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The Effects of The Clean Air Act Amendment of 1990 on The U.S. Coke and Steel Industry and Foreign Trade Balance

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

Btu	British thermal unit	in^3	cubic inch
ft	foot	lb	pound
g	gallon	NT	net ton
in	inch	tpd	ton per day

THE EFFECTS OF THE CLEAN AIR ACT AMENDMENT OF 1990 ON THE U.S. COKE AND STEEL INDUSTRY AND FOREIGN TRADE BALANCE

By A. T. Peters[1]

ABSTRACT

This report contains information on the following: the technology of production of coke; pollution controls used in cokemaking; usage of coke in the production of iron, and of iron or steel; and limitations of the emerging methods of production of iron or steel without coke. The probable effects of the Clean Air Act Amendment of 1990 on the production of coke in the United States resulting from the shutdown of several cokemaking plants by integrated steel producers in 1993-1995 or 2003 are addressed. Three options for replacing the resulting coke shortage are presented: 1) Importing coke; 2) importing coke from facilities jointly owned abroad with foreign coke producers; and 3) importing semifinished steel. Probable costs of these options are given. Effects of the act on costs of steel production in electric arc furnaces (minimills and high alloy steels) and loss of coke byproducts and of jobs are also included.

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EXECUTIVE SUMMARY

The objective of this study is to estimate the effects of the Clean Air Act Amendment of 1990 on the coke industry, and in turn the steel industry, especially in terms of its effect on the U.S. trade balance. It deals almost exclusively with the "integrated steel producers," producers of sheet and strip, coated or uncoated, which account for about 60% of U.S. steel production.

The role of coke in the production of iron for steelmaking is described first. The very limited possibilities of making iron, or steel, without coke are mentioned as well. Assuming the present level of steel production for flat products to remain unchanged for the next 12 years, the amount of iron and thus coke needed is calculated. Some details are shown in tables 1 and 2.

After allowing for closures of older batteries which could not be economically upgraded to the emission limits specified in the act, it appears that the coke shortage will be 6 to 7 million tons per year. Three scenarios for replacing this shortfall are considered:

1. Importing all the coke deficiency; this could cost $950 million in 1993-95 and more than $1 billion in 1998;
2. Establishing equally shared joint ventures with foreign coke producers abroad, with one-half of the coke imports coming from these ventures; this would reduce the costs of imports to $810 and $945 million in 1993-95 and 1998, respectively, but at a cost of capital outflow of $600 million (plus about $50 million in 1998);
3. Abandoning not only some coke batteries, but also some blast furnaces and, because of the lack of iron, closing down some steelmaking capacity. The needed steel is assumed to be purchased abroad as semifinished sections for finishing in the United States. This could cost as much as $3 billion in 1993-95 and $3.5 billion in 1998. The domestic savings due to the closures could partly compensate for the expense but not in terms of the dollars exported. Details are shown in table 6.

The relative proportions of these three solutions are impossible to predict: each steel mill has its own problems and expectations. Lack of sufficient capital recovery because aging blast furnaces and steelmaking shops and casters are fully depreciated would tend to promote the steel import option. Participation in foreign steel mills in countries with heavy foreign debts (e.g., Brazil) is even a possibility.

Other items relevant to the subject, such as loss of coke oven byproducts (chemicals), loss of jobs and tax base, the existence of imponderable but significant human factors, etc., are noted but not evaluated.

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COALS AND COKE

The main constituent of coal is carbon, a major source of energy when it combines with oxygen to burn. This affinity for oxygen is also utilized in the production of some metals from their oxides. For instance, carbon is used to remove oxygen from iron oxides in iron ores in their various forms, resulting in the production of crude, liquid iron. In all of these smelting processes, a part of the carbon produces heat and the remainder is for the reduction of the oxide in question to produce the metal.

Two characteristics of coals make them unsuitable for direct use in ironmaking in a blast furnace. Low crushing strength puts a limit on the height of the charge. A modern, high-output blast furnace is at least 100 feet tall. Low porosity of coal makes passage of gases, oxygen needed for combustion and resulting carbon monoxide, which converts the iron oxide to iron, very difficult. Furthermore, coals when burned emit large amounts of soot, tars, vapors of chemicals, etc. that would choke a blast furnace. Also, the heat conductivity of coal is very poor.

Many, but not all, coals can be converted into a strong, porous useful form by subjecting them to coking. **Coking is a process of high-temperature dry distillation of coal in**

the absence of air. The normal coking temperature for metallurgical coke reaches 2,000° F (1,090° C). The carbonaceous matrix is retained but almost all of the impurities are driven off, most as useful byproducts.

Coke is the only practical reductant that can make liquid iron suitable for conversion to steel in basic oxygen furnaces. Theoretically, other substances that readily react with oxygen, such as magnesium or aluminum could be used. The cost of the iron would increase at least a hundredfold, if the technology were even in existence.

As mentioned, not all coals give strong coke. Only some of the bituminous type are usable. The reserves of such coals are estimated to be 250 to 300 billion tons in the United States, several hundred years' supply.

THE COKE PLANT AND ITS OPERATION

All coke oven designs are limited by the undesirable coal characteristics: its low crushing strength puts a limit on oven height, and its low heat conductivity limits the oven width. As a result, most ovens are only 18 inches wide, because the heat penetration rate, which controls the coking rate, is only about 1/2 inch per hour from each side. The height is not more than 20 feet (6 meters). Length is usually 40 to 50 feet. Both ends of each oven are closed by doors.

These slotlike ovens are heated externally because admission of air would result in part of the coal burning. The old so-called beehive oven used internal combustion with resulting lower coke yield and loss of byproducts. A modern version of the beehive ovens will be discussed later.

Ovens are grouped into batteries, 40 to 80 ovens each, with heating flues between each oven. These heating chambers are generally fired with coke oven gas. A few use coke oven/blast furnace gas mixes. Hence each battery consists of a number of coking ovens and heating flues in an alternating pattern. Production of coke is not only self-sufficient in regard to energy, but gives an excess of combustible gas (and other valuable byproducts).

Typical sizes of large modern, and smaller, older ovens, and their production and coal charges per day, are:

	Oven dimensions	Battery coke production, tpd[2]	Battery coal charge, tpd
Large ovens:	20 ft by 50 ft by 18 in	2,200 to 2,700	3,400 to 4,000
Small ovens:	14 ft by 45 ft by 16 in	500 to 1,000	800 to 1,500

Ovens more than 5 meters (16 1/2 ft) tall are called "tall ovens."

[2]Tons per day. All tonnages in this report are short tons.

Typical operation of a coke battery is as follows:

A charging car traveling on the battery top positions itself over an empty oven with its doors closed, removes the three to four lids covering the charging holes and dumps the coal into the oven, which during this time is under increased draft into the flues caused by steam injection applied to minimize pollution. The lids are replaced. Some pollution is released at this stage, because the chilling of the hot lids when they are removed results in some poor fits and cracks.

Because the coal is heated from both sides and the heat penetration rate to reach the required 1,800° to 2,000° F is only 1/2 inch per hour on each side, 18 hours is required to coke through the charge. Then the front and back doors are opened and the glowing coke is pushed out by a ram acting through the "pushing" door into a waiting "quench car" on the exit door side.

It is at this point that some pollutants are emitted. Despite the use of sleeves around the pushing ram, coke guides from the exit side of the oven, and a covered quench car with a traveling hood, some emissions escape. The quench car moves under a covered water quench station and a measured amount of water is sprayed on the glowing coke, stopping any further coking or burning. Then the coke is discharged on a sloping ramp and finally taken directly to ground storage or blast furnace.

The door edges and oven jambs are cleaned by machine or hand. Then the doors are placed in position, luted with clays, plastics, sodium silicate ("water glass"), etc. The next coal charge is dumped into the oven, and the process is repeated. New type self-sealing doors do not need luting.

Doors represent a major problem. Although they are usually spring loaded for tight fit and tend to be sealed by tars generated in the oven, they tend to warp despite the use of heat-resisting materials. The reason is the distortion caused by the sudden cooling whenever a door, red hot on its inside, is opened. Much work has been done on door design and the degree of pollution was much reduced but leakages of some doors are still far above the levels specified in the new regulations. Coke quenching is another problem point.

Coke Plant Products

One ton of coking coal typically yields:

Coke	1,200 to 1,400 lb (60% to 70% yield)
Coke breeze (fines)	100 to 200 lb
Coke oven gas (calorific value approximately 500 Btu/ft^3 or one-half that of natural gas)	9,500 to 11,500 ft^3
Tar	6 to 10 g
Ammonium sulfate or	20 to 28 lb
Ammoniacal liquor	15 to 35 g
Light oils	2 to 4 g

The coke is used for ironmaking in blast furnaces; the breeze is burnt or sold; coke oven gas is used for underfiring ovens and reheating of steel. Tars are sometimes burnt but more often they are refined into numerous chemicals such as pitch, naphthalene, creosote, pyridine, acids, etc. Ammonium sulfate is a nitrogen-bearing fertilizer and ammoniacal liquor is usually also converted into some form of fertilizer. Light oils are the source of benzene, toluene, naphthas and other solvents, and chemicals.

Nonpolluting Coke Battery

There exists a design, really a throwback to 19th century technology, that is claimed to be nonpolluting. The design, known as the Jewell version of Thompson nonrecovery coke ovens, is specifically mentioned in the Clean Air Act with an instruction to the EPA to evaluate it and consider it as a standard for new coke ovens.

One such battery is operating in the United States, in Virginia. In late 1990, one major steel producer, Inland Steel Co., announced a joint venture with the Sun Coal Co., owner of the technology, to build such batteries in its Indiana Harbor, IN, steel mill.

The term "nonrecovery" refers to the fact that no byproducts are recovered. All the gases and chemicals evolved from the coal during coking are burnt in and swept out of the oven by suction applied in the exhaust stack. The resulting negative pressure inside the oven prevents any escape of pollutants. There is also no dirty process water to handle.

The final exhaust passes through waste heat boilers to produce high pressure steam that is used to drive power-generating turbines. Although the process does not produce any useful gaseous byproducts, it recovers heat as a coproduct, ultimately in the form of electrical energy used by the mill, with excess sold to outside interests.

Inland announced that it expects to have the first battery operating in the mid-1990's and, pending the outcome of the trials, plans to convert all of its coke making operations to the new design. The initial capital costs are reputedly lower than those of a conventional battery, but the operating economics are not known yet. A severe problem may be the fact that the space required is several times that needed for a standard battery with equivalent output.

Coal Briquettes

Fabrication of coke-like briquettes from noncoking coals is being reinvestigated in coal-poor Japan. The process, in its several variants, was examined in the United States in the 1960's, under the trade name of Form Coke. Briquettes, which could replace up to 25% coke, were produced, but the multistage, complex chemical operation was not promising, especially for large blast furnaces.

USE OF COKE IN IRONMAKING AND OTHER APPLICATIONS

The overwhelming majority of coke is used in the production of raw iron in blast furnaces. Liquid iron is always called "hot metal" in steel mills. Coke consumption runs about one-half ton per ton of metal, a little less in large, modern furnaces, like three units built in the 1970's which together produce about 9 million tons of iron yearly, consuming about 950 lb coke per iron ton.

Typical production of iron in the United States is about 54 million tons per year, requiring about 27 million tons of coke. Some more precise calculations of coke needs in the near future will be presented later.

Some coke is used in iron foundries in their cupola furnaces in making cast iron. About 2 million tons of foundry coke is used for this purpose, but the coke desired is different from the blast furnace coke.

Other uses, in nonferrous metallurgy, production of ferroalloys, space heating, etc. are small. Most of these are satisfied by coke breeze, small-sized coke particles that are normally screened out of the coke and sold as a byproduct. Coke capacity numbers disregard this fraction. Much breeze is exported.

Coal Injection Into Blast Furnaces

A technique well developed in Europe is the injection of coal dust into the air blast. Ground noncoking coals are used and up to 25% or even 30% of coke can be replaced by the injection.

The owners of the three mentioned large blast furnaces have announced their intention to install the coal grinding, screening, and injection machinery. Many less efficient blast furnaces will probably follow the same route once the practice is well established.

Costs of such an installation are not well defined. A sum of $25 to $30 million per large blast furnace was loosely mentioned. Operating costs may be fairly high in terms of maintenance; the unknown material cost would depend on the cost difference between the coke used and coal ground.

A version of coal injection has been used by Armco Inc. since the 1960's, but it did not become popular.

REFINING OF IRON INTO STEEL

Because of the intimate mixture of glowing coke with the iron ore particles, the liquid iron becomes saturated with carbon, carrying from 4% to 5% C, and also some impurities originating from the gangue in the ore, mainly silicon, sulfur, and phosphorus.

However, steel is, by definition, an alloy of iron with 0.02% to 1.7% (0.9% in practice) of carbon. Thus the large excess of carbon must be removed in the process of steel production. **Steelmaking is a process of controlled oxidation while ironmaking is a process of controlled reduction of oxides**. Hence these diametrically opposite processes cannot be carried out in one vessel.

Modern practice consists of removing the excess carbon from a charge consisting mainly of liquid iron by a blast of oxygen blown into the metal at supersonic speed. This is the Basic Oxygen Furnace (BOF), carrying out the Basic Oxygen Process (BOP), that is the mainstay of U.S. and world steel production. The term "basic" refers to the chemical character of the furnace linings, not to some economic or planning feature.

The BOF also consumes mill return scrap (process or circulating scrap) and some purchased scrap, but the thermochemistry of the BOF process is rather delicate, resulting in a narrow band of possible steelmaking charges. The process is very "charge inflexible."

This is the result of the carbon burnout producing large amounts of heat, which raises the temperature of the charge from around 2,500° F (1,370° C) of the hot metal to the 2,900° to 3,050° F (1,590° to 1,680° C) required at tap. The temperature would go much higher, to the point of destruction of the furnace, except for the cooling effect of the scrap.

As a result of the charge inflexibility, BOF's must charge, depending on the chemistry and temperature of the hot metal and properties of the steel desired, from about 75% up to 88% of hot metal. A BOF is a voracious hot metal eater. In a typical year the United States produces up to 60 million tons of BOF steel, consuming about 54 million tons of hot metal.

Due to the recent wide adoption of vacuum degassing and continuous casting to obtain improved steel quality, the steel temperature required at tap shows an upward trend. Such an increase can be realized best by increasing the hot metal charge. Thus in recent practices **1 ton of BOF steel requires 0.9 ton of hot metal**, which requires nearly 0.5 ton of coke.

Hot Metal Substitutes

It is possible to stretch a temporary shortage of hot metal by charging into the BOF, in place of 10% to 15% of hot metal, some materials that react exothermically (produce heat) in the furnace, and a corresponding amount of scrap (a BOF must be filled to nominal capacity to operate reliably). These materials are all expensive, and they introduce a number of metallurgical quality problems and severe operating complications. Hot metal extenders include scrap aluminum, scrap plastics, low-grade ferrosilicon, calcium carbide, etc. None of these is routinely used, and no planning should make allowance for their use.

Widely advertised European trials of operating BOF's with as little as 50% hot metal, the balance scrap, using supplemental gas or oil firing, were quietly abandoned. Two U.S. shops that put in supplemental heating equipment took it out after prolonged trials showed severe impact on steel quality and furnace lining erosion.

Methods of Production of Iron or Steel Without Coke

Two processes should be considered because they produce liquid iron or liquid steel without the use of coke. These are the Corex process and the Direct Steelmaking process. Steel made in electric arc furnaces uses only iron and steel scrap as its raw material.

The Corex process was developed in South Africa because of the advanced age of the existing coke batteries and paucity of coking coals. It is operating there at a rate of approximately 330,000 tons per year (tpy). The reducing agent is ground coal.

The inventors, the Austrian firm Voest Alpine, stated that they plan to expand the operation to 500,000 tons but did not sound optimistic regarding further upscaling. Hence, this is not a scale that would interest major U.S. steelmakers, but it may be useful for a minimill producing flat products.

A major problem of the Corex is its high capital cost, in the order of $300 per yearly ton, which translates to $150 million for a relatively small, 500,000 tpy, installation. Corex is unique in that it produces an excess of combustible gas of fairly high quality. If this energy can be used at or near the site, the operating cost may be similar to the current cost of producing hot metal or even lower; if the gas has to be flared, the economics become quite unattractive.

It seems reasonable to assume that, within the next 10 years, some future minimill making flat products will install a Corex plant. Perhaps one integrated producer would erect one as well.

The second process is the Direct Steelmaking process, which is presently being developed as a joint effort of eight U.S. steelmakers by the American Iron and Steel Institute (AISI) largely with funding by the Department of Energy (DOE). The idea is to reduce iron ore pellets with ground coal in one vessel and transfer the resulting hot metal to another vessel. There, injection of oxygen would remove most of the carbon dissolved in the metal and generate an excess of reducing gases which would be directed back to the reduction vessel, making the process self-sufficient in energy. Upscaling the process to a point that it would become interesting to major integrated steel producers is probably 10 years away. The economics of the process are unknown, but it is certain that the ore pellets have to be prereduced, partially removing the oxygen from the iron oxides and the steel refined in another furnace. This may result in unfavorable economics, especially since going much beyond 1 million tpy is not yet even planned. Replacing one blast furnace with three or four Direct Steelmaking units may not be attractive at all. For the purpose of this study, it may be assumed that by the year 2003 one semidemonstration plant of 1 million tons yearly capacity will be in operation.

A number of Japanese corporations are vigorously working on a similar joint project. Again, for the purpose of this study, it may be assumed that they are probably ahead in their development and may sell a license to a steelmaker, perhaps by 1998. Again, it would be realistic to expect a 1-million-ton plant.

Until recently, production of flat products steel in electric arc furnaces was regarded as impractical. These furnaces are charged with scrap, which contains many undesirable impurities (copper, chromium, etc.), which cannot be removed from the steel; substitution of so-called Direct Reduced Iron (solid iron produced from high-purity ores) for part of the charge reduced this problem.

The second barrier to production of flat products by minimills was the high initial cost of the rolling mills, more than $1,000 per ton yearly capacity. Recent development of the "thin slab continuous casting" process put the cost of a limited flat products operation (hot rolled products only) within the reach of some financially strong minimills. Nucor Corp. spent only $350 per steel ton in 1989 constructing the 0.8-million-ton Crawfordsville, IN, works. Plans to erect another similar plant were announced by Nucor in late 1990.

Future Coke Requirements for Steelmaking

Using the data and assumptions presented thus far, an estimate can be made of coke required for the production of iron and then steel. Unit consumptions are presented in table 1. Total consumption for the years critical to the coke plants from the standpoint of the requirements of the Clean Air Act is shown in table 2.

Table 1.—Unit consumption of coke in the production of iron and steel (Million short tons)

	1985	1986	1987	1988	1989
Coke consumed in blast furnance	25.6	22.3	25.5	29.4	29.2
Iron made	50.4	44.0	48.4	55.7	55.9
Coke unit consumption, tons/ton iron	.508	.507	.527	.528	.523
Steel made:					
Basic open hearth furnaces	6.4	3.3	2.7	5.1	4.4
Basic Oxygen Furnaces	51.9	47.9	52.5	58.0	58.3
Iron consumed:					
Basic open hearth furnaces	3.6	1.9	1.5	2.9	2.5
Basic Oxygen Furnaces	45.9	41.4	45.9	51.9	52.8
Iron unit consumption, tons/ton BOF steel	.88	.86	.87	.89	.91
Coke unit consumption, tons/ton BOF steel	.45	.44	.46	.47	.48

To sum up the main findings (some already quoted)

From table 1:

1. Basic Oxygen Furnaces consume 0.9 ton of hot metal per ton of steel made.
2. One ton of hot metal requires a little more than one-half ton of coke;
3. Hence, 1 ton of BOF steel requires one-half ton of coke.

Table 2.—Estimated total coke demand for 60 million tons of raw steel from BOF's (for flat products), million short tons

	1995	1998	2003
Steel demand	60	60	60
Less: Flat products made by minimills	3	5	5
Less: Steel made from non-blast furnace iron	0	1	2
Net BOF steel for flat products	57	54	53
Total required iron	52	49	48
Iron made with:			
0.5 ton coke	41	25	16
0.4 ton coke[1]	10	24	32
Total coke demand	25	22	21
Less: Coke from independent producers	2	2	2
Coke needed	23	20	19

[1]Blast furnaces equipped with coal injection.

After allowing for the phaseout of the open hearth producers, for flat products steel made by minimills (whether from scrap or, partly, from Corex hot metal or some other source) and for steel made from some hot metal obtained not via the blast furnace, the coke required for the BOF share of raw steel at an assumed demand of 60 million tons per year will be 25 million tons in 1993, 22 in 1998 and 21 in 2003. No reasonable predictions regarding demand, production, or amendments to the Clean Air Act itself can be made for the more remote future.

THE CLEAN AIR ACT AMENDMENT OF 1990

The regulation of air pollution started with the Air Pollution Control Act of 1955. This was amended in 1960 and replaced by the Clean Air Act in 1963. This act was, in turn, amended and expanded in 1965, 1967, and finally, in 1970, concurrently with the establishment of the Environmental Protection Agency (EPA). The last revision was in 1977 and was in place until the version under discussion here that was passed in 1990.

The act has seven titles of which only the first is of major technological importance to the steel industry, with four subsequent titles having a lesser (or more serious, depending on the viewpoint) effect. The five titles of interest are:

1. Air toxics,
2. Acid rain,
3. Nonattainment areas,
4. Permits, and
5. Enforcement.

The air toxics title singles out the coke industry in great detail. Basically, it deals with existing coke batteries, but includes new, replacement batteries and rebuilt, up-graded ones.

The limits of emission of pollutants are expressed as maximum percentages of visually leaking oven openings. There is no differentiation between heavy and light leaks. This will be discussed later.

The act specifies three groups of controls:

1. Maximum Achievable Control Technology (MACT),
2. Lowest Achievable Emission Rate (LAER), and
3. An "ample margin of health safety," expressed as residual health risk-based standard (R).

It also mentions "work practice standards" especially use of sodium silicate for sealing doors.

The act gives the coke managers two options to achieve the new pollution maxima:

1. The MACT option.

The standards required, including a "work practices" standard if deemed desirable by the EPA, are to be established by December 31, 1992, and compliance secured by December 31, 1995. The standards cannot be more lenient than:

8% leaking doors maximum,
1% leaking lids,
5% leaking offtakes, and
16 seconds pollution emissions per charge.

Industry estimates indicate a 66% reduction of emissions in comparison with the performance mandated in 1970.

The standards are to be reviewed every 7 years by the EPA to determine whether increased stringency is warranted. The performance of the best 12% of batteries may be established as a standard after 1995.

The residual health risk standard is to be met by January 1, 2003.

This option is likely to be elected by companies planning to close their coke plants by 2003 or earlier for any reason.

2. The "extension track" option.

The compliance with the above-mentioned work practices is to be achieved by November 15, 1993; at the same time, the same leakage standards, as in the MACT, are to be published by December 31, 1992 (together with the MACT standards) and cannot be less stringent than:

3% leaking doors (5% for tall, more than 5-meter batteries) with some exclusion for just charged doors; and same other standards as in the MACT standard.

The visual estimate of leakages may be replaced by some mass emissions equivalent.

A new LAER standard is to be proclaimed by January 1, 1998. If the EPA does not establish one, the new standard will be:

3% leaking doors (5% for tall ovens) with no charging exclusion;
1% leaking lids,
4% leaking offtakes, and
16 seconds pollution emissions.

Reduction of emission from the 1970 standard is estimated to be 86%.

This standard must be complied with by January 1, 2010, but the LAER must be reviewed, reapproved, or tightened by January 1, 2007.

Finally, the undefined residual health risk standard must be met by January 1, 2020.

Probably in recognition of the nonexistence or vagueness of the standards, the act orders a number of supporting studies. However, one-half year after the act's enactment, in April 1991, no funds were actually appropriated for their execution.

The EPA is to study, jointly with the Department of Energy, the entire problem of controlling coke oven emissions; $30 million is envisaged for this study of 6-years duration.

The EPA itself is to evaluate the described earlier Jewell design of the Thompson nonrecovery, nonpolluting battery and other, unspecified technologies. It is to develop a better, visual standard of coke oven leakage and a nonsubjective, mass emission standard as well, to quantify the amount of pollution. At least 50% of the costs of these projects is to come from non-Federal sources. The act does not specify from where or how these contributions are to be obtained.

The at present undefined "residual risk health standard" is to be developed by a joint study involving the Surgeon General and the EPA; the National Academy of Sciences is to work out the risk assessment methodology.

Title II, which deals with "acid rain," has little application to coke. It may strongly affect the nonintegrated steel producers that use arc furnaces. This will be discussed later.

Title III deals with the 80 to 100 "nonattainment areas." As far as coke plants are concerned, this is a relatively minor problem, but the plants may be forced to install additional pollution controls as a result of excessive general pollution at their areas. Bans on further construction are also possible.

Title IV, "Permits," transfers the issuance of detailed operating permits to the States. From 1996, the permits will be issued for a maximum period of 5 years. The minimum fee schedule is stated, $25 per yearly ton of regulated emissions (except carbon monoxide), but no maximum is given.

The "Enforcement" title specifies civil and criminal penalties for noncompliance, including the crime of false recordkeeping. In cases of doubt, a violation is presumed to exist. A bounty, not to exceed $10,000 per informant per case is specified, as are administrative penalties, $25,000 per day; field citations, $5,000 per day, etc.

None of the features of the entire act have been tested in court. Transferring direct administration of the act to the States as provided for in the act may result in a perplexing variety of rules, fees, and regulations. Furthermore, the act authorizes States and even localities to pass standards stricter than those specified in the Federal act.

Some possible consequences of the act should be pointed out:

1. By specifying the existence, but not the severity (at present impossible to define clearly) of leaks, the act may actually result in increased pollution: a manager, staying within the permitted percentages, may disregard a real "gusher" in favor of an easier to seal light leak;

2. The compression of the standards-setting process into only 2 years, may not allow enough time for proper development of standards by cooperation of the industry with the EPA—risking a spate of court actions.

3. The timing of the compliance dates, coupled with the uncertainty of regulations caused by the periodic reviews of the rules by the EPA and the periodic reissuance of permits by the States, and perhaps even localities, could present complex difficulties for the industry in attempting to comply with the act. Planning of a new coke battery requires about 5 years from inception to startup; many modifications must be developed, a process that easily could take 3 or more years. Managers are not likely to commit millions of dollars if facing the possibility of having to spend more or write off their investment, after 5 or 7 years. This situation would be alleviated if the permit issuance cycle and standards review cycle coincided. The Internal Revenue Service was not instructed in the act to provide for rapid writeoff of the necessary investments or residual values of undepreciated installations, which might have to be closed as a result of the impracticability of complying with some present or future regulation.

4. The act also does not address directly the complex question of air sampling and chemical determination of mass emission of contaminants implied in the future limits based on health risks. It is well known that aspiration of air into any sampling device is strongly dependent on very many outside factors, such as distance from the source, ambient air temperature and air movements (combined

effects of wind and natural convection, etc.), strength and pulsation of suction, etc. The accuracy of chemical analyses at the parts per million level is seldom good. At parts per billion, the variability within chemical analyses (on repetitive analysis of fractions of the same sample) and among chemists themselves may exceed the total content of the substance under analysis.

The American Iron and Steel Institute (AISI), representing the integrated steel producers, and the American Coke and Coal Chemicals Institute, cooperate with the EPA on the visual emissions grading, qualification of emissions and the door sealing work practices studies.

STRUCTURE AND AGE OF THE INDUSTRY

The description of the uses of coke indicates that the great majority of coke plants belong to the steel companies. These plants are at the ironmaking and steelmaking sites. The output of these captive batteries is commonly often supplemented by imported coke or coke bought from independent producers.

The age of the industry is considerable. Nearly 30% of all batteries are already more than 30 years old. Data from AISI updated for one closure in the first quarter of 1991 are shown in table 3.

Table 3.—Age and capacity of steelmaking coke batteries, in 1991

Age, years	Number of batteries	Capacity (million tons)	%
5 or less	2	0.6	2.4
6 to 10	9	5.0	19.9
11 to 15	14	8.5	33.9
16 to 20	3	1.6	6.4
21 to 25	2	.5	2.0
26 to 30	4	1.6	6.4
31 to 35	12	3.1	12.3
More than 35	19	4.2	16.7
Total	65	25.1	100.0

Average capacity per battery 0.39 million tons
Average capacity per battery built after 1970 0.51 million tons

Assuming a coke yield of 65%, about 39 million tons of coal is required at full capacity utilization.

The average age is close to 22 years, while 30 or 35 years is regarded as the limit of productive coke battery life. This does not compare well with that of several countries. A study by the International Iron and Steel Institute showed Finland, Taiwan, Korea, Pakistan, and Zimbabwe with an average age of batteries of less than 10 years; India, Brazil, Colombia, and the Netherlands were not far behind. The extent and enforcement of pollution controls in these countries, with the exception of Finland and the Netherlands, is minimal.

In the past few years, the United States imported coke from Japan, Canada, Italy, Belgium, and Yugoslavia, plus small amounts from many more countries. Some details are shown in the appendix. No doubt there could be many candidates to ship coke to the United States, using, if desired, U.S. coals. This has happened in the past.

THE INDEPENDENT (MERCHANT) COKE INDUSTRY

The part of the industry that is not owned by steel companies, usually called the independent or merchant coke producers, consists of 13 batteries with a combined capacity of approximately 4 million tons per year. About 1 1/2 to 2 million tons is consumed by iron foundries, and the balance made to blast furnace standards is sold to blast furnace operators. Foundry coke is not suitable for blast furnaces.

Most of these batteries are old. However, age is not a strong criterion of a foundry coke battery's usefulness because the operating conditions of the ovens are much more lenient than those of the steel mill coke plants. The coking temperature is lower, the kind of coal less destructive to oven walls, and the ovens are lower, usually not more than 4 meters (12 feet) tall, consequently with much smaller door distortion, etc. Thus, meeting a criterion of 5% leaking doors is not difficult and 3% is probably attainable with moderate trouble and expense.

According to the information from the American Coke and Coal Chemicals Institute, a majority of the existing batteries, perhaps 80%, will be adapted to the 1993 or 1995 conditions. Hence, it can be assumed that little if any change will occur in the deliveries of coke, approximately 2 million tons per year, to the present steel mill customers up to the year 2003 and possibly beyond. Apart from making a suitable allowance in the expected coke usage in the future, the independent industry will not be considered any further.

PROSPECTS OF THE STEEL CAPTIVE INDUSTRY

From table 3 it is possible to predict the status of the industry either for 1993 or 1995, but the period between these 2 years is uncertain. This is because of the existence of the two options regarding meeting the MACT standards: managers confident of meeting the tougher, LAER standard in 1998 and running their batteries beyond that year must meet MACT by 1993; those expecting to shut down in 2003 when the so far undefined Risk standard will apply to their operations have until 1995 to meet the MACT levels. It is assumed that batteries built before the Clean Air Act of 1970, older than 25 years in 1995, will be closed at the latest by 1995. Two replacement batteries, presumably built to LAER standards, will have been built by 1995 or shortly thereafter. This information is summarized in table 4.

Table 4.—Age and capacity of steelmaking coke batteries after 1993-95

Age, years	Number of batteries	Capacity (million tons)	%
5 or less	2	1.2	7.1
6 to 10	2	0.6	3.6
11 to 15	9	5.0	29.6
16 to 20	14	8.5	50.2
21 to 25	3	1.6	9.5
Total	30	16.9	100.0

About 26 million tons of coking coal will be needed for this 16.9 million tons of coke.

Estimates of the situation after 1998, the LAER year, are very uncertain because of the probable construction of some batteries of the nonpolluting type. An estimate of the situation after 1998 is shown in table 5.

Table 5.—Age and estimated capacity of steelmaking coke batteries after 1998

Age, years		Number of batteries	Capacity (million tons)	%
5 or less	(new batteries)	8	[1]5.0	38.5
6 to 10	(new nonpolluting batteries)	4	3.0	23.0
	(upgraded batteries)	8	5.0	38.5
Total		20	13.0	100.0

[1]Estimate by AISI.

NOTE.—After 1998, the coal requirement drops to 20 million tons.

COST OF CONSTRUCTION AND UPGRADING OF BATTERIES

The cost of building a large battery "from scratch" in the United States is estimated at $250 to $300 per ton of annual capacity; the practical limit of battery size is at the most 1.0 million tons per year. The cost abroad is lower, due to lower engineering and construction costs and lower levels of pollution controls. The cost of a nonrecovery battery is reputedly $200 to $240 per ton.

Costs of rebuilding or upgrading of coke batteries are quite variable because of the different degrees of work to be done, age of the battery, site specifics, etc. In 1987 (Federal Register, April 23, 1987), EPA estimated the cost of compliance to reach the 5% maximum-leaking-doors-standard to be $3 to $40 million per battery. This, on the one hand, may be an understatement because no allowance seems to have been made for spare doors and for the frequent warping of doors in the newer, tall batteries; on the other hand, it may be an overstatement because it seems very unlikely that a company would decide to spend $40 million for an older, less productive battery with not many productive years left.

Unpublished data from the AISI indicate that the cost of meeting the MACT standard of 8% leaking doors would require the replacement of all doors and door jambs on all except the newest batteries for an estimated average cost of $10 million per battery. The AISI seems to have accepted the EPA estimate regarding the 5% standard, but meeting a possible 3% limitation would cause the closure of all batteries more than 30 years old, to be replaced at at least $250 million each, and rebuilding others at a cost of about $100 million per battery. Most steel companies would probably find such expenditures unacceptable.

At present, pollution controls add about $8 to $10 per ton to the cost of steel; adoption of the initial, MACT standard would raise this to at least $15, depending on the situation and plans of individual producers.

EFFECTS OF THE ACT ON NONINTEGRATED STEEL PRODUCERS

The foregoing discussion is centered upon coke plants, i.e., the integrated steel producers, which usually make about 60% of the total steel production. However, the effects of the act on the balance of the steel production in the United States should not be overlooked, although numerical predictions of its consequences are even more difficult to make than those for the coke based producers.

Title II of the act deals mainly with "acid rain" which largely originates from power stations, especially those in the Midwest, which burn high-sulfur coals. Many plants in the South and East are also involved to different degrees.

By prohibiting any significant sulfur escape from the power stations, the act, in fact, forces these plants to install expensive scrubbers (or, what seems unlikely, import coal from other sources). The costs of erection and operation of this equipment will vary widely, depending on the sulfur load to be removed.

Unfortunately, sharp variations in the power tariff structures of steelmakers that use electric arc furnaces (i.e., those of minimills and special steel producers) make the determination of the impact of these changes almost impossible. If the affected powerplant costs were increased by 10% to 15% as estimated by various sources, a similar rise in tariffs should be expected. Since the power cost fraction of minimills is about 30% of the total, and of special steel producers 15% to 20%, the cost, thus final steel price increases, would be of the order of 3% to 4% (approximately $10/ton) for minimills and 2% for the makers of stainless and other special steels (about $25 to $30 per ton). In the case of the minimills, this is a major cost increase, exceeding the recent profit margins.

OTHER EFFECTS OF THE ACT ON THE STEEL INDUSTRY

The overall influence of the act on the steel industry is almost impossible to judge; it lists 189 substances to be controlled with probably more to be added to this list. The effects of the clean water acts and many other environmental laws, Federal, State, and local, are not discussed here.

The effects on industry's powerplants fired by coal will be similar to those discussed earlier; in any case, cost of purchased power will increase.

Emissions from steel reheating furnaces, boilers, etc. will probably be handled by improved but basically known technology. Operation of the improved devices will be costly in terms of electrical power and will shift the burden of pollution controls on the power stations.

REPLACEMENT OF THE COKE SHORTFALL

At least three scenarios should be considered:

1. The case of all the shortfall of coke being imported on a contract basis without coke plant ownership;
2. Assuring deliveries by entering into joint ventures operating outside the United States, with foreign producers, probably on a 50% contract basis; thus, all of the shortfall would still be imported, but 50% of it would be from joint venture operations at a reduced cost.
3. Importing semifinished steel. In order to secure continuity of supply, making investments in steel companies of countries in strong need of dollars to repay their large debts, especially Brazil, seems to be possible. This would be attractive to companies with old, fully or nearly depreciated blast furnaces and steelmaking furnaces and casters, which contribute little to the company cash-flow.

Moving the capacity abroad relieves the manager of uncertainties due to changing Federal and State rules and regulations and their interpretations, inspections by the EPA, OSHA, union representatives, etc. and possible litigations.

Consequently, there will be a tendency toward moving the operations abroad, although the final decision will be made mainly on the basis of the ratio of the cost of domestic (in steel mill) coke versus its cost delivered from abroad.

Foreign producers are well aware of our coke costs, and the prices of good quality coke do not lag far behind our costs (poorer quality coke from countries in need of hard currency, such as Mexico, may be significantly cheaper but seldom desirable). An assumption of $150 per ton delivered, in 1991 dollars, seems reasonable, when importing 6 to 7 million tons against about $120 for the 2 to 3 million tons imported now. The price difference is simply the consequence of increased demand. On this basis, and assuming the capital cost of 50% ownership of foreign batteries to be $100 per ton, a table of probable dollar outflows was constructed (table 6).

Table 6.—Probable cost (in 1991 dollars) of replacement of the coke shortfall

	1993-95	1998	2003
Coke demand, million tons (table 2)	23	20	19
Coke production million tons (tables 4 and 5)[1]	17	13	13
Coke shortfall, million tons	6	7	6
Scenario 1:			
All coke imported, $150/NT; million dollars	900	1,050	As in 1993-95
Scenario 2:			
One-half coke imported, $150/NT	450	525	As in 1993-95
One-half coke imported, $120/NT[2]	360	420	As in 1993-95
Total	810	945	
Capital cost			
Outflow million dollars	600	[3]50	As in 1993-95
Scenario 3:			
Semifinished steel imported tons coke/ton BOF steel (table 1)	0.5	0.5	As in 1993-95
Steel equivalent, million tons	12	14	As in 1993-95
Semifinished Steel cost, million Average $250/NT	3,000	3,500	As in 1993-95

[1]Assumes production at capacity.
[2]From joint ventures; the $30 difference allows for the dividend.
[3]Additional.

Although an expenditure of $3 or $3.5 billion by the steel industry for semifinished steel may appear prohibitive, in actual practice it may be very attractive because it could replace, possibly even more than replace, the costs of making coke and iron, refining it into steel and casting.

In addition to the coke batteries, older, less efficient blast furnaces, basic oxygen steelmaking shop and continuous casters could be shut down. Hence, there would be an additional loss of jobs and tax base.

The desirability of importing semifinished steel was demonstrated during the period 1986-88 when steel plants had to import "semis" to keep up with the swollen order books. The steel was of good or very good quality and the prices, delivered, in general at or slightly below U.S. manufacturing costs.

LOSS OF BYPRODUCTS

The magnitude of the loss of byproducts due to the shrinking of the industry can be roughly estimated from the amounts of coal coked and the average yields of byproducts, as shown earlier. Table 7 shows the probable losses using 1990-91 as the comparison base. The drop of coking coal consumption is 13 million tons in 1993-95 and 19 million in 2003.

Table 7.—Estimated loss of byproducts

Byproduct	Average byproduct	Loss in	
	Yield	1993-95	2003
Coke breeze	150 lb	0.7 million tons	1.1 million tons.
Gas	10,000 ft^3	97 billion ft^3	142 billion ft^3.
Tar	8 gal	78 million g	114 million g.
Ammonium sulfate	24 lb	117,000 tons	171,000 tons.
Light oils	3 gal	29 million g	43 million g.

Determination of the cost of replacing these materials or of export sales lost is beyond the scope of this study.

The coke breeze will probably be replaced with coal fines or oil and gas.

The coke oven gas used by steel mills to heat in-process steel will be replaced with oil and gas. Coal is far too dirty a fuel and its flame temperature too low for this application.

Tar and light oils and the resulting chemicals will be lost to the chemical industry. Perhaps they could be synthesized or may have to be imported.

The ammonium sulfate would probably also be synthesized, replaced by other fertilizers, or imported. Loss of the ammoniacal liquor could be a small gain because the cost of its disposal is high.

LOSS OF JOBS

At present, the coke industry employs approximately 15,000 persons, and approximately 7,000 miners are mining the coal. About one-third of these jobs will be eliminated. If scenario 3 fully materialized, 5 to 8 steelmaking shops and continuous casters would be closed with a loss of 2,000 to 4,000 jobs.

TRANSFER OF POLLUTION

The countries which would supply the coke have few pollution controls, and these are often not strongly enforced, maintenance of jobs being regarded abroad as of much greater importance than ecology. Hence, transferring coke production abroad will export the coke oven pollution that exists at the present in the United States in a much magnified form.

LIMITATIONS OF THIS STUDY

The entire study presented here is merely a set of estimates: the author attempted to predict the action of integrated steel companies, with the corresponding array of local costs and problems. At least three options for corrective action appear to be possible, but other, unforeseen circumstances may result in some other solutions in some specific cases, including a company going out of business, or eliminating steel production altogether and becoming a reroller of imported semifinished steel. Such cases are impossible to predict and allow for.

The trends will also be strongly influenced by the severity of the implementation rules and even by the outcome of the joint EPA/Department of Energy and EPA/industry studies of methods of determining the degree of pollution, and its avoidance, mandated in the act. Some arbitrary decisions may be made by Federal or State authorities to the benefit or detriment of the industry. The possibility of a State or locality requiring standards that exceed those of the act was already mentioned.

The Clean Air Act will result in a heavy outflow of dollars from the country, transfer of air pollution abroad, elimination of a number of jobs, and erosion of the tax base. The cost/benefit ratio of the act appears, in the author's opinion, to be very high.

APPENDIX.—COKING COAL AND COKE FOREIGN TRADE TRENDS

The 10-year trends of exports of coking coal, exports and imports of coke, and yearend stock positions are apparent from the summary of data shown in the Quarterly Coal Report, issued by the Energy Information Administration; all data are in thousand short tons:

Year	Steel production[1]	Coke		Stock at yearend	
		Imports	Exports[2]	1,000 tons	As % consumption
1980	80,679	659	2,071	8,627	20.9
1981	86,683	527	1,170	7,586	17.2
1982	51,419	120	993	8,190	31.2
1983	58,001	35	665	3,518	11.8
1984	61,158	582	1,045	3,716	12.4
1985	58,313	578	1,122	2,553	8.7
1986	51,215	329	1,004	2,066	8.1
1987	55,162	922	574	1,064	3.6
1988	63,078	2,688	1,093	1,583	4.7
1989	62,790	2,311	1,065	1,919	5.7

[1]Only basic oxygen and basic open hearth steel (scrap-based electric arc furnace production not included).
[2]Including breeze.

The years 1982 and 1983 were the lean years of steel production, which resulted in the establishment of the Voluntary Restraint Agreements (of steel imports to the United States) in 1984.

Following these years, the steelmakers learned to live with inventories as low as 15-days demand (4% yearly consumption). Hence, when steel production turned up in 1988, large amounts of coke had to be imported.

A more detailed examination of the import-export situation in the 2 high import years, 1988 and 1989, yields interesting information; the source is again the Energy Information Administration, and the data are in thousand short tons:

	1988	1989
Coking coal exports, total	61,950	65,128
Main recipients:		
Japan	12,116	11,449
Canada	7,278	6,820
Italy	6,395	6,662
Brazil	5,105	5,675
Belgium and Luxembourg	5,594	6,099
Coke exports, total (including breeze)	1,093	1,065
Main recipient:		
Canada	348	644
Coke imports, total	2,688	2,311
Main shippers:		
Japan	1,048	688
Federal Republic of Germany	48	470
Australia	607	464
Canada	484	207
Italy	125	17
Belgium and Luxembourg	108	98

It appears that a part of U.S. coal sent to Japan, Canada, Italy, and Belgium and Luxembourg is returned in the form of coke. The writer is personally familiar with such cases. Coke originating as U.S. coal also comes from Yugoslavia.

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