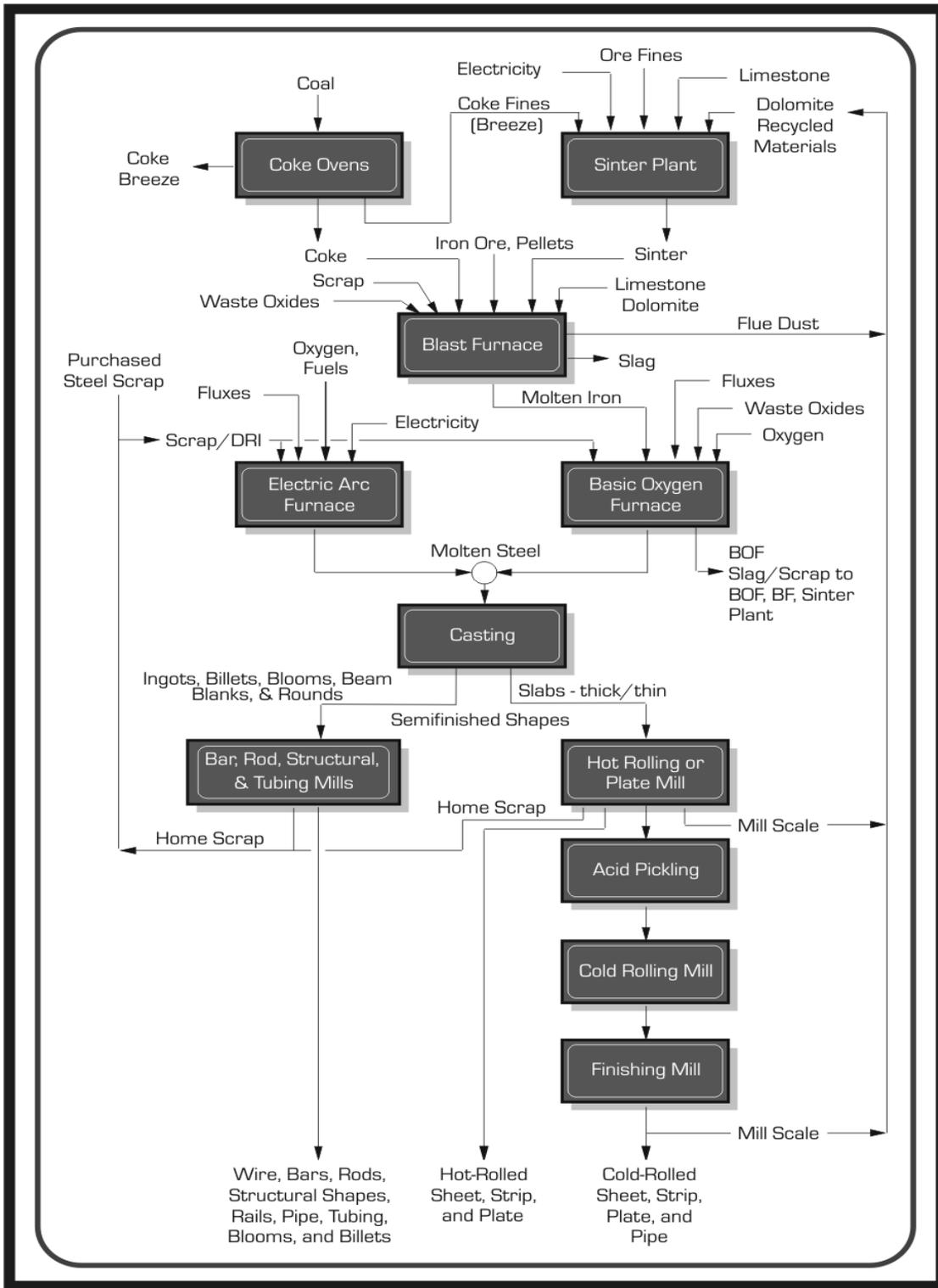


1.0 Cokemaking

Metallurgical coke is an important part of the integrated iron and steelmaking process (see Figure 1-1) because it provides the carbon and heat required to chemically reduce iron ore in blast furnaces to produce molten pig iron (hot metal). Because of its strength, coke also supports the column of materials in the blast furnace, and its physical nature provides porosity for counter-flowing gases to penetrate the material bed.

Despite the importance of metallurgical coke, naturally aging coke plants and corresponding impending shutdowns, high capital costs to replace those facilities, and tightening environmental regulations that create higher production costs threaten to reduce production capacity in North America.



Source: Adapted from U.S. Council on Wage and Price Stability, Report to the President on Prices and Costs in the United States Steel Industry, 1977 (COWPS, October 1977).

Figure 1-1. Overview of Steelmaking Processes

This gap also presents a challenge for coke manufacturers to explore new and emerging technologies that improve environmental controls at existing facilities or lend themselves to application at new facilities.

Metallurgical coke is produced by heating bituminous coal in a battery of large coke ovens, multiple vertical chambers separated by heating flues (see Figure 1-2). A blend of metallurgical coals is charged into ports on the top of the ovens and then heated at high temperature in the absence of air to drive off volatile substances from the charge while preventing combustion of the coal.

The heat from the flue walls is then used to heat the coal mass from the walls inward over a period of 16 to 24 hours. When heated, the coal turns into a soft plastic mass which then resolidifies into the coke mass. This plastic mass, which is formed from both walls, will meet in the center and constitutes the end of the coking cycle. When heated, the coal volatile matter is driven off and is absent in the final product. To make coke, one needs the correct type of coals and adequate time at adequate temperature.

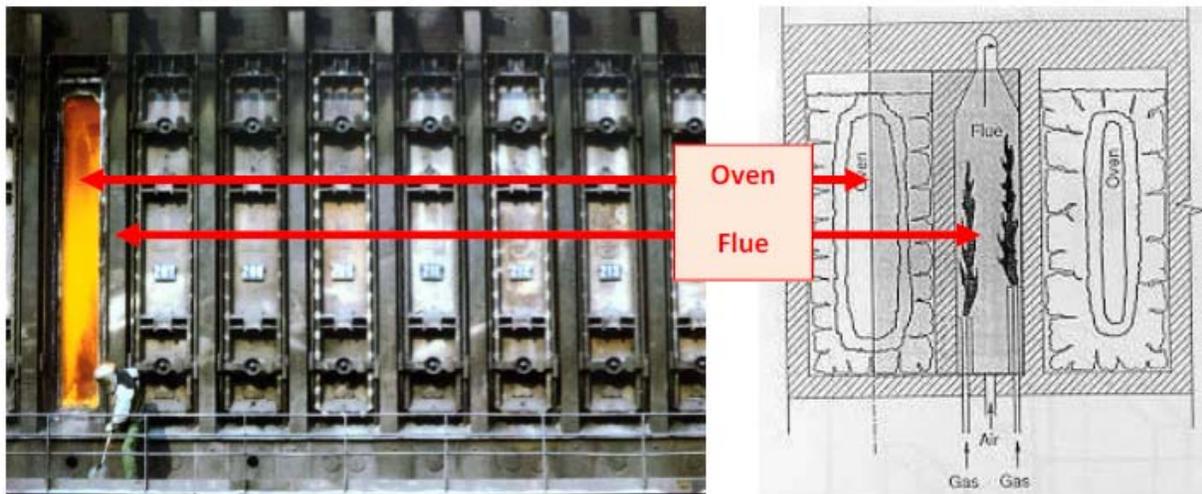


Figure 1-2 – Side view of coke ovens

When coking is completed, a pusher machine on one end of an oven is moved to the oven, removes the oven door, and rams the hot coke out of an opened door at the other side of the oven and into a mobile container car. The hot coke is then transferred to a station where it is quenched, either dry or with water, and then discharged to a conveying system for subsequent sizing and screening.

Coke plants are designed either for by-product recovery or heat recovery. By-product recovery plants have been the traditional means of production for more than 100 years, but most new plants over the past 20 years have been heat recovery facilities

1.1 By-Product Coke Plants

In a by-product plant, as the coal turns into coke, chemical processes are employed to recover a variety of chemicals from the volatile material, including coke oven gas, tar, light oil, ammonia, sulfur products, or other organic chemicals. Until the 1950s, the value of by-products largely offset or even exceeded the value of the coke. However, the advent of petroleum refining has driven the price of these chemicals to much lower levels and reduced the number of by-products recovered. These by-products are then

sold or used internally. For example, the tar is sold to refiners who then process this material into anodes for the aluminum industry or other coal chemicals such as pavement sealants or roofing tar. Ammonia-based by-products are sold into the fertilizer industry. Approximately 40% of the recovered coke oven gas, which has about 50% of the heating value of natural gas and is a valuable energy source, is used to provide energy to fire the coke ovens themselves, and the remainder can be used as a fuel for a variety of combustion purposes throughout the iron and steel plant, including blast furnace stoves, boilers, reheat furnaces, etc.

The by-product cokemaking process, which has changed very little over its more than 100-year history, is subject to strict environmental regulations. These regulations and changes in steelmaking force higher production costs or shutdowns, pressuring the steel industry to improve the cokemaking process. Aging facilities, primarily in developed countries, also need to be replaced, and combined with tightening of environmental regulations, these factors are reducing the amount of coke produced. For example, the United States and Canada currently have the capacity to produce approximately 14 million short tons of furnace coke each year. Normal aging of facilities will likely require the replacement of at least of an estimated 60% of that capacity over the next 20 years. Batteries that were expected to live only 30 years, have been pushed to operate 50 years or more. Maintaining coke capacity beyond normative ages is a technical challenge for all integrated steel plants.

1.2 Heat-Recovery Coke Plants

As by-product plants have been shut down in recent years, most replacement capacity has been constructed as heat recovery plants, which account for approximately 30% of current production of blast furnace coke in the U.S. Instead of being heated by vertical flues, the coal mass is heated from the bottom flues and the gas that is evolved is used to heat the coal mass from the top (see Figure 1-3). The unique feature of heat recovery batteries is operation with a negative pressure and combustion of the waste gas to recover the waste heat to produce steam and electricity or both. Operation of the ovens under negative pressure provides an environmental advantage by minimizing door and topside leaks. Because heat recovery ovens have larger coal charges per oven, coking time is also longer, i.e., 40-48 hours, but this is offset as more coke tons are pushed per oven and the ovens themselves are only opened up every 40-48 hours, which means less opportunity for environmental impacts. Also, since these ovens are horizontal compared to the traditional slot ovens, there are fewer concerns about wall pressure when designing a coal blend. However, a larger foot print for the battery proper is required. Capital cost savings by eliminating by-product recovery processing are offset, at least in part, by the need for waste heat recovery boilers and pollution control facilities for sulfur compounds and mercury at these facilities.

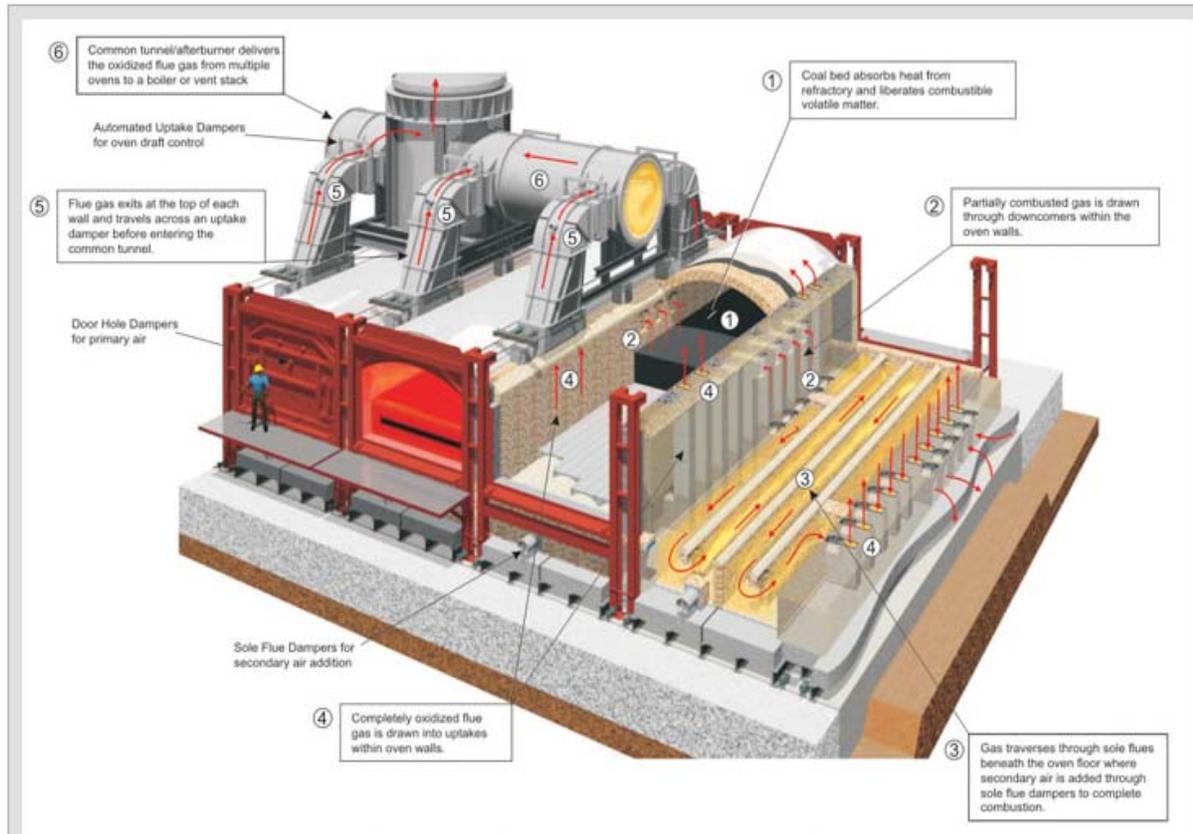


Figure 1-3 – Heat-Recovery Coke Plant Overview

Environmental Challenges. Cokemaking is subject to government regulations specified in the 1970 Clean Air Act Amendments and the Act's subsequent regulations to control emissions during charging, leaks during coking, discharging (pushing) of the ovens, combustion stacks, quenching, and by-product processing. For by-product plants the primary concern over emissions focuses on the doors at either end of the ovens and on the oven charging ports atop the battery because of inadequately sealed doors and charging port lids allowing gases to escape. The U.S. Environmental Protection Agency has developed the standards for both new and existing plants which must be adhered to in the USA. In Europe a pressure regulation technology during coking was developed to minimize battery emissions during the coking process, and a few batteries have been retrofitted in USA with this technology. Others are developing similar systems. By-product processing presents additional environmental control issues for cokemakers. Throughout the cokemaking process, organic compounds are recovered as gas, tar, oil, and other liquid products for reuse or conversion into by-products for sale or internal use. Some of the recovered compounds, characterized as carcinogenic, are also classified as health hazards and therefore require special processing. As noted above, heat recovery plants can avoid some of these environmental problems, and the 1970 Clean Act Amendments specified the use of heat recovery plants, or equivalent performance, as the requirement for new coke plants. For both by-product and heat recovery plants, wet quenching of the hot coke presents environmental challenges. Dry quenching and the energy recovery opportunities that the technology presents have been employed in Europe and Asia as a means of meeting these challenges, although dust control issues must be confronted. However, the energy savings opportunities of dry quenching have not been economically justified in North America.

New and Emerging Technologies. The need to improve environmental controls for existing cokemaking facilities and to find more cost-effective methods of producing high quality metallurgical coke has prompted several new and emerging technologies. These technologies were developed mostly in the 1980s and 1990s.

The ability to adopt these technologies and see them integrated into commercial reality is a function of:

- Global coke supply,
- Available capital, and
- Steel industry financial health.

In the 1990s, Chinese coke was available at very competitive rates, which provided less incentive for steel companies to invest in taking the new technologies beyond the pilot and demonstration stages in North America. Also the fragile financial health of the steel industry was not conducive for investment in new or unproven technologies to make coke. Nevertheless, some development did take place and can be summarized as follows:

- The Japanese SCOPE21 project (Super Coke Oven for Productivity and Environmental Enhancement towards the 21st Century) was sponsored by the Japanese Iron and Steel Federation. Initiated in 1994, pilot oven studies were completed in 2003 and commercial plants were initiated in 2008. The Scope 21 uses a formcoke process (US3969088) which combines briquetted formcoke with energy and environmental improvements in existing batteries. With this technology, cokemaking is performed in three steps: coal pretreatment, carbonization, and coke upgrading. Coking takes place at lower temperatures, with final coking taking place in a coke dry quenching station. This technology has been adopted at NSC's Oita and Nagoya Works. Not much has been published since about 2013.
- Caronyx technology makes a formcoke utilizing both lower and higher grade coals. Not much information on this process is available in the public domain, but it can be stated that U.S. Steel built the first Caronyx module at Gary Works in 2012, but decided to abandon the technology in 2014 as it was not successful in its scale-up to industrial production levels.
- The European Jumbo Coking Reactor has reconfigured batteries for larger individual batch process ovens. The capital costs for the technology, also referred to as the Single Chamber System, were significantly greater than conventional technology, and therefore interest in utilizing the technology was minimal. The pilot facility was closed down.
- The Coal Technology Corporation is using a formcoke process that produces coke briquettes from non-coking coals and waste coals. The process is currently referred to as the Antaeus Continuous Coke™ process, named for the Australian company which purchased the patent rights. However, this has changed names a few times and has tried to be resurrected but without much success. It is now known as Carbonite.
- In the mid to late 1990's a Calderon Cokemaking Technology pilot facility was built in Alliance OH. The technology turns the coke oven wall into a circular shape where the coal mass is coked in a round tube. Coke is continuously being produced as the coal mass moves down the heated tube. No scale up to demonstration has taken place.

- The Ukrainian State Research Institute for Carbochemistry is testing a continuous cokemaking process using a vertical shaft structure and a piston to push metallurgical coke blends through the heated zones. A pilot unit is said to exist at Kharkov but has been shut down due to economic reasons.

Research and Development Needs and Opportunities. The need for high quality coke for the blast furnace will continue. The blast furnace is still today the most economic means to produce hot metal for steelmaking. Even with the use of increased pulverized coal and natural gas injection in many of today's large blast furnaces and with beneficiated burdens, the need for high coke strength, high coke CSR (coke strength after reaction) and stabilized coke continues. The use of lower grade raw materials such as low grade coals has become more widespread, but increased blending of these materials will be a challenge. Maximizing coke production without building new facilities continues to be a goal by many cokemakers. With aging facilities, coal blend design and testing is most important to ensure safe coal blend contraction and acceptable wall and gas pressures for a given facility. The availability of traditional metallurgical coals is becoming tighter as the coal industry restructures and the coal seams that were historically readily available and easier to mine disappear.

Extending coke oven life is paramount. Maintenance and repair strategies and operational practices need to evolve to meet the new challenges battery operators face today. Instrumentation and controls need to be developed to ensure the correct amount of coal is charged, heated and pushed in the most cost effective way. Incorporation of existing or future automation developments needs to continue so that this technology is affordable to allow for extended battery life with high quality coke being produced.

With the new non-recovery cokemaking facilities that exist, a different type of research is needed to maximize their production, oven life and energy recovery levels. Questions exist as to whether lower grade coals can be utilized in higher percentages, whether briquetting can also be incorporated to advantage, and whether energy recovery can be maximized.

Cokemaking research and development needs and opportunities

- Sealed, continuous coking process - Scope 21 – no others on the horizon
- Cost-effective dry coke quenching and dust collection systems
- New cokemaking processes to produce valuable, environmentally friendly by-products
- Ways to extend life of existing coke plants
- Improved process control
- Ability to use non-coking coals and low value carbonaceous material
- Improved refractories and refractory repair technology
- Particulate matter, mercury, nitrogen oxide, and sulfur controls
- Methods to produce stronger coke
- Upgraded value of coke oven by-products
- Development of comprehensive economic models incorporating coal and battery operating parameters
- Energy recovery technology
- Use of bio-based carbon in the coal blend for carbon dioxide reduction

New cokemaking processes are needed to shift the by-product compositions to more valuable products. The off- gas from a coke plant could be used to produce direct reduced iron or serve as a feedstock for chemical processes. Also, technologies for extending the lives of existing coke plants should be developed.

On-line data collection is required to optimize process sequencing for the highest possible energy efficiency and lowest cost coke production. The operation of conventional by-product plants or syngas-producing plants could be improved with the implementation of modern distributed control systems. However, research is needed to develop plant simulations and sophisticated control algorithms.

The industry needs to take advantage of the availability of low value carbonaceous materials. Increased utilization of contracting coals will lead to less wall pressure, resulting in increased oven life and higher productivity. The practice of using low-value carbon materials such as petroleum coke, coke breeze, coal fines, coal tar, and non-coking coals should be adopted to lower operating costs.

Comprehensive economic models need to be developed to encompass coal quality and coke oven operating parameters and maximum use of low-value carbon materials.

Energy recovery cokemaking is becoming the standard for environmental and energy efficiencies. Greater emphasis on research in this area needs to be encouraged.

In the future, the use of bio-based carbon needs to be addressed for achieving carbon dioxide reduction in cokemaking to address growing climate change concerns while maintaining or improving coke quality.