

# Gasification

Contributed by Administrator  
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## Gasification

Simply stated gasification is the process of converting a solid fuel into a combustible gas. Gasification has been used as an energy source for over 100 years. Before electric lighting was available in cities there were street lamps fueled by gasified coal. In World War II there were over a million vehicles powered by wood and charcoal due to the severe shortage of petroleum going toward the war effort. In Sweden at this time it is estimated 40-60% of the cars were gasifier fueled. As a related technology synthetic gasoline has been produced ever since World War II by gasifying coal and through chemical reactions called Fischer-Tropsch. Toward the end of WWII Nazi Germany produced massive quantities of synthetic gasoline from coal and kept it's war machine operating over a year longer than it would have been capable with its rapidly dwindling supplies of oil as the allies advanced. For the last 30 years South Africa has produced it's own synthetic gasoline and diesel fuel from its domestic supplies of low grade coal. The vast majority of us here in the United States are not even aware that viable substitutes to oil even exist for producing fuel. Several viable substitutes to oil do exist as an energy resource and probably the most promising substitute is the gasification of coal, wood and agricultural wastes. It is estimated that the United States has a 2000 year reserve of coal domestically, while having an excess of coal the United States is chronically dependent upon foreign sources of oil for 60% of its oil consumption. Does something sound very wrong with this equation? It is, especially in light of the fact that we can actually produce our own synthetic gasoline from our own abundant sources of coal, forest waste, forest products and agricultural waste. While perhaps not a permanent solution to the energy needs of the nation the gasification and production of synthetic gasoline may very well prove to be in the near future an important bridge to permanent sources of renewable energy such as wind, solar power and gasification of biomass (wood, agricultural wastes, etc...) while at the same time offering complete independence from foreign supplies of energy resources such as oil and natural gas.

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For the water carbonator, see [Gasogene](#).

Gasification is a process that converts carbonaceous materials, such as coal, petroleum, petroleum coke or biomass, into carbon monoxide and hydrogen.

In a gasifier, the carbonaceous material undergoes three processes:

- [Pyrolysis of carbonaceous fuels](#)

The [pyrolysis](#) (or devolatilization) process occurs as the carbonaceous particle heats up. Volatiles are released and char is produced, resulting in up to 70% weight loss for coal. The process is dependent on the properties of the carbonaceous material and determines the structure and composition of the char, which will then undergo gasification reactions.

- The [combustion](#) process occurs as the volatile products and some of the char reacts with oxygen to form carbon dioxide and carbon monoxide, which provides heat for the subsequent gasification reactions. Pyrolysis and combustion are very rapid processes.
- [Gasification of char](#)

The gasification process occurs as the char reacts with carbon dioxide and steam to produce carbon monoxide and hydrogen. The resulting gas is called [producer gas](#) or [syngas](#) (or [wood gas](#) when fueled by wood) and may be more efficiently converted to energy such as [electricity](#) than would be possible by direct combustion of the fuel, as the fuel is first combusted in a [gas turbine](#) and the heat is used to produce steam to drive a [steam turbine](#). Also, [corrosive ash elements](#) such as [chloride](#) and [potassium](#) may be refined out by the gasification process, allowing high temperature combustion of the gas from otherwise problematic fuels.

The gasification process was originally developed in the 1800s to produce [town gas](#) for lighting and cooking. Natural gas and electricity soon replaced town gas for these applications, but the gasification process has been utilized for the production of synthetic chemicals and fuels since the 1920s.

Devices based on this process, called [Gasogene](#) or [Gazogène](#), were used to power motor vehicles in Europe during World War II fuel shortages [1].

It is now recognized that gasification has wider applications; in particular the production of electricity using [Integrated Gasification Combined Cycles \(IGCC\)](#), with the long-term aim of producing hydrogen for fuel cells. IGCC demonstration plants have been operating since the early 1970s and some of the plants constructed in the 1990s are now entering commercial service.

(Within the last few years gasification technologies have been developed that use also [plastic-rich waste](#) as a feed. In

a plant in Germany such a technology - on large scale - converts plastic waste via producer gas into methanol. [2]  
[3])

Gasification relies on chemical processes at elevated temperatures  $>700^{\circ}\text{C}$ , contrary to biological processes such as anaerobic fermentation (digestion) which produces biogas.

Breakdown of hydrocarbons into syngas is done by carefully controlling the amount of oxygen present while heating the hydrocarbons to extreme temperatures. [edit]

### Gasification processes

Four types of gasifier are currently available for commercial use: counter-current fixed bed, co-current fixed bed, fluid bed and entrained flow.

The counter-current fixed bed ("up draft") gasifier consists of a fixed bed of carbonaceous fuel (e.g. coal or biomass) through which the "gasification agent" (steam, oxygen and/or air) flows in counter-current configuration. The ash is either removed dry or as a slag. The slagging gasifiers require a higher ratio of steam and oxygen to carbon in order to reach temperatures higher than the ash fusion temperature. The nature of the gasifier means that the fuel must have high mechanical strength and must be non-caking so that it will form a permeable bed, although recent developments have reduced these restrictions to some extent. The throughput for this type of gasifier is relatively low. Thermal efficiency is high as the gas exit temperatures are relatively low. However, this means that tar and methane production is significant at typical operation temperatures, so product gas must be extensively cleaned before use or recycled to the reactor.

The co-current fixed bed ("down draft") gasifier is similar to the counter-current type, but the gasification agent gas flows in co-current configuration with the fuel (downwards, hence the name "down draft gasifier"). Heat needs to be added to the upper part of the bed, either by combusting small amounts of the fuel or from external heat sources. The produced gas leaves the gasifier at a high temperature, and most of this heat is often transferred to the gasification agent added in the top of the bed, resulting in an energy efficiency on level with the counter-current type. Since all tars must pass through a hot bed of char in this configuration, tar levels are much lower than the counter-current type.

In the fluid bed gasifier, the fuel is fluidised in oxygen (or air) and steam. The ash is removed dry or as heavy agglomerates that defluidise. The temperatures are relatively low in dry ash gasifiers, so the fuel must be highly reactive; low-grade coals are particularly suitable. The agglomerating gasifiers have slightly higher temperatures, and are suitable for higher rank coals. Fuel throughput is higher than for the fixed bed, but not as high as for the entrained flow gasifier. The conversion efficiency is rather low, so recycle or subsequent combustion of solids is necessary to increase conversion. Fluidised bed gasifiers are most useful for fuels that form highly corrosive ash that would damage the walls of slagging gasifiers. Biomasses generally contain high levels of such ashes.

In the entrained flow gasifier a dry pulverised solid, an atomized liquid fuel or a fuel slurry is gasified with oxygen (much less frequent: air) in co-current flow. The gasification reactions take place in a dense cloud of very fine particles. Most coals are suitable for this type of gasifier because of the high operating temperatures and because the coal particles are well separated from one another. The high temperatures and pressures also mean that a higher throughput can be achieved, however thermal efficiency is somewhat lower as the gas must be cooled before it can be cleaned with existing technology. The high temperatures also mean that tar and methane are not present in the product gas; however the oxygen requirement is higher than for the other types of gasifiers. All entrained flow gasifiers remove the major part of the ash as a slag as the operating temperature is well above the ash fusion temperature. A smaller fraction of the ash is produced either as a very fine dry fly ash or as a black coloured fly ash slurry. Some fuels, in particular certain types of biomasses, can form slag that is corrosive for ceramic inner walls that serve to protect the gasifier outer wall. However some entrained bed type of gasifiers do not possess a ceramic inner wall but have a inner water or steam cooled wall covered with partially solidified slag. These types of gasifiers do not suffer from corrosive slags. Some fuels have ashes with very high ash fusion temperatures. In this case mostly limestone is mixed to the fuel prior to gasification. Addition of a little limestone will usually suffice for the lowering the fusion temperatures. The fuel particles must be much smaller than for other types of gasifiers. This means the fuel must be pulverised, which requires somewhat more energy than for the other types of gasifiers. By far the most energy consumption related to entrained bed gasification is not the milling of the fuel but the production of oxygen used for the gasification. [edit]

See also

- FutureGen zero-emissions coal-fired power plant
- Fluidized bed
- Fluidized bed combustion

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It has been suggested that Syngas be merged into this article or section. (Discuss)

Town gas is a generic term referring to manufactured gas produced for sale to consumers and municipalities. Depending on the processes used for its creation the gas was a mixture of caloric gases: hydrogen, carbon monoxide, methane, and volatile hydrocarbons with small amounts of noncaloric gases carbon dioxide and nitrogen as impurities.

Prior to the development of natural gas supplies and transmission in the United States during 1940s and 1950s, virtually all fuel and lighting gas was manufactured, and the byproduct coal tars were at some times an important chemical feedstock for the chemical industries. The development of manufactured gas paralleled that of the industrial revolution and urbanization. The terms coal gas, manufactured gas and hygas are also common.

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## Manufacturing process

Manufactured gas is made by two processes: carbonization or gasification. Carbonization refers to the devolatilization of an organic feedstock to yield gas and char. Gasification is the process of subjecting a feedstock to chemical reactions that produce gas.

The first process used was the carbonization and partial pyrolysis of coal. The off gases liberated in the high temperature carbonization (coking) of coal in coke ovens were collected, scrubbed and used as fuel. Depending on the goal of the plant, the desired product was either a high quality coke for metallurgical use, with the gas being a side product or the production of a high quality gas with coke being the side product. Coke plants are typically associated with metallurgical facilities such as smelters, and blast furnaces, while gas works typically served urban areas.

A facility used to manufacture coal gas, Carbureted Water Gas (CWG), and oil gas is generally referred to today as a Manufactured Gas Plant (MGP).

In the early years of MGP operations, the goal of a utility gas works was to produce the greatest amount of highly illuminating gas. The illuminating power of a gas was related to amount of soot forming hydrocarbons (&ldquo;illuminants&rdquo;) dissolved in it. These hydrocarbons gave the gas flame its characteristic bright yellow color. Gas works would typically use oily bituminous coals as feedstock. These coals would give off large amounts of volatile hydrocarbons into the coal gas, but would leave behind a crumbly, low quality coke not suitable for metallurgical processes. Coal or Coke oven gas typically had a caloric value (CV) between 1 and 2 MJ/m<sup>3</sup> (250-550 Btu/ft<sup>3</sup> (std)); with values around 2 MJ/m<sup>3</sup> (550 Btu/ft<sup>3</sup> (std)); being typical.

The advent of electric lighting forced utilities to search for other markets for manufactured gas. MGPs that once produced gas almost exclusively for lighting shifted their efforts towards supplying gas primarily for heating and cooking, and even refrigeration and cooling.

Fuel gas for industrial use was made using producer gas technology. Producer gas is made by blowing air through an incandescent fuel bed (commonly coke or coal) in a gas producer. The reaction of fuel with insufficient air for total combustion produces CO: this reaction is exothermic and self sustaining. It was discovered that adding steam to the input air of a producer would increase the CV of the fuel gas by enriching it with CO and H<sub>2</sub> produced by water gas reactions. Producer gas has a very low CV of 3.7 to 5.6 MJ/m<sup>3</sup> (100-150 Btu/ft<sup>3</sup> (std)); because the calorific gases

CO/H<sub>2</sub> are diluted with lots of inert nitrogen (from air) and CO<sub>2</sub> (from combustion)

(Exothermic: Producer gas Reaction)

(Endothermic: Water Gas Reaction)

(Endothermic)

(Exothermic: Water Gas Shift reaction)

The problem of nitrogen dilution was overcome by the blue water gas (BWG) process, developed in the 1850s by Sir William Siemens. The incandescent fuel bed would be alternately blasted with air followed by steam. The air reactions during the blow cycle are exothermic, heating up the bed, while the steam reactions during the make cycle, are endothermic and cool down the bed. The products from the air cycle contain non-caloric nitrogen and are exhausted out the stack while the products of the steam cycle are kept as blue water gas. This gas is composed almost entirely of CO and H<sub>2</sub>, and burns with a pale blue flame similar to natural gas. BWG has a CV of 11 MJ/m<sup>3</sup> (300 Btu/ft<sup>3</sup> (std)).

Because blue water gas lacked illuminants it would not burn with a luminous flame in a simple fishtail gas jet as existing prior to the discovery of the Welsbach mantle in the 1890s. Various attempts were made to enrich BWG with illuminants from gas oil in the 1860s. Gas oil was the flammable waste product from kerosene refining, made from the lightest and most volatile fractions (tops) of crude oil.

In 1875 Thaddeus S. C. Lowe invented the carburetted water gas process. This process revolutionized the manufactured gas industry and was the standard technology until the end of manufactured gas era. A CWG generating set consisted of three elements; a producer (generator), carburettor and a super heater connected in series with gas pipes and valves.

During a make run, steam would be passed through the generator to make blue water gas. From the generator the hot water gas would pass into the top of the carburetor where light petroleum oils would be injected into the gas stream. The light oils would be thermocracked as they came in contact with the white hot checkerwork firebricks inside the carburettor. The hot enriched gas would then flow into the superheater, where the gas would be further cracked by more hot fire bricks [edit]

#### Early history of gas production by carbonization

The Flemish scientist Jan Baptista van Helmont (1577 - 1644) discovered that a 'wild spirit' escaped from heated wood and coal, and, thinking that it 'differed little from the chaos of the ancients', he named it gas in his *Origins of Medicine* (c. 1609). Among several others who carried out similar experiments, were Johann Becker of Munich (c 1681) and about three years later John Clayton of Wigan England, the latter amusing his friends by lighting, what he called, "Spirit of the Coal". William Murdoch (later known as Murdock) (1754 - 1839) is reputed to have heated coal in his mother's teapot to produce gas. From this beginning, he discovered new ways of making, purifying and storing gas; illuminating his house at Redruth (or his cottage at Soho) in 1792, the entrance to the Manchester Police Commissioners premises in 1797, the exterior of the factory of Boulton and Watt in Birmingham, England, and a large cotton mill in Salford, Lancashire in 1805.

Professor Jan Pieter Minckelers lit his lecture room at the University of Louvain in 1783 and Lord Dundonald lit his house at Culross, Scotland, in 1787, the gas being carried in sealed vessels from the local tar works. In France, Phillipe Lebon patented a gas fire in 1799 and demonstrated street lighting in 1801. Other demonstrations followed in France and in the United States, but, it is generally recognised that the first commercial gas works was built by the London and Westminster Gas Light and Coke Company in Great Peter Street in 1812 laying wooden pipes to illuminate Westminster Bridge with gas lights on New Year's Eve in 1813. In 1816, Rembrandt Peale and four others established the Gas Light Company of Baltimore, the first manufactured gas company in America. In 1821, natural gas was being used commercially in Fredonia, New York. The first German gas works was built in Hannover in 1825 and by 1870 there were 340 gas works in Germany making town gas from coal, wood, peat and other materials.

Working conditions in the Gas Light and Coke Company's Horseferry Road Works, London, in the 1830s were described by a French visitor, Flora Tristan, in her *Promenades Dans Londres\** - "Two rows of furnaces on each side were fired up; the effect was not unlike the description of Vulcan's forge, except that the Cyclops were animated with a divine spark, whereas the dusky servants of the English furnaces were joyless, silent and benumbed. ... The foreman told me that stokers were selected from among the strongest, but that nevertheless they all became consumptive after seven or eight years of toil and died of pulmonary consumption. That explained the sadness and

apathy in the faces and every movement of the hapless men."

The first public piped gas supply was to 13 gas lamps, each with three glass globes along the length of Pall Mall, London in 1807. The credit for this goes to the inventor and entrepreneur Fredrick Winsor and the plumber Thomas Sugg who made and laid the pipes. Digging up streets to lay pipes required legislation and this delayed the development of street lighting and gas for domestic use. Meanwhile William Murdock and his pupil Samuel Clegg were installing gas lighting in factories and work places, encountering no such impediments. [edit]

#### Early history of gas production by gasification

1850s: Gas producers invented, water gas process discovered. Mond Gas: 1850s Europeans discover that using coal instead of coke in a producer results in producer gas that contains ammonia and coal tar, Ludwig Mond's Mond Gas is processed to recover these valuable compounds.

1860s: Enrichment of BWG with illuminants from gas oil circa 1860s. Gas Oils, the volatile fractions that evaporate above kerosene, are a major problem for kerosene industry.

1875: The invention of the Carburetted Water gas process by Prof. TSC Lowe in 1875. The gas oil is fixed into the BWG via thermocracking in the carburettor and superheater of the CWG generating set. CWG is the dominant technology from 1880s until 1950s, replacing coal gasification. CWG has a CV of 2 MJ/m<sup>3</sup> i.e slightly more than half that of natural gas. Golden age of gas light develops with the Welsbach mantle. [edit]

#### The uses of gas and the later development of the gas industry

The advent of incandescent gas lighting in factories, homes and in the streets, replacing oil lamps and candles with steady clear light, almost matching daylight in its colour, turned night into day for many - making night shift work possible in industries where light was all important - in spinning, weaving and making up garments etc. There followed gas heaters, gas cookers, refrigerators, washing machines, hand irons, poker for fire lighting, gas heated baths, remotely controlled clusters of gas lights, gas engines of various types and, in later years, gas central heating and air conditioning, all made immense contributions to the improvement of the quality of life in cities and towns world wide.

By the 1960s, manufactured gas, compared with its main rival in the energy market, electricity, was considered 'nasty, smelly, dirty and dangerous', to quote market research of the time, and seemed doomed to extinction. In Europe, salvation came with the discovery of commercial quantities of natural gas, mainly methane, in the province of Groningen in the Netherlands and the demonstration that liquid natural gas (LNG) could be transported efficiently and economically over long distances by sea. Later developments in the technologies of pipelaying have made possible the transmission of gas on land and under sea across and between continents. Natural gas is now a world commodity. [edit]

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#### Development of Pacific coast oil gas process

1912. /Pintsch Railway oil Gas processes 1880s.

Massive problems with lampblack created from the Pacific coast process. Up to 20 to 30 lb/1000 ft<sup>3</sup> (300 to 500 g/m<sup>3</sup>) of oily soot. Major pollution problem leads to passage of early environmental legislation at the state level. [edit]

#### Layout of a typical gas plant

- 1880s Coal gasification plant.
- 1910 CWG plant [edit]

#### Issues in gas processing

- Tar aerosols (tar extractors, condensers/scrubbers, Electrostatic precipitators in 1912)
- Light oil vapors (oil washing)
- Naphthalene (oil/tar washing)
- Ammonia gas (scrubbers)
- Hydrogen sulfide gas (purifier boxes)

- Hydrogen cyanide gas (purifier) [edit]

#### WWI-interwar era developments

- Loss of high quality gas oil (used as motor fuel) and feed coke (diverted for steelmaking) leads to massive tar problems. CWG tar is less valuable than coal gasification tar as a feed stock. Tar-water emulsions are uneconomical to process due to unsellable water and lower quality by products. CWG tar is full of lighter PAH's, good for making pitch, but poor in chemical precursors.
- Various "back-run" procedures for CWG generation lower fuel consumption and help deal with issues from the use of bituminous coal in CWG sets.
- Development of high pressure pipeline welding encourages the creation of large municipal gas plants and the consolidation of the MG industry. Sets the stage for rise natural gas.
- Electric lighting replaces gaslight. MG industry peak is sometime in mid 1920s
- 1936 or so. Development of Lurgi gasifier. Germans continue work on gasification/synfuels due to oil shortages.
- Public Utility Holding Company Act of 1935 forces break up of integrated coke and gas companies.
- Fischer-Tropff process for synthesis of liquid fuels from CO/H<sub>2</sub> gas.
- Haber-Bosch ammonia process creates a large demand for industrial hydrogen. [edit]

#### Post WWII: the decline of manufactured gas

- Development of natural gas industry. NG is 37 MJ/m<sup>3</sup>
- Petrochemicals kill much of the value coal tar as a source of chemical feed stocks.(BTX, Phenols, Pitch)
- Decline in creosote use for wood preserving.
- Direct coal/natural gas injection reduces demand for metallurgical coke. 25 to 40% less coke is needed in blast furnaces.
- BOF and EAF processes obsolete cupola furnaces. Reduce need for coke in recycling steel scrap. Less need for fresh steel/iron.
- Steel is replaced with aluminum and plastics.
- Phthalic Anhydride production shifts from catalytic oxidation of naphthalene to o-xylol process. [edit]

#### Post WWII positive developments

- Catalytic upgrading of gas by use of hydrogen to react with tarry vapors in the gas
- The decline of coke making in the US leads to a coal tar crisis since coal tar pitch is vital for the production of carbon electrodes for EAF/Aluminum. US now has to import CT from china
- Development of process to make methanol via hydrogenation of CO/H<sub>2</sub> mixtures.
- Mobil M-gas process for making gasoline from methanol
- SASOL coal process plant in South Africa.
- Direct hydrogenation of coal into liquid and gaseous fuels [edit]

#### Environmental effects

From its original development until the wide scale adoption of natural gas, more than 50,000 manufactured gas plants were in existence in the United States alone. The process of manufacturing gas usually produced a number of by-products that contaminated the soil and groundwater in and around the manufacturing plant, so many former town gas plants are a serious environmental concern, and cleanup and remediation costs are often high. MGPs were typically sited near or adjacent to waterways that were used for the discharge of wastewater contaminated with tar, ammonia and/or drip oils, as well as outright waste tars and tar-water emulsions.

In the earliest days of MGP operations, coal tar was considered a waste and often disposed into the environment in and around the plant locations. While uses for coal tar developed by the late-1800s, the market for tar varied and plants that could not sell tar at a given time could store tar for future use, attempt to burn it as fuel for the boilers, or dump the tar as waste.

The shift to the CWG process initially resulted in a reduced output of water gas tar as compared to the volume of coal tars. The advent of automobiles reduced the availability of naphtha for carburetion oil, as that fraction was desirable as motor fuel. MGPs that shifted to heavier grades of oil often experienced problems with the production of tar-water emulsions, which were difficult, time consuming, and costly to break. [The cause of tar-water emulsions is complex and was related to several factors, including free carbon in the carburetion oil and the substitution of bituminous coal as a feedstock instead of coke.] The production of large volumes of tar-water emulsions quickly filled up available storage capacity at MGPs and plant management often dumped the emulsions in pits, from which they may or may not have been later reclaimed. Even if the emulsions were reclaimed, the environmental damage from placing tars in unlined pits remained. The dumping of emulsions (and other tarry residues such as tar sludges, tank bottoms, and off-spec tars) into the soil and waters around MGPs is a significant factor in the pollution found at FMGPs today.

Commonly associated with former manufactured gas plants (known as "FMGPs" in environmental remediation) are contaminants including:

- BTEX
- Diffused out from deposits of coal/gas tars
- Leaks of carburetted oil/light oil
- Leaks from drip pots, that collected condensable hydrocarbons from the gas
- Coal tar waste/sludge
- Typically found in sumps of gas holders/decanting ponds.
- Coal tar sludge has no resale value and so was always dumped.
- Volatile Organic Compounds
- Semi-volatile Organic Compounds
- Many heavier coal tar compounds are not very volatile, i.e PAHs
- Polycyclic aromatic hydrocarbons
- Found in copious quantities in coal tar, gas tar, and pitch.
- heavy metals
- Leaded solder for gas mains, lead piping, coal ashes.
- cyanide
- Purifier waste has large amounts of complex ferrocyanides in it.
- Lampblack
- Only found where crude oil was used as gasification feedstock.
- Tar emulsions [edit]

See also

- Natural gas
- Illuminating gas
- remediation
- Syngas

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