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Scrap for steelmaking 1950 - 2000
Impacts from changing technologies in the steelworks and iron industry

Jørgen Burchardt
National Museum of Science and Technology, Denmark

Almost half of the steel production worldwide is now made from scrap. It is the world's most recycled material with 366 m tons in 2000 – more than all other materials.
Several technologies at the steelworks can be used to make steel from scrap, but each has their strong and weak sides. There is a general competition among the technologies, where companies have had to choose one or another of the expensive ways of building steelworks. Their ability to handle scrap is in many ways important in this contest.
This study will see how changing technologies are interfering on the circulation of scrap. There are both new technologies within the steel industry itself and in the iron industry, which are using steel.

Many of the things mentioned in the article are true all over the world. Some of the examples are from the Danish Steelworks 'Det Danske Stålvalseværk' and from the Danish way of handling scrap, but this story will in many ways be the same for most other countries.

Iron has always been a worth full object. For many hundred years even the used iron was reused for other purposes, and at last it came back to the iron foundry to take a new cycle. It was possible to use the scrap for casting without any form of refinement.
As you properly know steel is iron with a carbon content between 1,5 and 2 % while iron for casting has around 4 % carbon. This casting iron had a lower temperature for melting, around 1.300 degrees Celsius while the steel had to go up to 1.600 degrees C.
It was not a problem for many hundred years, for the most scrap was cast iron and could go back without problems; only a small part was refined steel.
The situation began to change in the end of the 1800-years. After the invention of the Bessemer process there became much more steel in the world. After this the collectors of scrap had to sort the scrap: casting iron for the foundries and steel for the steelworks.
After some years (and after new inventions for the steelmaking process) the casting iron was no more the majority in the scrap any more. To day its part of the total iron scrap is less than 10 %. Besides there are no so interesting aspects as with the steel so I won't tell much more about this casting iron.
Foundries for steel could use scrap too. But again the percentage of the use of scrap to this was so low that this has only marginal interest compared with the production of new steel.
Steel scrap could be used as raw material too, for instance rails could be rolled to smaller dimensions. Neither this is mentioned because it had declined to almost nothing in the last decades.

For doing the things more complicated there became alloyed steel in the scrap. In 1912 the first patent was made on stainless steel with its 21 % chromium and 7 % nickel combination. Since then an enormous range of new steel qualities came on the market. When these steel qualities are returning the collecting companies had to sort them even in more separate orders after this keeping the special alloys together. In 1999 the total production of crude steel in Europe was 155 m tons while the production of alloy steels was 24 m tons.

In 1950 the situation after the world war was going to be normalized. The many steel products from the armaments gave a lot of scrap to the steelworks for some years. This had to have an end, and it happened around 1950, what fore the ironworks missed their raw materials in a time with a growing demand. The normalization was a growing efficient industry collecting the crap.
As you see in figure 1 the distribution of manufactured steel products and the gathering industry is like a mirrored picture. A little number of steelworks sends their products to some merchants that sends their steel to the many factories. From the factories the steel is spread all over the country to the distributing shops.
The collecting in the mirrored picture had to collect the used steel near at the consumers. Some decades ago collectors wandered from house to house asking about the used metals. To day the consumers themselves are collecting the used stuff and deliver it to special places. From here it goes to collecting companies that sells to bigger companies and at last the biggest are selling the steel back to the steelworks.

The process is not only to sort the scrap. It had to be handled so it can be used at the steelworks. Depending on the technologies at the steelworks the pieces had to have some maximum lengths depending on the dimensions on the furnaces at the steelworks. Therefore the scrap had to be cut in pieces by cutters, shears or by hand driven flame cutting.
General for all scrap: it had to be save to use for the steelworks. There must therefore be no things at all that can give problems later on in the process. Therefore all closed containers – not only grenades – had to be taken away or at least punctuated. Even small quantities of water were dangerous and so were pieces of ice that easy could be formed through the winter period at the storage yard.
For the late part of the history there have come new dangers in the scrap with the radioactive substances. Also these had to be identified by special instruments and removed for special treatment at special plants.
For convenient trade with the scrap it is divided in different qualities. The trade is worldwide but it is interesting that there are no international standard! Every steelworks or groups of steelworks have their own system.
Off course there are some similarities from company to company. In the same way the collectors have their special ways to keep the quality too.
Some of the most important qualities can be seen in the table 1.

At the collectors side there have been a mechanisation like in any other industry. They have got cranes with magnetic craps, automatic shears and other labour saving technologies.
Some of the new technologies ‘had’ to be invented when the many new cars from the 1960’s should be demolished. It happened in years too with a growing demand after raw materials.
The most important new technology was the shredder. Thanks to the many huge hammers in this equipment a car can be broken down to small fragments within 45 seconds.
As it will be explained later the quality of the scrap had to be better. It means that no parts from copper and no tyres should end at the steelworks. The collecting companies therefore had to use

separators. It can be with magnetic conveyers that takes the iron. A technology that saved much manpower was the wet separator from the 1960's that can separate the aluminium, lead and so on.

The scrap has its own pathway. Some 30 % of the iron and steel is disappearing and only 70 % is coming back. In average it takes 20 years. It can go a long way before it returns to the steel furnace. For instance only few elements of the Eiffel Tower have yet been scrapped. This capital scrap is general steel used for construction in houses or bridges have a long life. A shorter pathway has scrap from factories and machineries. Even shorter is the life of consumer products, where the scrap came from outdated or obsolete products. Cars lives around 11 years in Europe in general while they only lives 8 years in USA (from 1978).
Shortest way back has the steel from the iron industry. The many producing factories have their process scrap where the steel is only few weeks old. Shortest is this is the circulated scrap at the ironworks themselves that can be only hours before it is back in the casting ladle again.

The production of scrap is almost constant. Off course will the amount of scrap from the production in the producing industry will be dependent of the economic activity in the society in the same way that the consumers only buys more goods under better contours. But it is not possible to stop the 'fabrication' of scrap unlike the mines where the owners can stop the works for a while.
It is one of the reasons while the prices on the scrap are fluctuating with many ups and downs. A merchant in the trade had no reason to play poker or bet on horses; the prices can fall to the half or rise to the double within few days.
General the contracts for iron ore are made for several years while the buying of scrap is for a much shorter period. As we later will hear the scrap can be used as a buffer at the ironworks.

As you see of figure 3 the production of crude steel have for the last years been around the same made by iron ore and made from scrap. It is moving a little up and down and is mostly around 40% of all production in the world that came from scrap.

The different steelmaking processes

There are many different technologies behind the production of steel. In this chapter some of the most important technologies in the present time will be presented.
Please observe that some of the first described processes are preparing the iron ore a step before the process where the steel finally is made. The first processes are important because they reduce the ore to iron.
In this way the blast furnace is one (very important) step for the iron ore on its way for being steel. Since the Middle ages (and probably a long time before) this well-known technology were used to refine the iron ore with charcoal (and later coke).
The air to the modern furnace has been preheated and because of this the temperature can easy be as high as 1.500 Celsius.
Many different chemical processes are happening in such a blast furnace. One important is that the coal or coke gives a lot of carbon to the steel.
In theory you can use 100 % scrap as the source of the iron, but in reality it is seldom to use more than a few percents. It could be the local scrap made from the internal processes at the ironworks or it could be some very bad qualities of scrap that no other methods would be convenient to use.

There are some rather new processes for making iron. One is the Direct-Reduction Iron Plant (DRI) where the iron ore is treated in a shaft furnace fired with gas. It gives a very fine quality of iron and it is fine where you have very cheap delivery of natural gases.
Another new process is the Hot Briquette Iron (HBI) Process where the end product not is fluent like from DRI but is dry.
It is the same as in the process COREX.

These mentioned processes can handle iron ore. The next processes can handle the melted iron from these processes and/or can melt scrap itself.
One of the oldest processes of these is the Bessemer process, which from 1855 was a cheap way of making steel – important for the industrial revolution and especially the railway industry. The well-known converter, this round furnace blowing its beautiful white star drops when air was blown through it, could make a fine quality of steel. It was not suited for all products because it couldn't remove the phosphorus, but for railways the steel was fine.
The process was a kind of refinement process. The steel for the Bessemer had to be melted beforehand. In the converter itself could therefore only be put few percent of scrap.

The Bessemer process was enhanced by Thomas. He found that the not wanted things within the steel could be removed by adding lime at the same time that the building stone within the converter should be of a basic character. There were made much slag where the phosphorus and other unwanted substances gathered and could be removed.
This so called Thomas-process had the same conditions like the pure Bessemer Process – the steel had to be melted beforehand and there could therefore only be some few additions of scrap within the steel.

This process got soon competition from the Open Hearth Furnace. The process was also named Siemens-Martin after the two inventors, which found the ground making technologies.
The first special thing with this furnace was the high temperature it could make. It was made thanks to two similar chambers. Every half hour or so the gas from the furnace was shifted from being pumped through one chamber and to the other. Instead the intake of air went through the first chamber and was preheated by the many bricks.
The other invention showed a method to make the reduced steel. By blowing burning gas (later oil) on the surface of the furnace this process could happened. The whole process took around six hours from tap to tap. Also here were used basic materials for building the furnace and with supplemented with lime.
This furnace could use scrap and it was so good that it became the furnace for scrap par excellence. Here you could use 100 % scrap because you started with cold iron and heated it up to the 1.600 degrees.
Normally there were added different amounts of pig iron. It could be convenient for making special qualities of steel that the pig iron gave some special chemical effects. It could also be the best way of treating steel from a blast furnace, what fore the percent of scrap was rather low, if any scrap was used at all at the integrated works.
This technology was introduced 1865 and around 1900 it was a mature technology that wandered victoriously through the world. For some decades it had been replaced by other technologies. In Western Europe the last furnace stopped in 1983 but still in 2001 26 % and 48 % of the steel in respectively Russia and Ukraine were made by this way.

First many years later came a competitor. This technology was first used for melting aluminium but after some years it was a mature technology that could came up on the desired degrees for melting steel.
The technology was the Electric Arc Furnace original invented in the late 1880'Ths. The most used form was build with three electrodes in graphite with alternating current under a high voltage. This noisy process made so high degrees, even more degrees up to 3.300, that it was fine to melting scrap. Oxygen is often used to blow through the steel bath.
Again the process could use up to 100 % scrap.
The electric arc furnace came to ironworks in numbers in 1950'Ths but it soon got competition from another technology, the basic oxygen process, that were suited for the blast furnace steel works, the so called integrated works, that have plants for making coke, the blast furnace, the refinement process and the following rolling mills. Therefore the electric arc furnaces often were installed at plants where they were the only steel melting installation.
In the 1960'Th they became so victorious that they were a threat to the big companies with their integrated plants. They were called 'mini-mills' because they were small and flexible compared to the bigger integrated works.
This process alone couldn't make all qualities of steel. But instead the mini-mills were flexible and could even make some special alloy steel qualities.
Even it was possible to use the mentioned 100 % scrap in the furnace like the Siemens-Martin furnace there often were used some amounts of pig iron.

To complete the mentioning of processes we had to have the Basic Oxygen Furnace too. In a way it was the Bessemer and Thomas process superiored. Instead of blowing air through the steel bath there were blown pure oxygen through lances. Hereby the N was avoided that made bad things with the steel.
Again this process should start with melded steel. Therefore it was a process fine for integrated works with blast furnaces.

Problems around scrap
Scrap is a fine raw material for steel making. This is right. But it is also right, that there are some problems or at least some special characteristics that give some consequences compared with steelmaking from iron ore.
Iron ore is normal a well-known material. The steel plant knows its ingredients and therefore it can be used in a large-scale production.
Ironworks working with scrap do not always know exactly the content of the scrap. Some qualities are well known – for instance the circulated scrap from its own production but other types of scrap came from different companies that have bought the scrap from other companies. The content can be different on the content of not wanted materials. The materials from shredders for instance can be filled with rests from tyres, copper spools, composite materials and so on.

There is a long row of chemical substances that came with the scrap. For them there are three main ways for them in relating to their removal.
The first – and biggest – group is the elements that can be removed during refining and ladle treatment. It is the sulphur, phosphorus, hydrogen, nitrogen and oxygen. Besides came the alloying elements that can be oxidazabled (=burned away) as chromium, silicon and manganese.
The second group are elements that can be removed through evaporation. It is materials like lead and zinc.

Back are the third and last group with some elements that can’t be removed and at the same time often are unwanted tramp elements. It is copper, tin, antimony and arsenic. Besides comes the nonoxidizable alloying elements like nickel, molybdenum and cobolt.
These last materials are in some ways poison for the steel. They had to be avoided. It can be done through a tougher sorting process at the companies collecting the scrap. There can also be made some refinement processes before the scrap comes to the steelworks. For instance used tin cans can be treated so the tin and the steel were separated.
The use of this ‘polluted’ crap can also be done through a tinning of the steel through putting more clean pig iron in the steel. It is more expensive but occasional necessary.

Different products can have different content of these materials. As you can se of the table X in some steel qualities there had to be a little percent of these and in other it is OK with more.

It is worse than that. Like the poisoning with quicksilver in the food chain in the sea, the steel scrap itself has its own food chain that can be polluted. When the materials like copper, tin and so on once had come into the steel, it will never go out again – at least no inventor have yet made it commercially possible to remove the substances.
Some researchers have made a predicting for the future: if this pollution with the unwanted materials continues as to day what will that mean for the quality in the long run?
As you can see the quality will be so badly influenced that the scrap will be unsuitable for producing several qualities of the types of steel mentioned in table X. For instance will the XX no more could be made by steel from scrap.
Even to day the most steelworks don’t want to have some special qualities of steel. For instance reinforcement bars have such a high content of Cu that they are worthless for steelmaking.
And the poisoning will continue forever – if there not will be invented methods for separating the unwanted things from the steel.

Competition among technologies
The economy is an important factor in the competition between the different technologies that they are used at the integrated plant and at a mini-mill.
The use of energy is very different. By using the scrap you have the steel and ‘only’ had to melt and refine it. There are many arguments for using scrap. One is that it is cheap compared to iron ore because it saves 70% of energy. One tons of scrap saves 1½ tons iron ore and besides ½ tons coke. You see too an aspect for the environmental reasons.
As it can be seen from table XX the energy used for making a ton of steel by the electrical arc process is two GJ but at the integrated plant with a coke plant, blast furnace and the following BOF the use of energy was 16,2 GJ.
The difference is obvious. It is though not possible to compare the two amounts of energy because the electricity normally is an expensive way of making energy.
At the same time the capital used for building the two different types of plant is also in the favour of the mini-mill. As seen in table XXX there are a long row of production elements that had to be build at the integrated steelworks. The interesting numbers are how many money there had to be invested for making a ton of steel. For the integrated work the investment is 1.300 $ and only 400 $ at the minimill.

After the presentation of the single elements in the steelmaking process it is time for looking for some trends in the historical development for the last 50 years. In the following will be mentioned some of the most important things that have happened.

--1 The equipment at the laboratories developed in the period. In the beginning it was necessary to find the content of a charge through chemical processes. This was slow. But when a production cycle with a Siemens-Martin furnace was around six hours the speed didn't had the big influence.
--2 The electrical arc furnaces is superior to the Siemens-Martin process. They give a better quality by not having the contact with the air and not polluted with sulphur from oil burners. Besides they can in a shorter time give a charge. Because the mentioned better ways of making analysis the full potential of the furnace can be used.
--3 The refinement process has been better for the last years. By using a kind of BOF system at the plants with electric arc furnaces there can be made more pure qualities of steel. Hereby the electrical arc furnaces (and Siemens-Martin furnaces) in some ways became competitive with the steel from the blast furnaces. There could be removed some of the materials for steel qualities that before only could be made by the blast furnace melted iron.
--4 The casting methods have changed too. Original there were casted in ingots and this were rolled into billets or blooms. From its breakthrough in the 1960'Ths came the continuously casting method where the plant could spare a production process.
Again it was a fine thing for the mini-mills that they could reduce their economic expenses and made scrap more useful.
--5 A new casting method changed this – the thin slab and flat rolling plant first seen in Indiana in 1989. Before the blooms and the slabs had to be rolled to smaller pieces, but now they could cast in an on-going process without stops what fore the rolling could make the finished thin coils.
This process demands better qualities – and at least – the same quality all the time. This can be difficult to make by the electrical arc furnaces from not the better qualities of scrap.
--6 The production all over in the industry became better with less waste. In all factories there have been successful efforts and campaigns for reducing the waste. It means lesser percentage of this high valued scrap because the content of the ingredients are well known.
The same process has taken place at the steelworks. Also here the percentage of waste has been reduced. As you can se in table X there are a down going tendency for waste for the process scrap and the most important reduction comes from the reduction of the circulated scrap from the steelworks themselves.
--7 There is a political effort to higher the collecting of scrap. It has been made with success in that kind of way that the quantities are growing. On the other hand there are coming more scrap from the capital and obsolete scrap with a lesser quality of the scrap when the collectors had to use scrap that before not were used.
--8 In general the contemporary production processes needs better and at least equal qualities of steel. The factories had to have an equal quality thanks to the production flow, and the steel works themselves with their computer steered production want a continuous process.
--9 Many new products gives demands for better quality of steel. Off shore platforms, power plant turbine rotors and gas tubes for artic areas to mention a few.

Table
Use of scrap – inclusive internal – m tons

	1972	future
circulated scrap	120	50
process scrap	60	50
capital and obsolete scrap	40 (18 %)	100 (50 %)

The table shows the total use of scrap worldwide. It indicates that the quantities of unknown quality and possible 'poisoned' scrap have a higher percentage than before.

Table
Use of energy for different types of steelworks

	Integrated	Mini-mill	
process	coke BF, BOF		EAF
pr. t. steel	16.2 GJ coke	2 GJ	
	335 kWh electr.		640 kWh electr.
(= at 10 MJ/kWh:	19.55 GJ	8.4 GJ)	

This table shows the use of energy. Each steelworks is using both energy in form of electricity and from other sources – mostly coke.
The last line gives a the total use of energy translated to GJ.

Table
Capital for different types of steelworks

	Integrated	Mini-mill
equipment	1 cooking plant	1 EAF
	1 agglomerating pl.	1 x 6 strand cont. billet caster
	2 blast furnaces	
	3 converters (BOF)	rod mill
	2 continuous slap casters	
	continuous strip mill	
Capacity Mt/yr	6	0,6
Investment M US$	7.800	240
Invest US$/t	1.300	400

Table
Scrap classification

Old heavy steel
Old steel
New heavy steel
New pressed
Shredder
Heavy machinery
(Shaving)
(Burned – combustion)

Table
Major product markets for different types of steelworks

Integrated	Mini-mill
sheets	

plates	plates	
long products		long products
reinforcing bars		reinforcing bars
small structural		small structural
large structural		
rails		
wheels, axles		
seamless tubes		seamless tubes

The table shows the types of products the two different steelworks can make. This situation is in the 1980'Ths. Later on has new technology widened the possibilities for the mini-mills.

Table
Processes using scrap

	Year	scrap %	tons	time
Blast furnace	< 1500	(100 %)	13.000	cont.
Bessemer	1855	10 %	60	25 min
OHF	1867	100 %	500	8 hours
BOF	1952	30 %	340	35 min
EAF	1900	100 %	400	30 min

The year is the time of inventing or the first commercial use. The scrap percentage is the maximum used; often is used less or none. The tons are for some of the largest furnaces to day but at the time of introduction they were much smaller. The time is for starting to finish the process (pr. heat); this tap-to-tap time can be less under some circumstances. Again the time was considerable longer when the technologies were new.

Table
Maximum allowable tramp elements in steel.

	Cu	Ni	Cr	Mo	Sn	
Deep Drawing		0.06	0.10	0.07	0.02	0.01
Sheet & Coil	0.10	0.10	0.07	0.03	0.015	
Wire Rods (low carbon)	0.12	0.08	0.07	0.02	0.01	
Springs	0.20	0.10	0.10	0.03	0.02	
Wire Rods (special steel)	0.25	0.12	0.12	0.03	0.03	
Bar & Shape	0.35	0.15	0.15	0.04	0.03	

Table
Scrap used 1998 (world wide m tons)

iron foundry	40	11%
steel foundry	7	2%
BF	3	1%
OHF	16	4%
BOF	80	21%
EAF	230	61%
	376	100%

Figure
The cycling for steel

Figure
World crude steel production, by process (percentage)

Figure
Scrap flow 1977 around a steelworks

Figure
Crude steel – raw materials (m tons)

The figure shows an almost stable relation between the use of scrap and new iron to the production of crude steel for the present time.

Figure
Scrap prices ($/t USA, heavy metal)

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