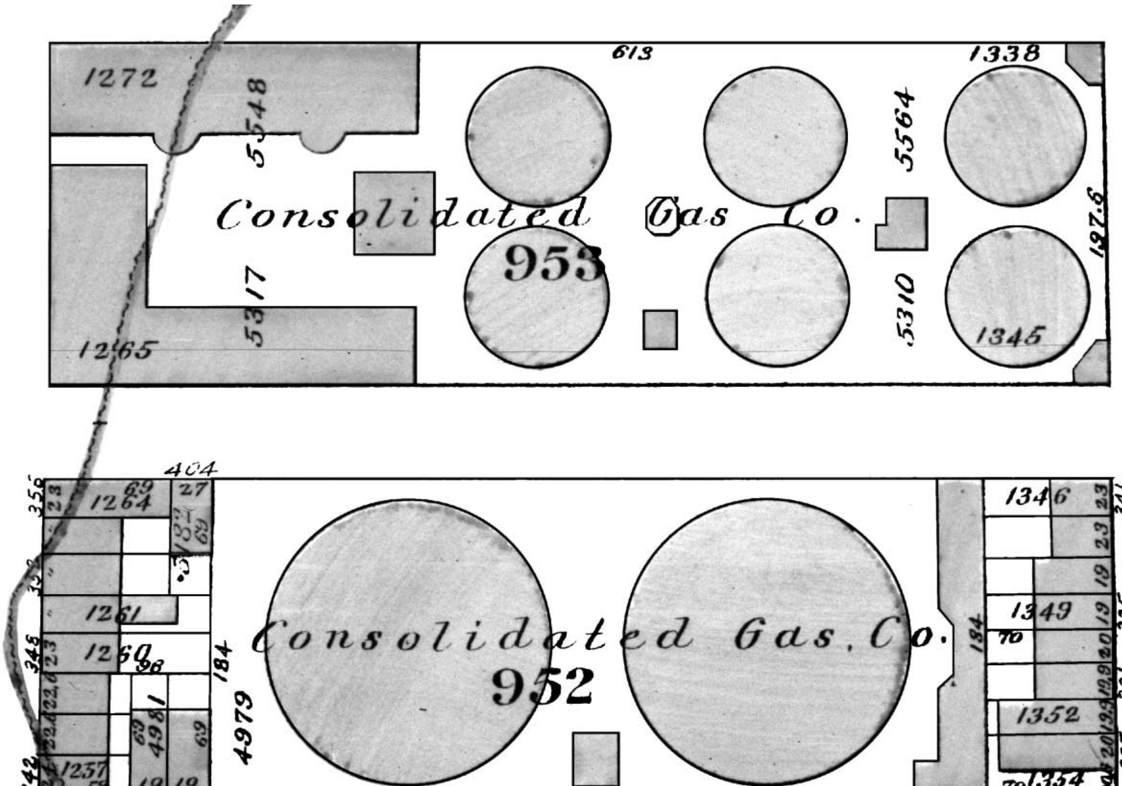

Fig. 2. Large urban gas works, that of the Consolidated Gas of New York City, 1884, when it was formed to consolidate six of the many competing manufactured gas companies. This portion of the plant covers most of two city blocks, with a rail spur in the alleyway. The remainder of the gas works occupied nearly three more city blocks. Each of the blocks is nearly 200 ft wide at the sidewalk. The drawing is a portion of G.M. Hopkins' Ward Maps of the City, published in many water-colored plates. Of course, no external trace of the gasworks exists today but the subsurface predictably will be saturated with tars, to include probable invasion of the utility systems, including drinking water. The bold, irregular line represents a topographic break in slope (from the author's collection of manufactured gas memorabilia).

Table 2
Typical components of FMGPs as potential waste sources

Component	MGP use	Waste source location and potential
Transportation spur	Delivery point of feedstocks; exit point of salable residuals	Human labor was a significant cost to gas making. Feedstocks were brought as close as possible to the retorts and generator houses.
Coal yard	Storage area which kept coal dry for optimal use in firing boilers or as retort feedstock	Kept as close as feasible to the retorts and generators. Many plants chose to place coal in sheds so as to optimize gasification in the presence of minimal water content.
Coke yard	By-product coke from coal-gas plants	Used symbiotically as feedstock for various water gas plants, especially as co-located.
Retort house	Coal-gas retorts housed internally in *benches*; groups of benches as *stacks*	The central building of the gas-making process; generally located at the corner of the plant with highest elevation and near the gate, from which the processed gas left the plant through the station meter.
Generator house	Location of *generator sets* for carburetted water gas process	Generation capacity such that vastly smaller space required for commensurate production over coal-gas process.
Condenser house	Building or addition immediately adjacent to retort house or generator house	After 1920, tended to be out-of-doors. Same configuration used for all gas generating processes; usually a wet process.
Scrubber	Tall (5–10 m) right-circular cylinders with slanted trays holding wood fiber/chips	Usually employed a water shower to remove tar and other process residuals from the gas.
Washer	Gas immersed in agitated water bath to cool gas and drop tar particles	With carburetted water gas and enhanced oil-gas, placed first in the clarification sequence as a seal against back-flow of gas.
Combined washer–scrubber	When employed, generally post-1895	Enhanced the recovery of tar from gas.
Sumps of clarification devices	Condensers, scrubbers and washers, and their combinations had bottom sumps to trap and yield tar and tar sludges	Tar generally removed manually for recovery, reuse or dumping. Spills and leaks assumed in a generic sense. Tar sludges contained refractory geologic impurities such as quartz and feldspar.
Exhauster	Steam-driven gas evacuator to reduce gas pressure and promote flow through system	Position of exhauster chosen by the plant gas engineer to achieve optimal flow of gas through the tar-removal clarification process; most plants had a backup exhauster.
Purifiers (Purifier Boxes)	Gas was passed through "boxes" containing layers of lime, wood chips and/or strips of iron as various forms of sorbants, often in conjunction with each other Generally employed minimally as a pair of "boxes" in series, with at least a spare pair in series	Trapped some tar, but designed to trap sulfur, cyanide, arsenic and other heavy metals all of which originated in or from the organic gas feedstock materials.
Relief holder	(1) With coal gas, the oldest of the gas holders, serving as a raw-gas exposure to tar-dropping seal water before clarification/purification (2) With carburetted or oil-enhanced water gas a necessary presence to buffer gas-pressure variations on blow-run cycles	Relief holders of the first variety can be expected to be of the subsurface variety and left virtually full of unrecovered tar as commonly abandoned. Second variety holder tanks tend to be less commonly abandoned with large volumes of water-gas tar, unless dumped at time of plant decommissioning.
Gas holders (Gasometers)	As many as needed Generally predicated on the largest being equivalent to 1 day's *make* Of prime concern are the subsurface tanks most common to pre-1900 varieties	Of several basic design variations. Those pre-1900 have a subsurface water-seal tank likely to have leaked considerable amounts of PAHs to the subsurface through various fractures related to brick, masonry and/or

Table 2 (*continued*)

Component	MGP use	Waste source location and potential
		concrete or composite construction materials. Valve pits commonly exhibit hot-spot concentrations of PAH contamination.
Tar wells and tar cisterns	Subsurface tanks, right-circular cylinders and rectangular or square-sided; brick, masonry or concrete or composite Less commonly known as "ammonia wells"	Commonly designed with a self-functioning gas-liquor (process water) discharge system to carry off lightest-fraction of gas liquor while retaining the gravity-separated tar fraction; all subject to through-fracture flow leakage to the surrounding earth during the operational period.
Tar separator	Both as above-ground devices housed in structures and as subsurface rectangular-form concrete or wood "tanks," the latter often made of wood planks subject to between-plank leakage	Above-ground devices were machines built to physically separate tar particles from liquor; below-ground devices contained flow baffles functioning to slow in–out flow of gas liquor carrying suspended tar, the latter dropped to the sump of the tar separator.
Boiler house	Necessary to power the exhauster and a variety of small steam engines and fluid pumps	Generally consumed coal or by-product coke; could be rigged for burning tar, under close supervision of temperatures. Ash not expected to be toxic unless exposed.
Oil storage tanks (above ground and underground)	Illuminating or enriching oil for non-coal-gas production	Generally petroleum oils susceptible to biodegradation if leaked or spilled; generally no incentive or reason to dump.
Plant plumbing	Below-ground piping, often in trenches or pipe chases	Virtually all process piping was subject to corrosion and release of PAHs, or release through joints and seams.
Yard drips (Drip Pots)	Light-oil (drip oil) collection sumps placed along gas-flow pipes in the gas yard	Used to collect naphthalene and other light oils; these were of value and were recycled, usually as carburettion oils for water gas, or as industrial solvents.
Furnaces	The fire box located below gas benches and all boilers	Source of operational heat; residue was only ash, cinder, clinker or slag; not expected to be hazardous by nature of its formation.
Station meter	Plant production measuring device housed in a structure at the gas-outlet from the plant	Generally co-located with the plant office and in the up-gradient end of the site, near the plant gate. Not a source of contamination.
Governor	Gas flow control device adjusting distributed gas to main distribution pressure	Should not be a source of contamination.
Rail-spur spills	Operational-era spills of tars and other fluid residuals (light oils and ammonia) being transferred off-site as by-products	Naturally most prominent at larger plants and those plants engaged in by-product recovery operations.
Purification box media spreading ground	Wood-chip and some forms of iron oxide media could be *revivified* on this pad and returned for re-use short of ultimate "spent" condition	Action implies shaking and mass-expansion via pitch forks. Sulfur and Prussian blue (cyanide) could be raked up and sold as by-products in many instances.
Spent wood-chip box waste burning ground	A corner or side area of the gas yard where dry chips could be torched and destroyed by fire	Required dry climate or dry season; ashes carried to a plant dump.
Plant dump	Primary disposal site on the gas yard; broken, fractured, slagged retort bricks; generator lining bricks, all manner of scurf or other carbon-slag wastes, ash, clinker, slag, off-specification tar, tar sludge, lampblack, box wastes, bottles, purifier shelf slats, broken windows, corroded pipe, scrap iron, wagon and vehicle parts, and broken gas-plant equipment	Expect a toxic character in general. Plant dump likely will be found in or at the furthest down-slope corner or extension of the gas yard, along the adjacent creek, stream, or river, or filling any original topographic declivity of the ground at the site. In almost all cases, the plant dump was filled early and supplemented with multiple dumps around the periphery of the gas plant, to within a several-block wagon haul distance.

initially by veteran gas men, who later included master plumbers, and after about 1870 in North America and Europe, by graduate gas engineers, mostly of the mechanical discipline, but including a significant percentage of civil engineers (about 40%). The overall governing condition was the topography of the site, mainly site surface gradient and the presence of an adjacent stream or body of surface water. The designer

Fig. 4. Solid waste typical of the gas works dump. This riverside location displays a variety of maker-marked fire and refractory brick into which typically liquid-waste PAHs were channeled or dumped, either out of convenience to the operators or during times and conditions under which the economics of by-product recovery were considered infeasible (photograph by the author, Lansing, MI, 2001).

made the components fit the site and the flow of activity was from higher to lower elevation. Fig. 1 is the small original gas works at Los Angeles, CA. A

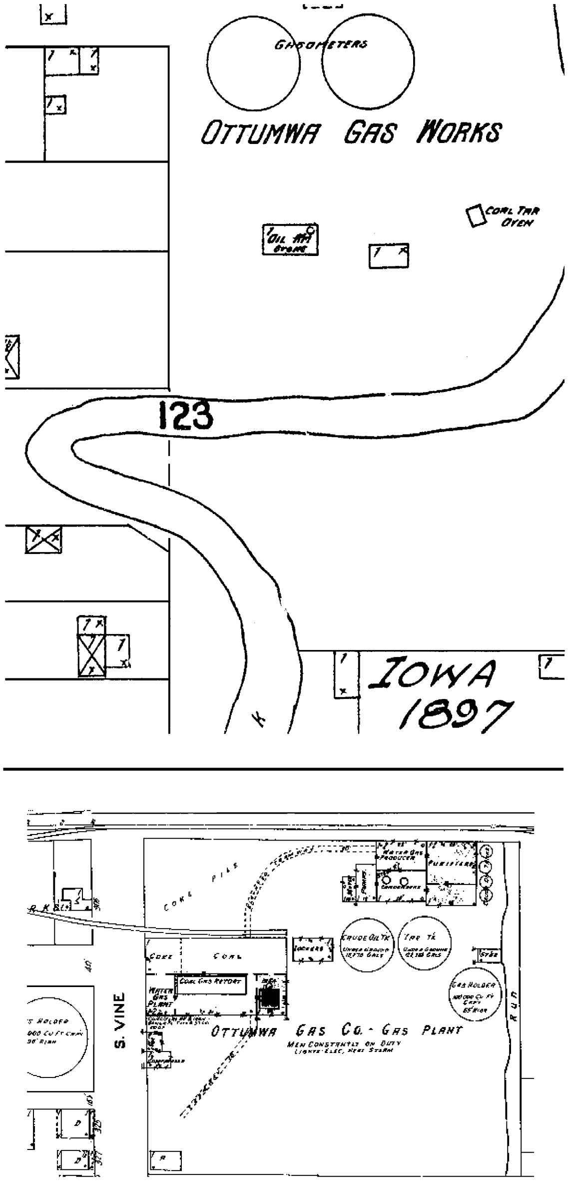

Fig. 3. Medium-sized works displayed by two editions of the Sanborn Fire Insurance Maps of Ottumwa, IA. The plant was independent as shown in the first view and as shown in the second view, was controlled by the United Light and Power, of Chicago (after the Library of Congress Collection). Upper view shows a portion of the plant in 1897, with a prominent “run” (creek) plies the gas yard flowing from the right toward the bottom of the view on its way to join the nearby river. At this time, the plant appears to have been burning at least some of its tar residuals, while other wastes likely made use of the large unoccupied gas yard rear (bottom) for disposal of ammoniacal liquors to the run and disposal of box wastes and other solid debris to the ground. Lower view, drawn in 1930, shows no trace of the now-infilled run, surely the plant dump. Owner Ottumwa Gas Company is modern in its array of symbiotic gas manufacturing processes. Coal gas yet is prominent, for Iowa coal was everywhere abundant and the agricultural rail grid was the finest in America. Coke from the coal-gas retorts likely was fed to the carburetted water gas generators and carburetting oil tanks are prominent. Water gas (blue gas) producers, the third gas manufacturing process, were present to make fuel gas for lively sales for heating and cooking and such gas likely was stored in the 100,000 cf. gas holder by the run. Illuminating gas was stored as a mix of CWG and coal gas in the newer gas holder across South Vine Street. The two older gas holders (gasometers) had been converted to carburetting oil storage and for accumulation of tar for minimum loads to be shipped via tank cars arriving on the nearby railroad siding (both maps are after coverage held in the Library of Congress).

truly large urban FMGP, the 1884 Consolidated Gas Company of New York City is shown as Fig. 2 and portrays the heroic dimensions of the gas yard and its individual buildings such as were common to large cities. Today, greater New York City is the site of at least 130 FMGPs.

To develop an accurate and effective site characterization plan for an FMGP site, an investigator must first understand how the individual *components* of the gas works (Table 2) contributed to the gas-making, treatment, storage and distribution process. The physical layout of the various plant components on a site and the likely subsurface piping connections between them will dictate where wastes were generated, leaked, or spilled. Conversely, bodies of wastes not having these associations were likely dumped around the fringes of the gas yard, in adjacent gullies or topographically low areas (Figs. 3, 4 and 5 and Hatheway, 2000). Without an appreciation of the functions of the various process components, and a knowledge of their locations, field investigators with the best of intentions can develop site and waste characterizations that are flawed. Worse-yet, such flaws may prompt injudicious choices and decisions related to public health and environmental protection. To be blunt, a flawed, inaccurate, or possibly incom-

Fig. 5. Some outstanding gas works residuals. (5L) Motor spirit (a.k.a. Benzol) was the forerunner of our gasoline and benzine was a distilled derivitive of the benzol. Today, these two light nonaqueous-phase liquids (LAPLs) are commonly found as groundwater contaminants, though more often not as free phase (from the Author's collection). (5L) The motor spirit can is British and holds one imperial gallon (both are from the author's collection). (5LL) Freshly excavated box-waste wood chips from the gas works dump at Sacramento FMGP no. 2, California (photographed by the author, 1999). (5RR) Typical appearance of the gas works dump at creek or riverside. This is at Manistee, MI (photographed by the author, 2001).

petent site and waste characterization of an FMGP destroys the accuracy and purpose of risk assessment of any sort. This is especially the case when carcinogenicity is considered.

4.2. Identifying the process flow path

Through the use of standard references sources, such as *Brown's Directory of North American Gas Plants* (Brown's Directory of North American Gas Companies; From 1889), *Sanborn* (Sanborn Fire Insurance Maps) or other fire insurance maps, and the many technical and association journals, it is possible to identify a chronological history of operations of the subject FMGP. I generally employ a working enlargement of the plant layout as found in the literature. To this drawing is applied a series of dashed arrows to denote the likely locations of leaks, spills, or discharges of toxic gas-making residuals to the ground (including discharge to surface drainage and bodies of surface water). Fig. 5 shows two prominent Light, Non-aqueous-Phase Liquid (LNAPL) "light oils" that frequently are encountered as solubilized into ground water passing below the surface of FMGPs.

This is a desktop assessment made before visiting the field. For this exercise, it is always prudent to attempt to secure both historic and recent aerial photographs of the site, particularly stereoscopic coverage. The use of image interpretation, of course, is a standard technique in engineering geology. A search for archival topographic and planar map coverage may well yield additional information concerning original topography. Of special consideration are high and low elevations and topographic lows that will have influenced, if not governed, the layout and the fate of site wastes, whether solid, liquid, toxic or non-toxic.

4.3. A word about sampling gas-house wastes

Characterization of FMGP sites in the United States is rather hindered by the fact that the Resource Conservation and Recover Act (RCRA, 1976, as amended) regulations (Code of Federal Regulations [CFR], Part 260–299) lists only 16 PAHs. In reality, there are some 500 to 3000 separate PAH compounds that can be expected to have been produced and wasted on and around a given FMGP. It is important also to recognize that "tar" and PAHs originate from non-petroleum organic material and it is "asphalt" that is the SVOC product relating to petroleum refining. A distinction is made, however, with the residuals formed from the various processes of oil–gas generation, all of which also are termed "tars" and which contain PAHs. Incomplete combustion of wood, whether used in manufacturing resin-gas or from wood fires, wood furnaces, or forest fires, also produce PAHs.

Since 1995, the popular Voluntary Cleanup Program (VCP), developed by the State of California as the *Expedited Remedial Action Program Act of 1994* have been selected by Responsible Parties (RPs) as a more favorable basis for conduct of their FMGP site cleanups. USEPA embraced this concept nationally and has allowed the States considerable freedom in the conduct of these actions. As with all hazardous waste cleanups, the VCP program generally offers the greatest degree of freedom to the Responsible Party (RP) in proposing key chemical parameters and other sampling and analysis details for site and waste characterization work plans. VCP also is the seat of the ensuing *Brownfields* program of USEPA.

With this in mind, an early site sampling effort designed to test the interpretations generated under the recommended provisions presented later in the paper is recommended. It may be in the best interests of those requesting the investigation or those funding the characterization, to generate an accurate assessment of which detectable PAHs are present in the largest concentrations, thereby possibly indicating those species that may also represent the greatest environmental threats. If strict adherence to the RCRA Appendix VIII list (40CFR261, Appx. VIII) is mandatory, a few supplemental compounds may be proposed for purposes more directly associated with the remediation philosophy of the funding organization.

The hazardous waste list that applies to Comprehensive Environmental Response, Liability and Compensation Act (CERCLA) or SUPERFUND LAW activities (40CFR302.4) does not specify individual compounds, rather, "characteristic" wastes as well as "listed" wastes.

Furthermore, in selecting plant waste bodies for sampling, high priority should be given to selecting samples representative of detected waste sources ("hot spots") as well as of the host stratigraphic unit (the latter for waste that has invaded the interstices or discontinuities of earth material units). Hambley (personal communication, Jul, 2001) notes that species-detection by means of a chromatograph, from tar samples, generally requires verification by mass spectrography, and that strict proof is a function of the resolution of the test column, and the length given over to the analysis. PAHs are not well separated by the gas chromatographic/mass spectrophotometric (GC/MS) method (SW 846 Method 8270) and High Performance Liquid Chromatography (HPLC; USEPA analytic protocol SW 846, method 8310) separates only a limited number of compounds—the 16 PAHs usually specified plus 2 isomers of methyl naphthalene. Also, several compounds can elute at a given time in a GC and identification by MS signatures is not always straightforward. Finally, long-chain hydrocarbons and multi-ring aromatics tend to travel through the chromatograph in a mass without separation. Caution is the word here and additional sampling and analysis generally will be required.

The benzene, toluene, ethylbenzene and xylene (BTEX) VOC compounds all were generated at FMGPs and are often given attention because of their capacity to dissolve away from their source volumes and to form separate, definable groundwater contamination plumes.

As a means of considering relative threats from various source areas or source volumes, it is sometimes appropriate to consider these three artificial groupings of PAH:

1. Total PAH detected and analyzed (TPAH);
2. Total carcinogenic PAH (TCPAH), and;
3. Total non-carcinogenic PAH (TNPAH).

Heavy metals, especially the carcinogen arsenic, were captured and detained at the purifier boxes and generally pose a major concern when present as dumped box wastes.

Parties to the FMGP and related remediation should feel free to suggest or require (as the case may be) screening or detection of elements or compounds in addition to those that may be required State or Federal regulatory consent orders. Such a selection may be helpful in support of the interpretation of operational or environmental conditions to support the remediation concept preferred either by the responsible party or the regulatory agency.

5. Identifying and predicting generic gas plant wastes

The relationships between various toxic wastes produced by FMGPs, and the various processes of gas manufacture are well known, both in characteristics and in relative quantities per thousand cubic feet of gas produced.

5.1. Predicting FMGP waste types

Knowledge of the character of the expected wastes is essential for planning, performance and interpretation of FMGP site and waste characterization efforts. Much of the character of the wastes to be expected at individual gas works sites can be predicted with the assistance of some of the history of that works (Table 3). In particular, Figs. 6 and 7 show drawings typical of the information traditionally held in utility company archives. Application of the following five-step sequence of logic is useful for guiding initial investigation planning efforts:

1. What residuals are to be expected on the basis of the gas manufacturing and treatment processes employed at the plant, by time period?
2. What was the overall flow path of gas and liquors, including precipitation points and likely locations of leaks, spills and other discharge, along with locations of typically leaky gas holder pit tanks, tar wells and tar cisterns, and dedicated plant sewerage?
3. Where were the wastes, as separated from useful residuals likely discharged?
4. How did the geologic setting likely affect the fate and transport of each of the potential gas works wastes and their likely points of discharge?
5. How were the wasted residuals likely removed from the site and to where?

The waste-type analysis forms the basis for the site and waste characterization effort. Some workers representing Potential Responsible Parties (PRPs) indulge in the speculation of "risk assessment" as regards the most likely scenario of exposure of gas-house wastes to human, animal and food-chain receptors, though the

Table 3
Predicting FMGP waste types as the basis for site and waste characterization

Residual	Conditions as a waste	Guidelines to quantities per 10,000 cf. gas produced
Coke	Always a candidate for fuel, for sale in the community or for use at the plant	About 60%, by weight of the original quantity of feedstock coal; approximately 2000 lb of coal per 10,000 cf. of coal gas produced yields of about 1200 lb coke.
Tar	Salable under local and regional market conditions when produced or treated to have less than 4.0% water content	When marketable and containing less than 4.0% water, sold at the plant and via rail tank cars to the many tar distillers, in the range of US$0.05 to US$0.02 per gallon. Required an effort to capture and separate from liquors and its own unsalable sludge. Calculate at 10 to 14 gal per 10,000 cf. gas, depending on the feed stock and operating conditions.
Tar-water emulsion	Commonly formed in CWG process, especially after 1910 and whenever soft coal was substituted for coke and when heavy or crude oil was used in carburettion in lieu of light petroleum oils or light tar oils	Generally unsalable whenever untreated to reduce the water content of tar water emulsions, which ran from in excess of 4% market limit to as much as 92%, as noted in the literature. Calculate at 4 to 6 gal per 10,000 cf. gas.
Liquor	Always a contaminant; was the process water used to extract tar from the tar fog of produced gas. *Ammoniacal Liquor* with coal gas and *Gas Liquor* with CWG	Highly dependent on plant design and mode of operation; generally in the range of high hundreds to tens of thousands of gallons per day. Difficult to relate to quantities of liquor per 10,000 cf. gas produced.
Tar sludge	Made up of the refractory geologic debris minerals and lithologic fragments from the parent coal or residues from parent oil feedstock	Tens to hundreds of gallons per day, depending on local design and operating conditions. Difficult to relate to quantities of liquor per 10,000 cf. gas produced. Sludge was unsalable, unusable, and nearly always dumped.
Lampblack	Uncommon to coal-gas Sometimes found in CWG Common to oil gas	Major amounts produced by Pacific Coast Oil Gas process; as produced, nearly pure, powered carbon; easily sorbs toxic PAHs in post-operational deposits or in gas works dump environments.
Ammonia	Released mainly from coal-gas production, stemming from feedstock coals	Typically wasted in both (post-1875) and smaller coal-gas plants; required special equipment to capture; after 1870 some large-city collection as cleaning agent; after 1920 sometimes a market as ammonium sulfate fertilizer.
Naphthalene	Captured at plant and distribution-system sumps, as pumped from yard and street trips on a weekly basis	Had to be captured and pumped or would cause blockages of transmission and distribution pipes and clogging of gas lights and stove jet ports.
Naphtha	Chemical term for crystallized naphthalene	AKA "moth balls" in commerce.
Light tar oils	Monocyclic and duocyclic PAHs	Historically, these were sold as commercial solvents and fuels or used as carburetting oils at CWG plants.
Medium tar oils	Another term for medium tars of the general 3 to 4-benzene-ring tars	Miscible and co-soluble with the tar mass; separable through distillation; seldom done on plant site.
Heavy tar oils	5,6,7-benzene-ring tars, includes anthracene and the "green oils" (tars)	Miscible and co-soluble with the tar mass; separable through distillation; seldom done on plant site.
Tar pitch	Heavy ends of any residual tar of manufactured gas Common to all processes	Not encountered on site in absence of a still; the end reside from distillation; favored for use as waterproofing and roofing material
Cyanide/Prussian blue	Cyanides formed from C and N released from coal Captured mainly at purification boxes and found as several compounds depending on plant conditions	Most formed in coal gas production; minor amounts to be expected with CWG and lesser amounts with oil gas. Can be released to environment in modern times under locally acidic conditions, mainly in the presence of box-waste sulfur; comes out as water-soluble or as poisonous gas.

Table 3 (*continued*)

Residual	Conditions as a waste	Guidelines to quantities per 10,000 cf. gas produced
Sulphur	Captured in purification boxes	Could be gathered and sold under favorable market conditions, mainly to generate vitriol (sulfuric acid) in urban centers; generally not the case elsewhere.
Ash	Inert refractory mineral residue of coal as a gas-making feedstock or as a plant furnace or boiler fuel	Not expected to contain contaminants above remedial action levels. Should be sampled and tested, however.
Clinker	Partially fused ash	Not expected to contain contaminants above remedial action levels.
Slag	Mineral-fused ash	Forms from retort and boiler furnaces. Not expected to contain contaminants above remedial action levels.
Scurf	Hard carbon deposits formed on interior surfaces of retorts and generators	Removed by manual chipping via iron rods. Not expected to contain contaminants above remedial action levels.
Spent lime (“Blue Billy”)	Spent lime cleared from one-time use in purifying boxes; most common before 1875; crushed limestone as well as pulverized sea shells	Generally a toxic waste containing cyanide and heavy metals, possibly sulfides. May be associated, as dumped, with other spent purification media.
Spent wood chips, excelsior[a] or coarse sawdust	Sorbant wood waste brought to the plant for purification medium; Generally from 1870 to end of manufactured gas era	Consider potentially toxic unless shown otherwise. May be associated with other spend purification media. May not display Prussian blue color until exposed to air.
Spent iron Spirals, Spent iron strips, Spent iron oxide, Spent bog iron (ore)	Sulfur-capturing media brought to the plant for purification; generally post-1875 to the end of manufactured gas	Considered toxic unless shown otherwise. Be concerned with sulfur-related pH conditions that can lead to release cyanide to the environment.[b] May be associated with other spent purification media.
Retort and bench fragments	Retorts replaced at 24-month or lesser frequency	Approximately 1 ton per bench per year. Forms a void matrix for dump-sequestering of PAH toxic waste.
Replaced CWG generator shell lining brick	Average brick liner replacement each 6 months	Approximately 3 tons of brick removed and replaced per generator set per year. Forms a void matrix for dump sequestering of PAH toxic waste.

[a] Spiral-form wood shavings.
[b] “Sulfuric” spelling is consistent with historic usage.

latter two computations generally are neglected. It is recognized, of course, that there are differences in the degrees of potential exposure involving the food chain, between urban and rural areas, with the exception of urban residents who rely on fish and other aquatic life to supplement their diet. Likewise, USEPA has largely abandoned its own regional prosecution of FMGP cleanups in favor of limited special funding to those of the State regulatory agencies that have elected to pursue this highly worthwhile area of environmental remediation.

This paper therefore is presented especially as suggested guidance for the States and Provinces in their deliberations related to defining full disclosure FMGP characterization. Without deliberation as to the likely presence and location of gas-house toxic waste ‘‘sources’’ (a.k.a. ‘‘hot spots’’), the entire exercise of risk assessment takes on the nature of a ridiculous ‘‘drill,’’ conducted with the reality of a charade that bears little or no bearing to actual site conditions.

5.2. Generic forms of manufactured gas plant wastes

Gas-house wastes are herein classified as a series of groups (Table 4) that are useful for site and waste characterization. In this classification presented physiochemically, it is theoretically possible for PAHs to contain more than six rings; however, no such

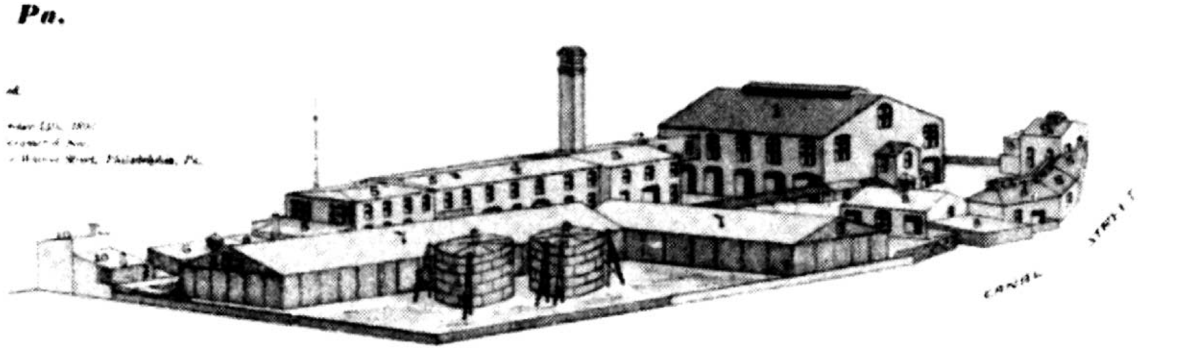

Fig. 6. Ernest Hexamer's Fire Insurance perspective sketch of the Northern Liberties Gas Works off Canal Street, in Philadelphia, 1875. Hexamer was an innovator with this well-appreciated visual feature in his atlases. The 2.5-story generator house proclaims that this works had already adopted T.S.C. Lowe's carburetted water gas sets, as produced at the Lowe factory at nearby Norristown, PA. The plant boiler supplies steam for pumps, gas holder external heating, and drives exhausters and feedstock elevators. The long farside building was the site of clarification and purification of the gas, and such was stored on the gas yard in two gas holders with subsurface pits ("tanks"). Coal and coke was stored in the sheds on the near side of the plant and the works was surrounded by a low fence. Pipe-fitting and maintenance shops and a stable occupy the uphill Canal Street corner of the works, while pipe-fitting shops fill the far downhill corner (from the author's collection).

compounds have been reliably reported as of this writing.

Though many readers will have significant experience with volatile organic compounds (VOCs) such as halogenated (chlorinated) solvents, gas-house tars are non-chlorinated and are classed as semi-volatile organic compounds (SVOCs). This distinction is important, for much of the knowledge of modern remedial-mitigation technology does not apply to site and waste characterization of FMGPs. USEPA recog-

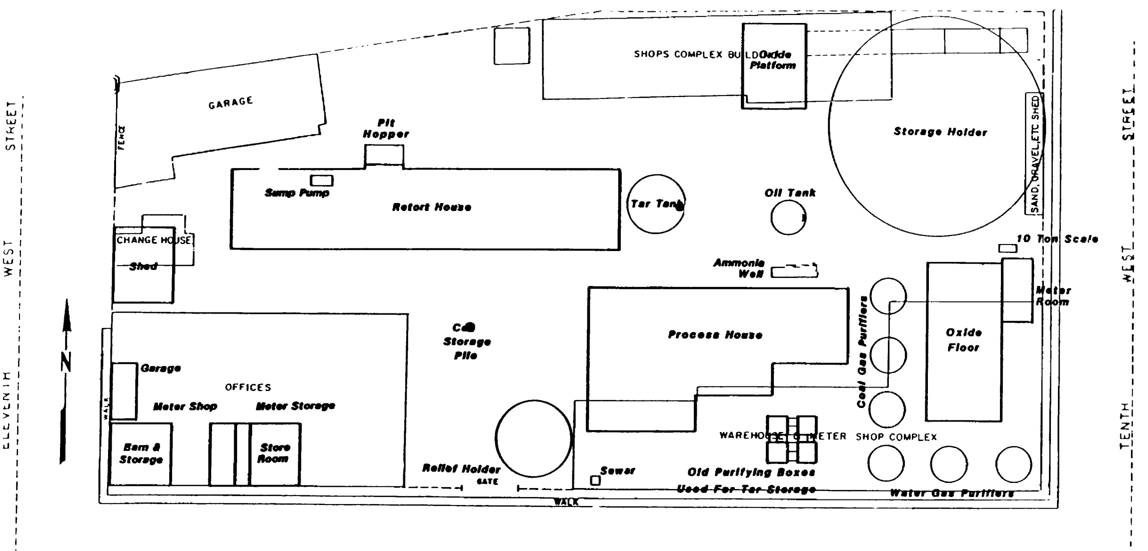

Fig. 7. Salt Lake City's first gas works was established in 1872 at the direction of Mormon Church President Brigham Young. Here is a composite plant layout drawing of the Salt Lake City plant of the Utah Gas and Coke, established in 1907 as an opposition company. This 1924 configuration is as taken from design plans by its holding company owner, American Public Utilities, a subsidiary of the engineers, Kelsey Brewer & Company, of Grand Rapids, MI, also operators of gas and electric properties. Utility company archives were famous for the breadth and detail of their holdings. The FMGP is bordered on the right by 10th West Street and on the left by 11th West Street (after drawing in files of Utah Department of Environmental Quality).

Table 4
Generic forms of manufactured gas plant wastes

Waste form	Nature	Character as a waste source
Solid waste	Plant operation, maintenance, expansion, and demolition debris Found both on-site and in near off-site environs Every site had at least one gas-yard dump Most plants were ringed with multiple off-site dumps	Typically inert and dominated by service-damaged ceramic retort fragments, fractured fire brick, scrap iron and pipe, along with scurf, ash, clinker and slag, some from gas machines, some from plant boilers. Ash and clinker is subject to sorption of PAH if such later comes into contact. Often this inert mass contains dumped toxic tarry wastes in its void interstices.
"Box waste"	Potentially toxic solid waste such as cyanide and heavy metals Found both on-site and in near off-site environs	Media were introduced at about the times shown; Lime (1805), wood chips, excelsior and sawdust (1870), and iron oxide (1875), as borings, scraps, strips, bog iron ore and various forms of particulate oxide. Often used contemporaneously, as layers.
"Gas liquor" (Generic Term) A.k.a. "Ammoniacal Liquor" (Coal-Gas Process) A.k.a. "Gas Liquor" CWG and Oil-Gas Processes)	Combined aqueous condensate of gas manufacture plus process waters applied for gas cooling and precipitation of tar Includes coke quench waters at the retort house and at by-product coke ovens Subject to final, long-term precipitation of PAHs to sediment of the receiving area Tend to be found throughout the site and its subsurface, as ubiquitous waste fluids and as groundwater contaminants	Known as "ammoniacal" if from coal gas, other wise and generally known as "gas liquor." This was the plant process water effluent and may have been treated to recover tar, especially where such documentary evidence exists. The treated residue always was discharged in some fashion, either through leaking subsurface vessels or from design-overflow discharge, or directly into plant surface drainage channels or dedicated sewers. It is important to recognize that some gas liquor is BTEX, as "light oils", are LNAPLs, and the remainder are "medium" to "heavy tar oils" and therefore are DNAPLs.
Tar	Created as a result of all gas-manufacturing from organic feedstock Had to be removed from the raw gas, at the plant, to serve the consumer Was totally lost to the environment at charcoal plants and "beehive" coke ovens	Recover and reuse or sale based entirely on philosophy of plant management as well as on current market conditions for sale. Generally unsalable when water content exceeded 4%; CWG tars typically had a high-water-content emulsion form after 1910. Usually present at FMGPs as bodies of contaminated soil, in abandoned subsurface vessels such as gas holder tanks and tar wells, and as subsurface pockets or "hot spots."
Lampblack	Relatively largest quantities to be found at oil-gas plants	Typically non-toxic but capable of sorbing PAHs later, to significant degrees.
PAH in site ground water	Released continually, from each source area, solubilized into passing groundwater Released from the source in relation to their solubility in the passing ground water	Typically most active during active operation of the gas works. Will persist indefinitely afterward, unless physically removed, as the source areas are essentially non-degradable in nature and have lives measured in geologic time. "Light oils" do not reflect the totality of groundwater contamination.

nizes 16 PAHs as defined toxic compounds (Appendix VIII, 40CFR261), though it is well known that gas feedstocks can produce from 500 to 3000 separate PAH compounds at a single instance of pyrolysis.

We used to have considerable reservation toward penetration of sources for the purpose of sampling for laboratory analysis. Site exploration equipment and skills are now established well enough that all FMGP

Table 5
Predictable general geologic influences on gas plant wastes

Geologic condition	General effect	Implication
Vadose zone	Transmits SVOCs to depth	Depth controlled by magnitude and duration of the discharge or leakage.
Groundwater surface	Terminates free downward component of fluid gas waste flow during active addition by source-creating mechanism, unless the waste is DNAPL	Major force in lateral movement, mainly along flow gradient, with some side-spreading.
Hydraulically conductive vadose-zone bottom stratum	Base of toxic source volume sits on or in the waste mass	Common occurrence in disused sand pits in which original borrow pit was terminated at depth of entry of ground water, and that case repeats itself to flush or leach the waste volume to local ground water.
Alternating sequences of vadose-zone soil stratigraphy	Direct relationship on how much lateral flow transport distance will occur for the less-viscous tar fractions	Vertical trace of horizontal migration will have the irregular appearance of a geophysical borehole density signature (i.e. furthest outward in the most conductive strata).
Geomorphic channel-and-fill	Become selective pathways for lighter tar fractions and, especially gas liquors (as PAH-contaminated wastewaters)	Acts as an overwhelming conduit for contaminant migration as long as supply and relative viscosity overcome gravitational effects, along with channel-bottom permeability to the gas liquor or its suspended tar or dissolved PAHs.
Lateral distance to topographic declivity	Will significantly alter flow path of contaminated ground water	Always be on the lookout for gully-side breakouts.
Solubility in ground water	Most soluble tar fractions will strip off the outer rind of each tarry source volumes and contaminate passing ground water	The situation has the potential to yield and transport contamination for thousands of years or more. Often detected by iridescence of floating water-surface sheens or from fish and other aquatic-life kills, particularly fresh-water clams.
pH of vadose-zone host soil	Under acidic conditions can lead to release of box-waste cyanides and heavy metals	Arsenic, a known carcinogen, is the most common of the box-waste heavy metals.
Active cone of depression	Cone of depression touches host earth material holding the contaminant source volume	Active withdrawal from adjacent ground water supply may induce activated flow movement of FMGP toxics.
Pockets, lenses or channels of higher porosity and/or conductivity	Stratigraphic bodies present as anomalies in an otherwise more dense and less porous/less conductive host medium	Become operational-era sumps as natural "hot spots" of accumulated PAHs as leaked spilled or otherwise discharged to the ground.
Top-of-rock	Very important to anticipate and/or recognize this situation as a potential DNAPL trap, especially if at the base of a soil sequence	Traps most of the tar oils, yet lighter or free-phase DNAPLs will likely have penetrated the more open rock discontinuities. May, in some cases, cause PAH migration counter to the recognized saturated-zone groundwater flow gradient.
Psuedo-geologic pathways for PAH transport	Formal (municipal) and informal (plant) sewers	Most gas plant operators chose to keep the gas yard dry for optimization of plant operation.
	Gas yard drainage features such as tiles	Most gas yards were laid out to drain from the entrance to the adjacent stream or lowland.
	Often leakage occurred along the exterior of the sewer/pipe	Some of these drains leaked wastes before ultimate discharge.
Fluvial sediments	Generally present in thalwegs and channel inverts of natural drainage and as accumulated in lowland areas formerly known as "swamps," adjacent to the FMGP	Usually has an appreciable content of clay-particle and clay mineral content that was instrumental in local capture of the PAH and other impurities discharged with the plant liquors.

Table 5 (*continued*)

Geologic condition	General effect	Implication
Glacial geologic features	Lodgment (basal) till restricts contaminant transport	Light oils could and did penetrate glacial lodgment till joints however.
	Periglacial and proglacial drainage features	May constitute high-velocity operational-era contaminant-transport pathways.
	Buried channels	May constitute high-velocity operational-era contaminant-transport pathways.
	Geomorphic "holidays" ("windows") in glacial-lacustrine clay horizons	Known to destroy natural restraints to PAH migration downward in the soil sequence.

subsurface structures deserve careful, incremental sampling to their ultimate depths. In most cases, hot spots will require some sort of direct treatment and the imperative of maintaining their integrity during field exploration should not be cited as a deterrent to sampling. Nevertheless, invasive sampling should be planned and conducted so as to only minimally disturb contaminated ground.

5.3. Special nature of "tar"

"Tar," as a technical form, refers strictly to the viscous residue from pyrolytic (in the absence of oxygen) combustion of organic matter. Strictly speaking, use of the term "tar" thus implies an origin from coal. Its counterpart term "asphalt" strictly connotes a petroleum origin. During the manufactured gas era, the tars were also referred to as "oils," and they came in combined degrees of specific gravity, from light through medium to heavy oils. The final high-gravity, high-viscosity residue was known as "pitch," which readers older than age 50 will recall having seen tar as a waterproofing roofing material melted on-site in roaster trailers and applied with hot mops.

Tar oils consist of chains of benzene rings. Those that contain three to six benzene rings are known as polycyclic aromatic hydrocarbons (PAHs) or less commonly as polyaromatic hydrocarbons or, equivalently, polynuclear aromatic hydrocarbons (PNAs). The tar "light oils" properly are one-ring (monocyclic) and two-ring (duo-cyclic) PAHs, but these are light, non-aqueous-phase liquids (LNAPLs). PAHs of three or more benzene rings are dense, non-aqueous-phase liquids (DNAPLs). Theoretically, it is possible for PAHs to form in chains of more than six benzene rings, but such has not yet been reliably reported in the literature.

5.4. Typical hot-spot waste locations

In the absence of gas company historic design and layout drawings, the historic Sanborn Maps (Goad Maps in Canada) are the most reliable, generally available indicators of potential FMGP site waste locations. Design and layout drawings, along with equipment inventories and interior and exterior photographs were routinely produced for and by the gas utilities during the era of manufactured gas. Regrettably little of this well-known trove of company archives has been declared as surviving in the traditionally meticulous and comprehensive utility archives. State archives sometimes yield such contributions from the public service commissions. Almost impossible to locate is other such evidence in the hands of collectors, as historic "paper."

As revised aperiodically, it is important to ensure that the Sanborn Map coverage of subsequent editions spans the entire operational period of the plant. In many instances there were process and equipment modifications and replacements, along with other additions that can greatly impact the locations of present-day hot spots.

The author prefers to identify, in prediction, likely locations of hot spots of plant toxic by a series of circled "x" marks with numbers to identify the suspected nature of the wastes and their waste-source form.

Information regarding plant decommissioning and demolition also must be considered. Those FMGPs that were formally decommissioned, most likely in the 1946–1965 time frame, were subject to dumping of on-hand tars left in place at termination of plant activities. Those sites at which derelict tar wastes were brought to the ground surface and spread across the site can greatly alter the resultant contamination. Decommissioning by utilities was typically carried out under formal bid and work-order documents specifying final site conditions.

I strive to overcome not only subtleties but some outstanding misconceptions that have been applied to FMGP remediation since Federal emphasis was placed on remediating such sites in 1985 by USEPA.

6. Geologic controls

The nature of the location of wastes at an FMGP relate mainly to historic gas works technology. For most FMGP sites, the historic record is cloudy due to the fact that archival records relating to most plants are claimed by RPs to have been destroyed. A diligent search of the relevant gas literature (e.g. American Gas-Light Journal) will provide most of the missing events affecting plant operational history.

It becomes paramount, therefore, that the actual search, discovery and verification of gas works wastes be a geologically intensive field activity, following a competent attempt to predict such wastes. Most gas plant remediation professionals have witnessed clean-up overruns of "unexpected" caches of contaminated soil or hot spots of tar pockets that easily reach the magnitude of several thousand cubic meters. The "surprise" was, of course, generally rooted in an unwillingness of the RP to categorically predict the potential for such wastes and to place explorations in the potential area for such waste. Regulatory officials must also be prepared to make such predictions and argue for, or stipulate, that such ground be investigated to their satisfaction.

Once in the ground, and certainly after termination of plant activity, most gas-house wastes become relatively immobile, either because they are SVOC liquids with typically low solubility in ground water and high viscosity, or that they were solid wastes in the first instance. SVOCs basically come to rest in the vadose zone due to a positional equilibrium between their fluid density and viscosity and the pore or fracture medium of the host earth material, upon which gravitational force has acted as the driving mechanism. The viscous SVOC compounds lack the pressure to overcome interstitial forces and to invade pore or fracture space at that point.

I have discovered some geologic truisms as a result of my own FMGP and other site characterization experience. These are offered in Table 5 as the most likely conditions to be expected in planning for characterizing FMGP sites and can be used to develop the first phase of field explorations and to test the resulting observations. Geologic features of the FMGP site may themselves present the greatest physicochemical control over the fate and transport of plant contaminants that have been leaked, spilled or discharged, and were not the subject of plant dumping during the plant operational period.

6.1. Site and waste characterization planning

Once the historic site layout information has been evaluated and interpreted and the predicted sources and location of wastes have been delimited on the site map, explorations can be allocated to the verification of the expected (pre-exploration) stratigraphy and the discovery of waste sources or other hot spots.

Site exploration costs can be managed in an economically effective way if the general findings of Expedited Site Characterization are followed (Beam et al., 1997); to wit, to produce and evaluate findings on a daily basis while the team is mobilized for field activity, and to apply corrections to the plan on that basis. Corrections are made from evaluation of visual observations and from incoming laboratory determinations. Of course, the exploration team must be on a highly credible level of communication with regulatory officials in order to conduct the work plan within a rapid-response framework. Generally, it is most efficient when the RP arranges with the State or Provincial regulatory agency to pay for the presence of an on-site regulatory oversight official.

6.2. Geological and geophysical exploration techniques

Sensitive FMGP site characterization efforts generally begin with the use of a backhoe. Good photo-interpretation skills, followed by field-mapping observation, are primary and essential, as leads to backhoe exploration. Then, on evaluation of site evidence, it is proper to consider some form of push-probe, capable of sensing the geologic character of the subsurface with minimal disturbance of the ground itself, should waste sources be directly encountered. Direct-push devices are ineffective, however, where gas-house solid wastes have been disposed with retort and generator brick fragments.

Backhoes are particularly useful in locating the outer surface of gas holder tank walls, as well as those of the various forms of tar wells and cisterns (same meaning). For most other applications of site characterization technique (Hatheway, in press (b)), exploration of FMGPs do not differ significantly from the prudent choices available for site exploration and sampling for UHWSs in general.

Where soil-vapor gas analysis collectors are appropriate, the gas-collection port must be pushed to such a depth as to avoid the usual background. By their very nature, however, PAHs are only weakly volatile at

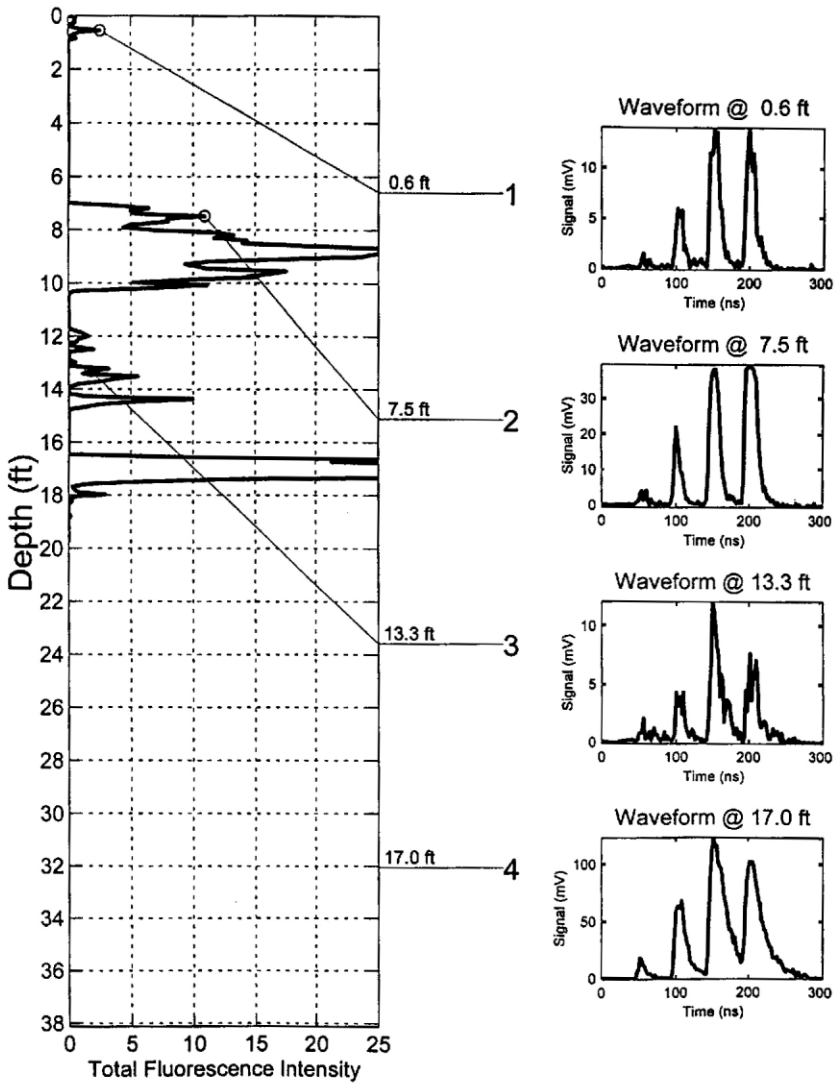

Fig. 8. Composite SCAPS signature from a FMGP site in New York State. The wave form is diagnostic of PAHs with four peaks. The laser-induced fluorescence is tied directly to highly reproducible soil typing by the Unified Soil Classification System (USCS) of the U.S. Army Corps of Engineers (courtesy of Fugro Geosciences, Houston, TX).

ambient temperature. Many probe operators are ultra cautious about incurring damage to their equipment, so that it is prudent to allow extra time for slow advance rates in this ground suspected of having subsurface obstacles.

Of particular use are push devices equipped with fluorescence scanning capability. The original tool in this field is the Site Characterization and Penetration System (SCAPS) developed by the U.S. Army Engineer Waterways Experiment Station, and field-tested in 1990. SCAPS became commercially available in 1994 and is equipped with a fiber-optic laser-induced fluorescence (LIF) device that excites spectral response in soils penetrated outside its sapphire–crystal lens. The collected soil/contamination response is computer-recorded and plotted as a LIF signature opposite the geotechnical push-resistance plot of the stratigraphy being penetrated.

Together, the two vertical plots define the soil types penetrated (in accordance with the Unified Soil Classification System [USCS]) and such contaminant groups as are present, including those groups with compounds and elements typical of gas-house wastes.

Fig. 8 is a segment of an FMGP exploratory boring response signature captured by FUGRO-McClelland consultants, of Houston, TX, who are one of several

Table 6
Criteria for producing a complete and accurate FMGP characterization

Criteria	Scope	Questions to be raised and resolved
Chronological history of the site	Minimally to include screening and abstraction of dates and time periods, gas-manufacturing process, site ownership and configuration (1) *Brown's Directory* (2) Fire Insurance Maps (3) Historic Photographs (4) Local Newspaper Coverage (5) Proceedings of Gas Associations (6) Gas Industry Journals	(1) Fundamental layout of the site, from establishment to termination. (2) Relate gas manufacturing and necessary treatment activity to types of gas-house residuals and wastes. (3) Estimate, quantitatively, the gross amount of site wastes that would likely have been produced for each period (say, decade) of plant history.
Definition of gas-production and treatment paths	Provide layout interpretation of the locations of component steps and transport of gas and residuals on the property	(1) Location and function of all definable components of the gas plant. (2) Pathway of movement of gas and residuals at the site.
Predicted locations of wastes remaining on site today	Examine historic evidence; evaluate such in terms of site as it exists today.	(1) Most likely present location of wastes associated with each component device and structure and each gas production and treatment activity. (2) Portions of the gas yard shown as vacant on Sanborn Maps likely are on-site dumps.
Complete coverage of the plant site area	Apply geologic assessment to all field data to gain an appropriately high-level of confidence that undetected toxic wastes are not left undetected	(1) Ensure that each predicted lead is subject to individual field investigation. (2) Leave no portion of the former gas yard unexplored; To commit such an error is to flaw the entire Remedial Investigation or characterization.
Possible off-site dumps	Commensurate with access to property and the risk assumption policy of the responsible party and the oversight public agency	Presentation of a real question of environmental ethics, especially considering that the adjacent property will likely be owned by interests other than those of the project at hand. May require being addressed by public officials and the regulatory agency.

geoenvironmental firms that market the technique nationally, as their Rapid Optical Screening Tool (ROST)-LIF services.

6.3. Development of the characterization assessment

Characterization should be terminated only when its scope and findings meet established criteria for completeness. Table 6 is offered as a checklist for conduct of FMGP site and waste characterization.

A guiding philosophy for site and waste characterization of FMGPs should always reflect the fact that these toxic compounds are non-degradable with time and are relatively immobile. Whenever they are in contact with ground water, they transfer their toxicity to the environment. Whenever and wherever there are flaws in the characterization of a FMGP (or other coal-tar site) there will come a day when resultant human or environmental damage will be detected after the fact. Our larger cities are rife with derelict MGP sites (130 in Greater New York City and at least 87 in Greater Chicago). Nearly priceless building sites will be heavily cost-impacted by premium foundation treatments when they occur at an FMGP.

7. Conclusions and recommendations

All parties to the characterization of FMGPs and other related sites should bear in mind that incompleteness or flaws in the characterization may leave the public and/or environment at peril.

Some agents working with these sites prefer to apply the concept of Risk-Based Corrective Action (RBCA), in accordance with the provisions of applicable ASTM standards. Based on his own background and experience, the author is strongly opposed to the application of RBCA to any FMGP, because none of the site wastes are environmentally degradable (as opposed to petroleum-based compounds) and seldom are FMGP sites explored with enough thoroughness to preclude that gasworks waste are not left undiscovered. It is unrealistic to expect or factor in any form of future "natural attenuation" for the medium-to-heavy "oil" associations (three-plus benzene-ring molecular structure) of the tars. This objection is based not only on possible reliance on "natural attenuation" but on fate-and-transport assumptions that are not borne out by comprehensive and competent site and waste characterization exploration, logging, evaluation and interpretation.

This paper constitutes a very brief overview of what the author has attempted to encapsulate in his forthcoming technical book *Remediation of Former Manufactured Gas Plants and Other Coal-Tar Sites*. Unlike nearly all other uncontrolled hazardous waste sites, FMGPs represent the most difficult of characterization sites, mainly because of the largely SVOC nature of much of the toxic wastes and the fact that all waste bodies are intimately united with the subsurface geologic conditions at the individual site. The author invites the reader to visit his web site (www.hatheway.net) and to contact him with suggestions, comments and/or questions.

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