The U.S. Steel Industry: Energy Consumption and CO_2 Emissions

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ABSTRACT

The historical reduction in energy consumption per shipped ton by the U.S. steel industry and the associated drop in CO_2 emissions is reviewed. The future level of energy consumption and CO_2 emissions will depend upon structural and technical developments within the industry over the next decade. These changes will be dominated by blast furnace performance and decommissioning, and the growth of and feedstock for new "greenfield" EAF melting facilities. The level of energy consumption by the steel industry, which is presently around 17 MBtu/shipped ton, will be put into perspective relative to other sectors of the economy. A decrease of another 2 MBtu/shipped ton is projected by 2010.

Introduction

The profligate use of energy by iron and steel makers is captured vividly in most early prints of steelplant operations by belching smokestacks (Figure 1- Plain Dealer).

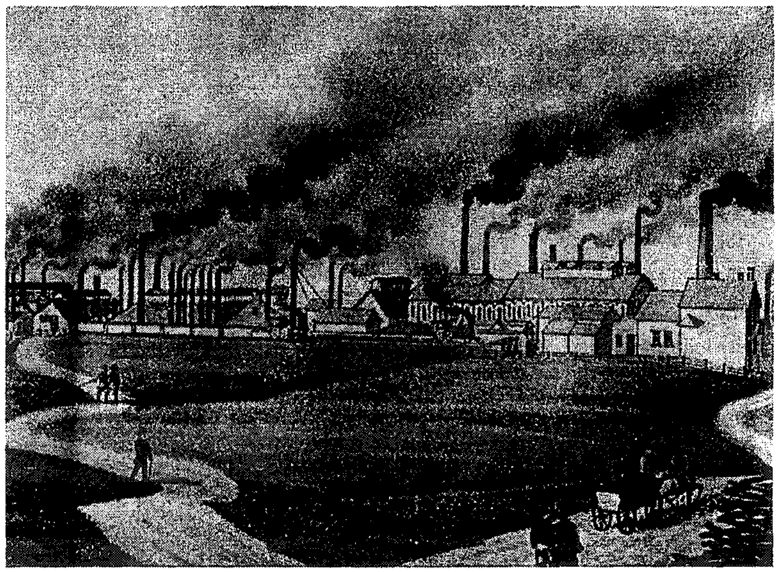

Figure 1. Cleveland Rolling Mills, 1880

They equated with jobs and profits. To coin an English North Country phrase, "where there's muck there's brass". Even though the smokestacks have largely disappeared today -- unfortunately along with jobs and profits -- the industry's "smokestack-rustbelt" image is hard to shed. During this last half-century, there has been a complete metamorphosis of the U.S. steel industry with respect to processes (Stubbles 1999). Demand for steel is still high (Figure 2), shipments are at record levels, the most productive steelmills now look like warehouses in cornfields, industry yields, productivity and quality are world-class, and energy per shipped ton has decreased by over 60% (Stubbles 2000). In each decade since WWII, a key process development occurred which reshaped the industry. The historical and future impact of these on steel industry energy consumption and carbon equivalent (CE) emissions, are the subject of my presentation today.

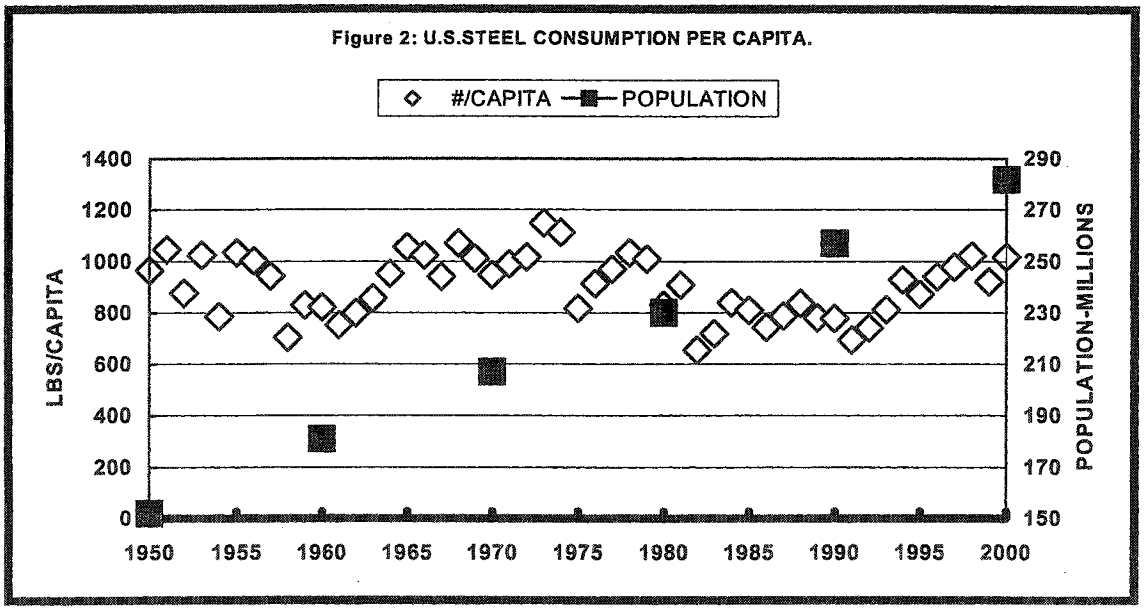

Figure 2. **Steel Consumption per Capita and Population Growth in the U.S. (AISI and Census Bureau)**

1900 – 1950

During these years, the steel-producing workhorse was the open hearth, which was a ludicrous process from the standpoint of a chemical engineer, but served the U.S. well through two world wars and the boom times that followed (Figure 3). In 1950, about 250 operable blast furnaces existed, with burdens of raw iron ore. An output of 1000 tons /day/furnace was rare as against 10,000 today (AIMME 1961). Pre-war electric furnace production was only about one million tons annually but thanks to some war-time government subsidies, this rose to about 6 million tons by 1950 (AISI 1950). All steel was teemed into ingots, and the average shipped yield from these had been stuck at around 73% since the turn of the century. As shown in Figure 4, energy consumption was about 45 MBtu/shipped ton, energy was cheap, and there were no environmental restraints (Energy units are English throughout the paper.The conversion factor of 10,500 Btu/kWh is used to allow for coal conversion efficiency). Steel was in great demand. The U.S.steel industry was globally dominant and profitable. It had no time for change, and seemingly no reason to consider change. But various technical and social forces were in the air and change was inevitable.

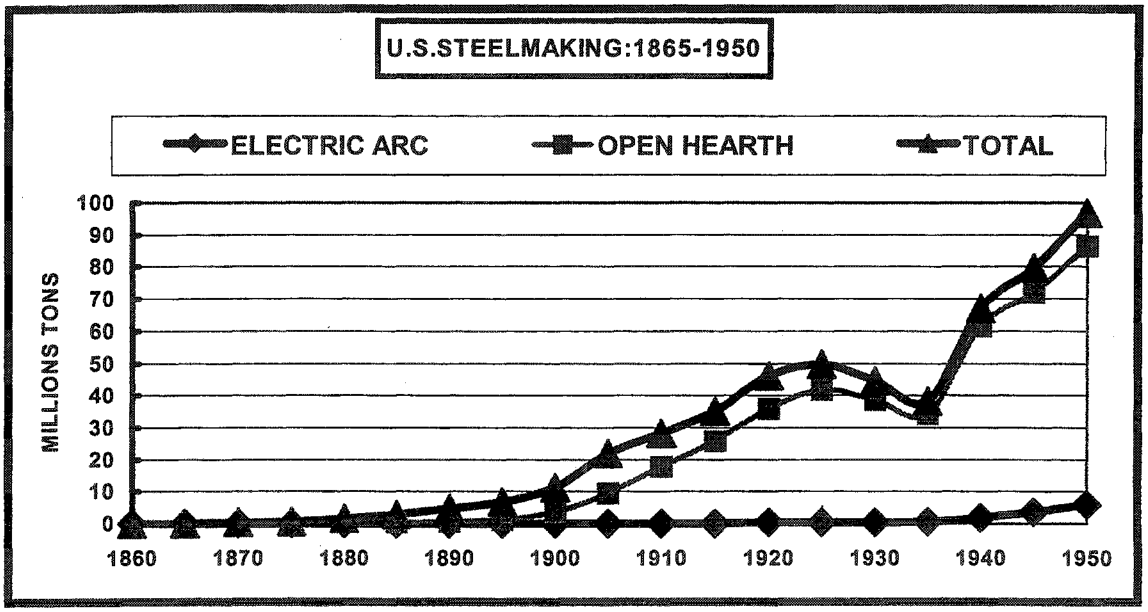

Figure 3. U.S Steelmaking 1865-1950

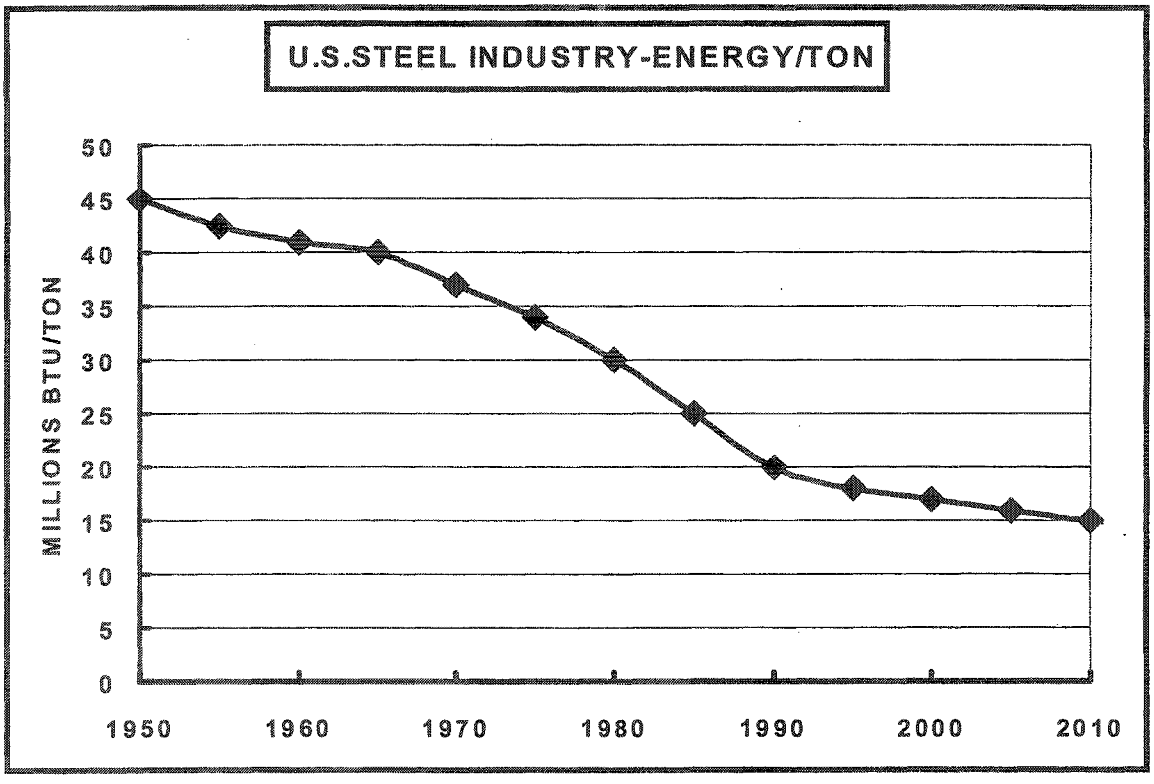

Figure 4. U.S.Steel Industry; Energy Consumption (Million Btu/Shipped Ton)
(AISI and Stubbles 2000)

1950-1960

The rich Mesabi ores (55 to 60% iron), which had been the primary source of ore for the U.S. since 1892, were nearly depleted by the late 1940's. While millions of tons of taconite ore was available on the iron range, it contained only 30% iron (Rose 1961). However, the beneficiation and pelletizing of taconite powder (ore ground to 300 mesh to release the iron-rich magnetite) produced a sized burden material even richer in iron (65%) than Mesabi ores. In-house sintering of iron oxide fines was also developed. The use of these burden materials was carefully evaluated along with tuyere injectants at the pilot blast furnace operated by the Bureau of Mines at Bruceton starting in the 1950's. Commercial pellet production on the North American iron ranges followed swiftly and use by blast furnace operators was welcomed. In the space of less than twenty years, over 80 million tons of pellet capacity was built in North America. Burden ratios (weight of iron bearing material/ton iron) and coke rates fell dramatically (Figure 5) (Stubbles 1995; AISI).

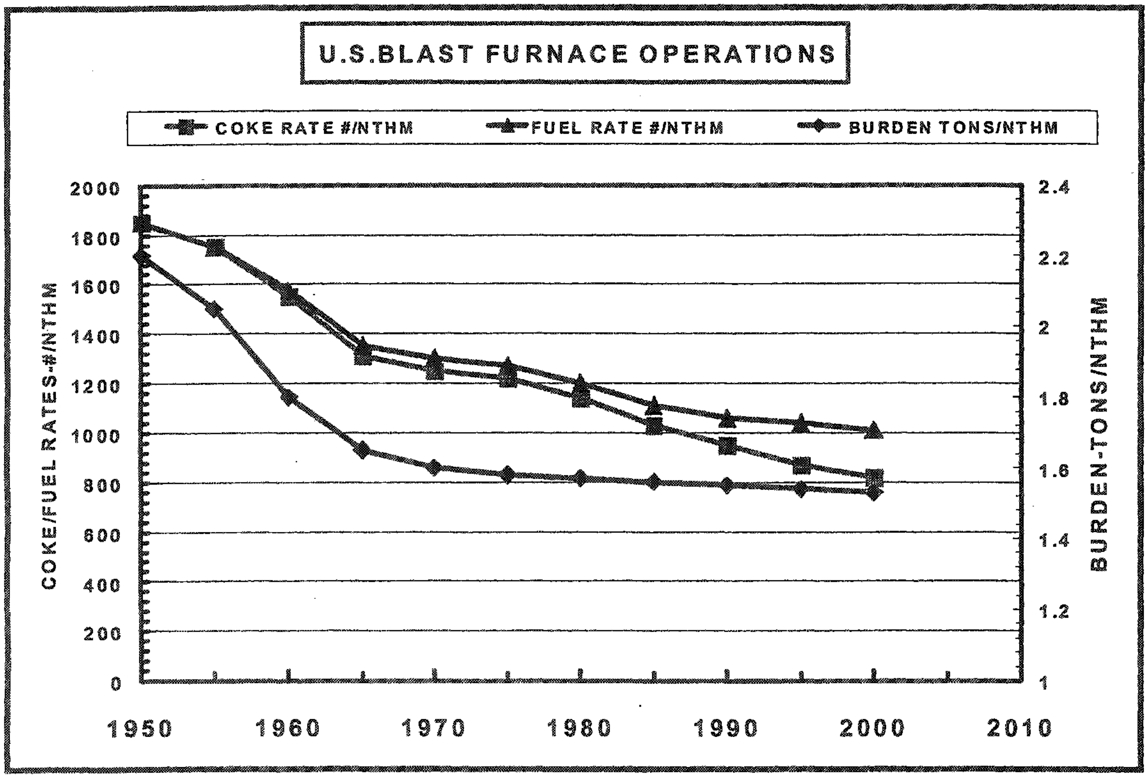

Figure 5. Fuel Rates and Burden Ratios of U.S. Blast Furnaces (fuel includes #/NTHM of coke, coal, oil, and natural gas)

Independently, coke quality was also much improved. In the following decades, more productive and better instrumented furnaces displaced older ones. Less than 40 operable blast furnaces now exist in the U.S., producing over 55 million tons annually at carbon rates of around 1000Lbs/NTHM (I&SM 2000). In 1950, it required over 200 furnaces to smelt 71 million tons. The injection of pulverized coal (PCI) has reduced coke but not carbon rates. The future of modern U.S. blast furnaces depends on coke availability (there is a limit to coal injection) and the economic viability of companies operating blast furnaces (Poveromo 1999).

1960 – 1970

After WWII, the Europeans needed to rebuild their steel industries, while Japan was being encouraged by the U.S. to install open hearths. The Austrians explored the top blowing of Bessemer converters using pure oxygen, which was available on a tonnage scale and therefore less costly as a result of the German V2 rocket programs. In 1952, the first commercial Linz-Donawitz (LD) shop was commissioned, and the Japanese also bought into the process. In North America, there was a general reluctance to adopt an untried, small-scale process (30 ton vessels) as a replacement for efficient 250-300 ton open hearths. Indeed, more open-hearth capacity was "on the books", waiting to be built. However, Dofasco (1954), McLouth (1954), and Jones and Laughlin (1957) pioneered the inevitable transition to the Basic Oxygen Process (BOP) as it was christened on this continent (AIMME 1961). By the end of the sixties, the open hearth was no longer king (Figure 6), and energy consumption per ton was reduced another notch. In all honesty, the open hearth was not as thermally inefficient as assumed, but it did consume large tonnages of energy intensive refractory products. Although not foreseen in the sixties, the BOP made possible the eventual introduction of continuous slab casters because it's consistent tap-to-tap time could match casting time per heat. Note the low level of continuous casting tonnage even as late as 1970.

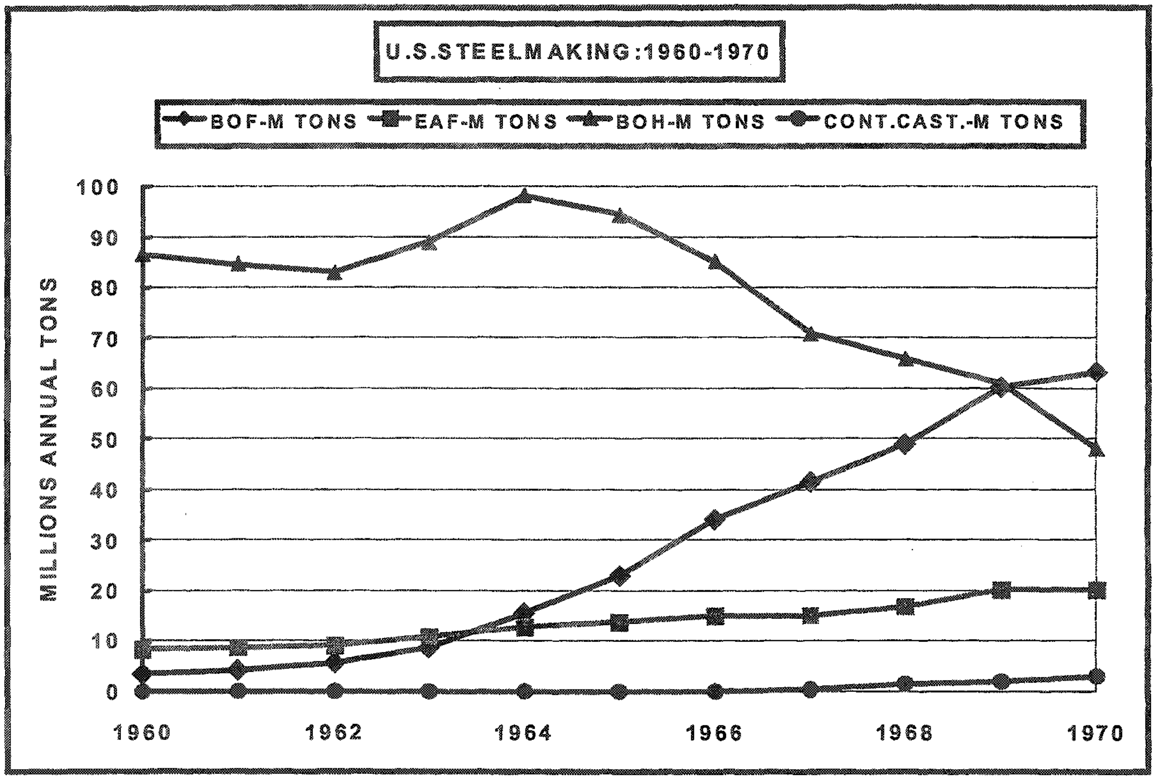

Figure 6. Installation of the Basic Oxygen Process in the U.S.

1970 – 1980

The decade started on a high note for the industry, but no-one foresaw the economic chaos that would be created by the oil embargos of the seventies. The integrated companies also faced huge mandated environmental costs, rising labor costs, underfunded retirement programs, and high quality imports. It was a time of crisis for these companies as they saw shipments drop from a record 110 to 80 million tons between 1974 and 1975 (Stubbles 1995).

For some entrepreneurs however, there were opportunities. Small-scale steel companies had been around for years, but the stringing together of an electric furnace, a billet continuous caster and a rolling mill for a relatively small capital investment was new. Annual output of these plants was modest at around 250,000 tons, and markets were generally at the low end of the quality spectrum. A glut of cheap, recyclable scrap as the primary raw material for the electric furnaces minimized operating costs. These "minimills" made their serious appearance in this decade, and changed the face of the industry. First, they were profitable even in bad times, and drained "gravy business" like rebar from the integrated mills. They embraced novel compensation systems, were "lean and mean" at both the supervisory and working levels, and were quick to buy and exploit new technology. Casting techniques, slide gates on ladles, ladle furnaces, porous plugs etc all became reality due to minimills. The net result was an upscale in product quality and productivity. The integrated companies could not compete, and were forced to abandon all markets but flat-rolled.Energy-wise, the minimills consumed less than half that of the integrated mills per shipped ton, even allowing for the conversion efficiency in producing electricity from coal. Many argue that recycled scrap has an inherent energy value which should be counted, but the reality is that most commercial scrap would be buried were it not for the minimills. Steel scrap recycling at over 60 million tons annually in the U.S. to create new, high quality steel is a logistical and environmental triumph which has not received the recognition it deserves

1980 – 1990

This was a desperate decade for the integrated mills and it called for desperate measures. Ingots had to go. Cooperative programs with the Japanese resulted in a spate of slab caster, degasser, and galvanizing installations to produce new and high quality flat rolled products. The results exceeded all expectations. Primary processing yields surged as did downstream yields due to better quality (Figure 7). This meant far less raw steel was needed for the same level of shipments, as shown in Figure 8 (AISI 1998). Note the unchanging yield until about 1980, the dramatic drops in shipments in 1975 and 1982, and the high yield data over the last decade, with almost record levels of shipments. Today, only specialty items like large forging rounds and thick plates are produced from ingots. All other steel (>95%) is continuously cast. Energy per ton dropped significantly due to these factors and the continued growth of the efficient electric furnace sector. The U.S. steel industry was now technically competitive on a global scale, but continued to restructure in an attempt to achieve marginal profits. And just when the integrated mills seemed to be turning the corner financially came the "unkindest cut of all". The minimills penetrated the flat-rolled market via thin slabs.

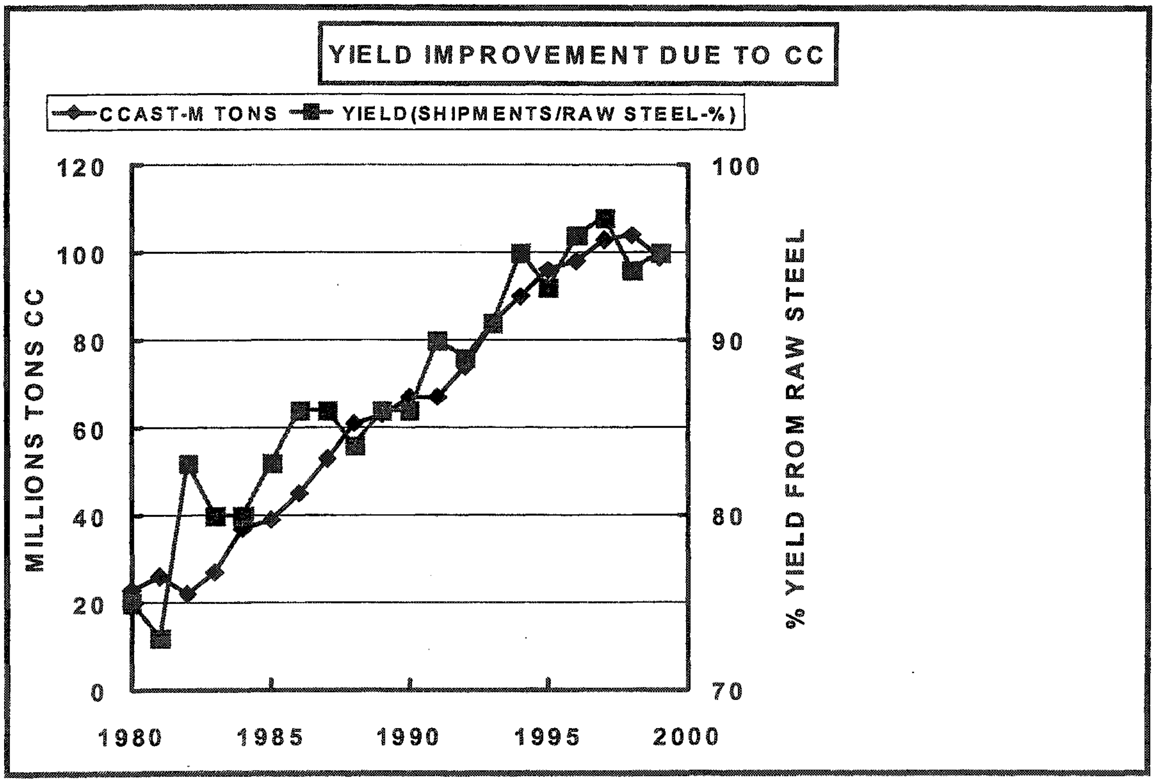

Figure 7.Yield Improvements Due to Continuous Casting

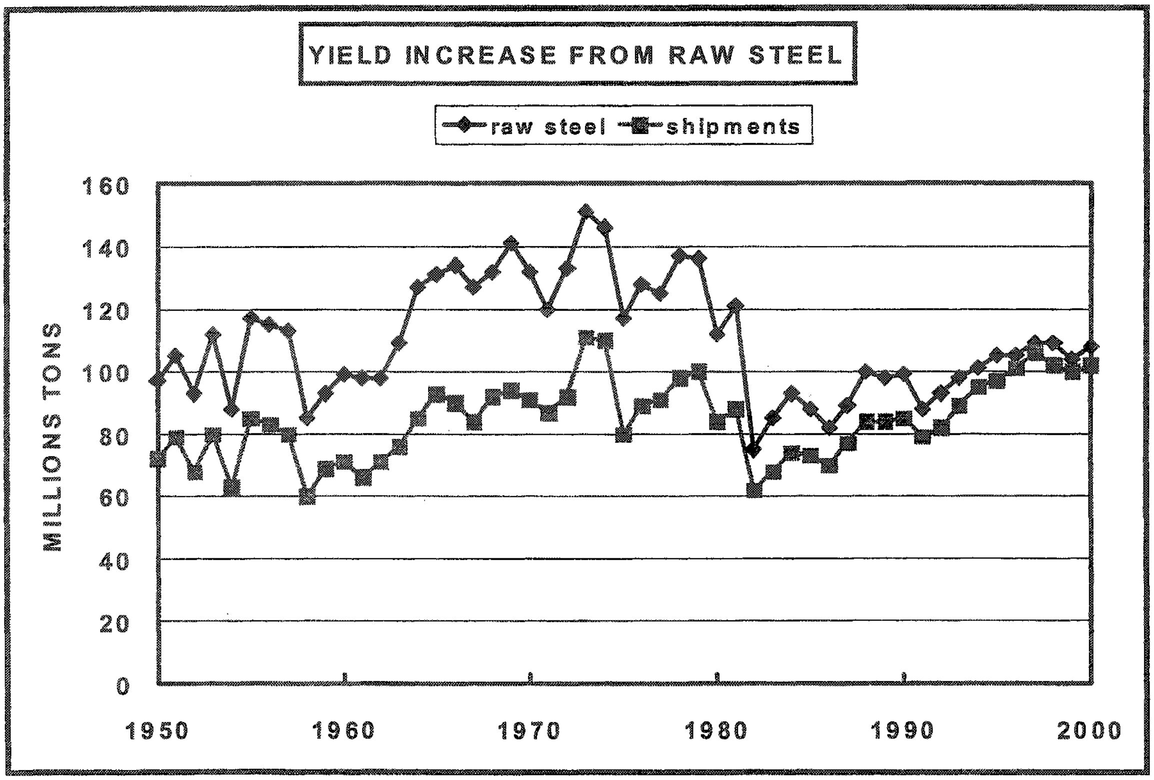

Figure 8. Increase in Raw Steel Yields (% Shipments/Raw Steel)

1990 – 2000

This decade has spotlighted thin slab casting, which was introduced by Nucor at Crawfordsville in an Indiana cornfield in 1989. It was German technology that had been viewed by numerous companies in the 80's, but Nucor had the guts to pioneer it commercially (Kuster 1995). It was a struggle initially, but the lessons learned were quickly incorporated into a second mill at Hickman. The nickname "minimill" became obsolete; these mills had capacities of millions of tons annually. They supplied products to the automotive industry, had galvanizing facilities, and operated at around 1.0 man-hour per ton (the industry average level is just under 4). Energy-wise, the sensible heat in the cast 2" slabs was captured in tunnel furnaces, which acted like the obsolete soaking pits. After shearing the hot strand, the thin slabs moved in-line from the caster, through the tunnel furnace and directly into a hot mill. With a productivity penalty, this could take the gauge down to 1mm i.e. cold rolled sizing. Several thin slab and semi-thin slab mills appeared after Hickman, including some built by integrated companies. Today, annual domestic hot band capacity of these new EAF mills is around 14 million tons (Barnett 2000). There are several energy implications in this development. First, the market thrust by the electric furnace sector mirrors that of the 1970s' into long products and must lead to the closure of more integrated capacity.This means less average energy per shipped ton for the industry.

Offsetting this is the change in raw material needs for electric furnaces. Flat-rolled products demand lower residual levels (copper, tin etc), which forces the "minimills" into either selective scrap purchases or the use of low residual alternative iron (AI).

This can be sponge iron (directly reduced iron, DRI or hot briquetted sponge iron, HBI) and even cold pig iron. Such products can be manufactured on-site or imported. The on-site production of sponge iron with subsequent melting in a submerged arc furnace is being practiced by Steel Dynamics in Indiana (Rokop 1999). On-site production is a hedge against increased scrap prices and a potential way to increase EAF productivity. However, any use of AI should be counted in the energy consumption data because these are manufactured products, whether they be produced on-shore or imported. Energy consumption at electric furnaces increases per melt ton depending on the AI type and usage level. Cold DRI requires about 10 MBtu/ton to produce, and may raise kWh consumption in the EAF. It is therefore probable that an upwards swing in energy consumption per shipped ton will be seen for the EAF sector in the future. The elimination of inefficient integrated capacity offsets this however, and the overall downward trend is maintained (Stubbles 2000).

Table 1 is a simplified breakdown of the contribution to carbon equivalent (CE) emissions by the electric furnace and integrated sectors of the U.S. steel industry for a shipment tonnage of 105 million tons. This has been typical for the last few years and is projected to continue for some time, assuming the economy remains stable. The table highlights the major contributors, about which a few comments are appropriate.

Electricity consumption, primarily for melting in EAF's, is based on generation from 100 % coal whereas the fossil fuel figure for the U.S. is actually 60% (51% coal). Therefore the actual CE emissions are probably lower than shown in the table.

Coal for domestic coke production and PCI, and coke imports account for 2/3 of the units for integrated mills. While carbon CE rates will continue to decline slightly, the elimination of the few remaining less efficient blast furnaces will have a greater impact on

CE emissions. There is a minimum coke rate even for the most efficient blast furnace because coke is physically needed to support the burden, and thus remains the primary source of reducing gas.

Table 1. U.S. Steel Industry: Energy Sources and Carbon Equivalent (CE) Tons

	MINIMILLS		INTEGRATED		TOTAL INDUSTRY	
	QUADS	C.E MTONS	QUADS	C.E. MTONS	QUADS	C.E. MTONS
NAT.GAS	.09	1.44	.36	5.76	.45	7.2
COAL/COKE	.04	1.17	.78	***21.47***	.82	22.64
KWH(COAL)	.38	***10.86***	.2	5.79	.58	16.65
OIL	.01	.18	.02	.44	.03	.62
TOTAL	.52	13.65	1.36	33.46	**1.88**	**47.11**

Natural gas is used in billet and slab reheating and other downstream processes like hot dip galvanizing, which has surged in the last decade. There will be a general move to conserve heat in cast products as better sensors are developed to measure cast product quality in-line. However, product quality criteria and rolling schedules often preclude such conservation.

To separate iron from oxygen, and then melt and process the iron into over 100 million tons of diverse high quality steel products in large scale units requires far more energy than the thermodynamic minimum because of intrinsic heat and conversion efficiency losses. No revolutionary technologies are on the horizon to change the energy consumption scenario. But the U.S. steel industry will continue reduce energy consumption per shipped ton with an asymptotic figure probably close to 15 M Btu. Figure 9 is a summary of past and future developments.

If shipments are maintained at the 105 to 110 M ton level annually, the absolute consumption of energy and thus CO_2 emissions will also decline (Figure 10). This bucks the trend for most sectors of the economy.The steel industry, which as recently as 1970 accounted for 5% of domestic energy consumption, is heading towards 1% in a couple of decades as the voracious appetite for energy in the U.S. continues to increase (Figure 11-DOE/EIA 1998). Note that the orange line for steel relates to the right hand ordinate. The industry has few options with respect to fuel selection, since as shown in Table I, it is 84% dependent on coal and 15% dependent on natural gas (Stubbles 2000).

Conclusions

The U.S. Steel industry has restructured itself over the last fifty years through the introduction of new processes and the elimination of obsolete capacity. Some of these changes (e.g. the introduction of slab casting) appeared glacial in speed but there were mitigating circumstances. The spirit of the minimills ultimately prevailed and today, the U.S. is unquestionably the world leader in large-scale EAF operations. The fact that the ratio of EAF raw steel output in the U.S. (now>50% of the total) to integrated steel output is higher than anywhere else in the world also means that U.S. energy consumption per shipped ton is the lowest in the world. This structural trend to reduce energy/ton is likely to continue as economic pressures force integrated companies either to liquidate or adopt EAF technology. In a healthy world economy, imports might decline and more EAF capacity will be required for a growing population. In a depressed economy, some integrated companies and weaker minmills will disappear. Either way, the survivors will be very efficient, and a downward trend in energy consumption from 17 to about 15 M Btu/ton is projected.

No new technology (e.g.strip casting, HiSmelt) jumps out as a major energy saver and we are approaching "practical" theoretical energy consumption in conventional BF/BOF/EAF/Caster/ operations. However, myriad conservation projects, driven by the continuous improvement philosophy in the industry and rising energy costs, will account for about 2/3 of the projected savings.Since coal and electricity are the key energy sources for the industry, coal will remain the over-riding primary source of energy, although regionally, nuclear and hydro-power may prevail.

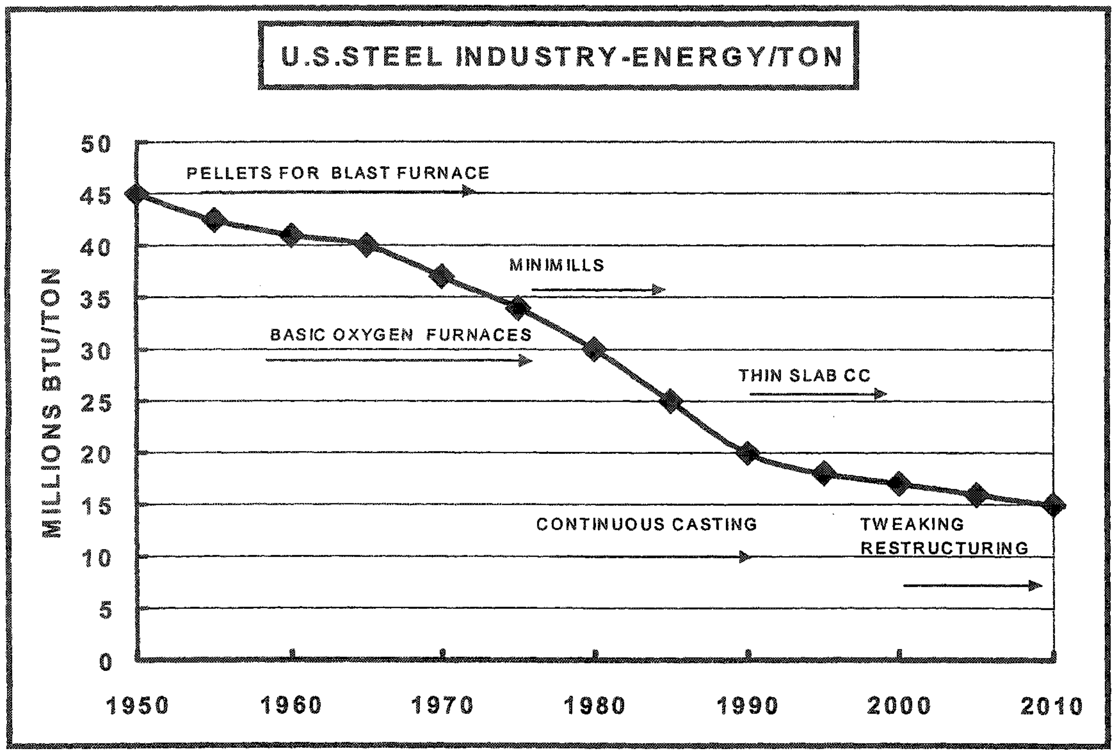

Figure 9. Major Factors Contributing to Reduced Energy Consumption/Ton

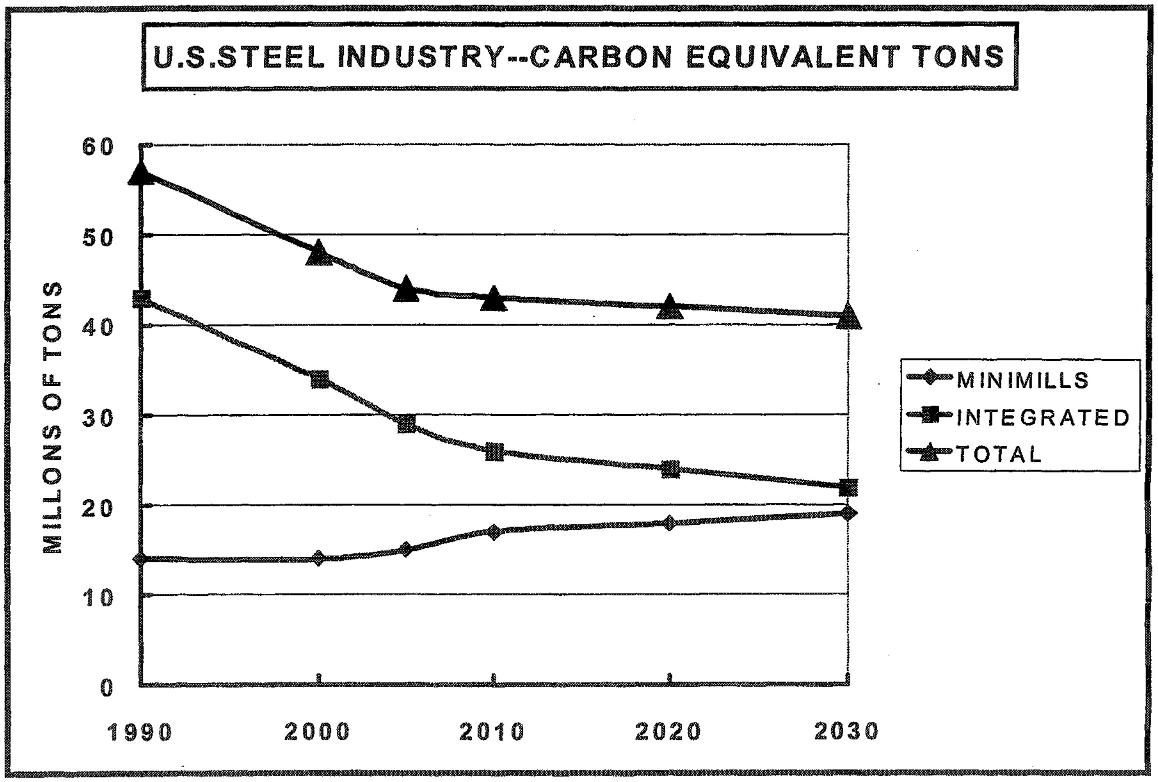

Figure 10. Carbon Equivalent Emissions for the U.S. Steel Industry

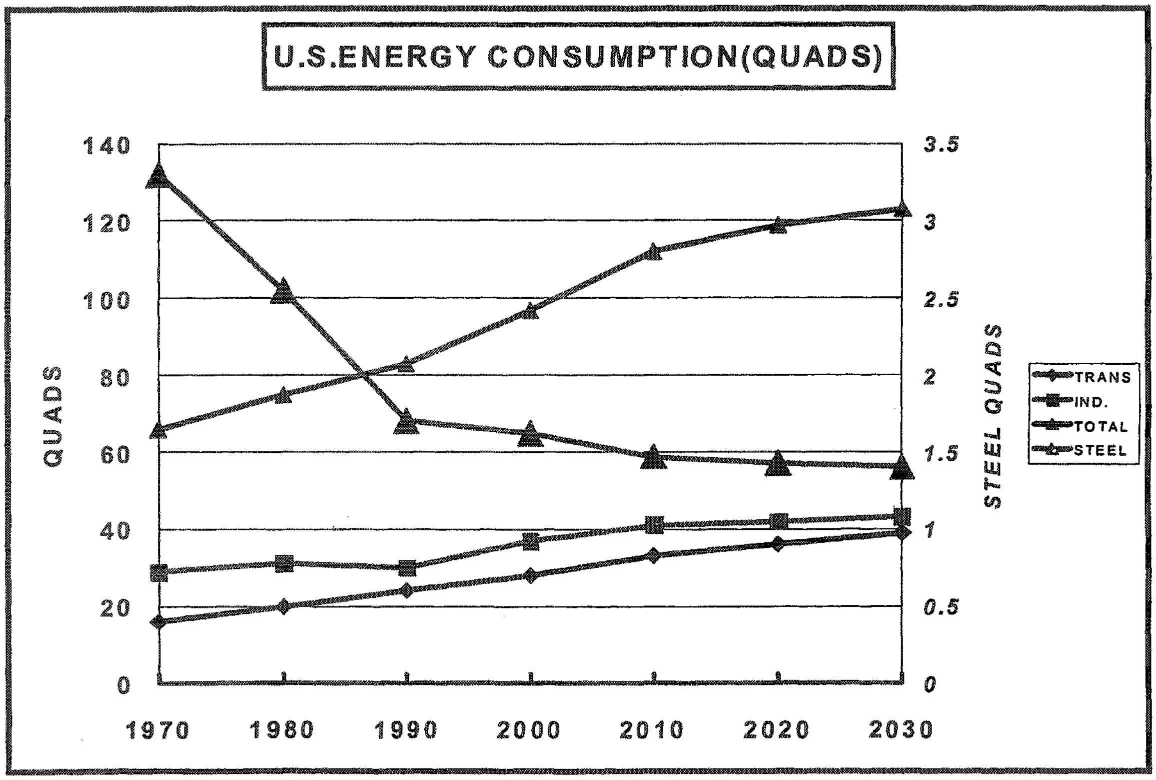

Figure 11. U.S. Energy Consumption

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