Steelmaking from a Scrap Supplier’s Point of View

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Hagar the Horrible

IT WOULD BE A PERFECT WORLD IF ONLY PEOPLE ALL OVER THE WORLD WOULD TRY TO UNDERSTAND EACH OTHER!

YOU'RE RIGHT!

THE PROBLEM IS TO GET EVERYONE TO SPEAK NORWEGIAN LIKE WE DO!!
Electric - arc furnace

- Electrodes
- Slag
- Arc
- Molten steel
- Charging door
- Spout

www.substech.com
Why Talk About Scrap At All?

Steel Company Cost Structure

- Melt Shop: 75%
- All Others: 25%
Why Talk About Scrap At All?

Melt Shop Cost Structure

- Scrap & Alloy Materials: 75%
- All Others (Electricity, Electrodes, Labor, Refractories, Maintenance): 25%

- Scrap & Alloy Materials
- All Others (Electricity, Electrodes, Labor, Refractories, Maintenance)
Why Talk About Scrap At All?

Steel Company

- Scrap & Alloy Materials: 56%
- All Other: 44%
Why Talk About Scrap At All?

Advantages of Using Scrap in Steelmaking:

• Considerably less total energy used (about 20%)
• Recovery of valuable alloys that would otherwise go to waste
• Cost
• Advantages in processing (lower Phos, Sulfur, Carbon etc)
• Sustainability: Steel is the most widely recycled material.
Why Talk About Scrap At All?

Scrap is not a manufactured product. **No one makes scrap on purpose!** Therefore…

You can get **GOOD** scrap

*or*

You can get **CHEAP** scrap
Why Talk About Scrap At All?

But you cannot get GOOD CHEAP scrap
Why Talk About Scrap At All?

- Stainless & Specialty producers work much more closely with scrap suppliers; NOT an adversarial relationship

- Scrap suppliers get paid on what the Steel Mills recover in test assay heats

- Quality, Residual Control, and Yield are all measured and reported and are part of the Payment / Penalty Structure
It Pays to get the crap out of Scrap

A 1% yield improvement is worth:
Carbon Steel - $8/ton
Stainless Steel - $24/ton
Aerospace Ni Alloy - $150/ton
Three Dimensional Slag Model

- Slag tetrahedron – A model of the four ternary refractory oxide phase diagrams
- $\text{Al}_2\text{O}_3 \text{ CaO SiO}_2$
- $\text{Al}_2\text{O}_3 \text{ MgO SiO}_2$
- $\text{CaO MgO SiO}_2$
- $\text{MgO CaO Al}_2\text{O}_3$
Stainless Steel Demand Structure

Other Processing Industries: 17%
Other (Mechanical, Engineering, retail): 16%
Consumer Goods: 18%
Automotives: 11%
Other Vehicles: 4%
Construction: 9%
Food Processing: 12%
Chemicals: 13%
SERVING THE MARKET

Scrap vendors serve the market through a strong presence and a comprehensive information network.

Approx. 4,000 sources worldwide

Mediator between generation and demand

Special steel producers
The Scrap Cycle

- **Revert Scrap**
  - Production
  - 3 Months
- **Industrial Scrap**
  - Processing
  - 6 Months
- **Old Scrap**
  - End-consumer
  - 15-20 Years
Most Important Value Factor

Historically, nickel is the most important value factor when determining the price of Stainless Steel, e.g. 304 Stainless Steel:
Stainless Steel Blends

Alloy scrap in many different physical forms & analyses.

- 50t Cr Fe: 15% Cr
- 7.5t 37/18: 37% Ni 18% Cr
- 7.5t Inco 600: 76% Ni 15% Cr
- 35t Cast Cr: 23% Cr
- 100t un-yielded Type 304 Stainless Steel: approx. 8.5% Ni 18% Cr

Stainless Steel in the form of Ingots, Billets, Bar, Coil etc.
Thousands of Scrap Generators
Hundreds of Scrap Dealers
A Handful of Scrap Processors
The Scrap Consumer (melter)
A Handful of Finished Product Processors
Hundreds of Finished Product Distributors
Basic Mill Requirements

- Minimum levels of payable elements; e.g. Ni, Cr, Mo, Fe etc.
- Maximum levels of residual elements; e.g., Mn, P, S, Cu, Co, Sn, Pb, B, V, Nb, etc.
- Minimum density and maximum physical size requirements; e.g. 60 lbs/cubic ft to provide two bucket charge capability - which may require cutting, bundling, shearing, shredding or crushing and packaging in dump hoppers for small materials such as turnings and grindings
- Safety requirements – NO detectable radiation, NO sealed containers, NO liquids, NO flammable materials, NO ordinance, and NO non-conductors. (non metallics)
- Delivery requirements – on schedule with ease of unloading and NO physical problems in handling and storage
- Cost requirements – provide all of the above at the minimum cost. This is capped by the underlying intrinsic value of the elements in the scrap and by competitive pressures in the marketplace.
Scrap before sorting & preparation
Scrap before sorting & preparation
Scrap before sorting & preparation
Scrap before sorting & preparation
Loose 18/8 stampings
Loose cut catalytic converters
Shredding
Bundles made from coil side trimmings
Sampling Techniques

Full laboratory facilities include:

- Emission Spectrometry
- X-ray Fluorescence Spectrometry
- Conventional chemical methods
What Makes Scrap Blending Difficult?

• With thousands of grades used in millions of applications, I am going to restrict the balance of my remarks to the most difficult part of the scrap blending process.

• **RESIDUAL CONTROL** – Why it’s so important and why the mills have the rules and restrictions they do.

• General Rule of Thumb – “Don’t put them in, ‘cause they can’t get them out” (easily)
Ellingham Diagram

\[ \Delta G = RT \ln \frac{P_{O_2}}{P_{O_2}} \text{kJ} \]

- H: Gold
- C: Copper
- M: Melting point of metal
- B: Boiling point of metal
- M: Melting point of oxide

The Ellingham diagram for selected oxides.
The kitchen sink!...with residual brass/bronze
Prepared & blended - shipping by barge
Everyone's Distant Memory of the Periodic Table of the Elements

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The atomic mass is shown with two significant figures. For elements with no stable isotopes, the value enclosed in brackets indicates the mass number of the longest-lived isotope of the element.

However, three such elements (Fr, Ra, and U) do have a characteristic terminal isotope composition, and for these an atomic weight is tabulated.
Sulfur, Selenium and Tellurium

- Group 16 – same group as oxygen
- Effects – decreases hot strength and impact resistance; forms low melting point iron sulfide that causes hot shortness
- Removal mechanism – time & lime, i.e., highly basic slag(s) \((\text{CaO} + \text{S} \rightarrow \text{CaS} + \text{O})\) may require second slag; not desirable from productivity standpoint
- Source – Heavy section carbon & stainless plate & long products and/or their associated turnings & scraps which were designed for free machining applications and any of the above where added to 0.30% for proper chip formation, i.e. type 303, 11xx, & 12xx
- Mill requirements
  - Sulfur – 0.030% /max, usually removed to less than 0.010%
  - Selenium – generally LAP (low as possible), not hot short; compounds are toxic
  - Tellurium – always LAP; NEVER in Ni stainless
Phosphorus, Arsenic, Antimony & Bismuth

- Group 15 – same group as nitrogen
- Effects – decreases ductility and toughness
- Removal mechanism – P generally oxidized and removed from carbon steel as $P_2O_5$ and held by an oxidizing slag however, AOD process includes both an oxidizing and reducing step and essentially ALL P reverts back to the metal
- Sources – added in combination with S, Se, Te in free machining applications to make the turning chips brittle enough to break
- Also found as residual powders or coatings in pipes, pumps & valves from Florida “phosphate mining” industry
- Mill requirements
  - Phosphorus – 0.035% max
  - Arsenic – generally LAP, never added @ high toxicity – trace amounts in steel
  - Antimony – generally LAP, compounds are toxic; tramp element found with lead
  - Bismuth – generally LAP, NEVER in Ni stainless
As phosphorus is the most difficult “poison” in stainless steel refining to deal with, I have prepared the following outline:
Sources of Phosphorus Contamination
Stainless Steel Scraps

- Automotive catalytic converter screens
- River Screens
  - Coal Washing & Handling
  - Flue Dust & Ash Screening
- Residues in Pipes, Pumps, Valves especially from the Phosphate Mining Industry
- Re-Phosphorized Grades – Type 303 (Long Products)
- Re-melted Pigs from Wastes
- Ni Buttons w/ Plating Residues
Carbon Steel Scrap

- Contamination
- RePhosphorized Grades (12XX)
- Truck Demo – Brake Drums, Cast Components
- HSLA
- Di-Electric Coating on Si Electrical Steels
- Bushelling
- Slags from EAF/BOF Steelmaking
Alloys

- FeP – 23-26% P Used in Making RePhosphorized Grades
  - Alloy inventory secure?
- High Residual Content – FerroAlloys, Charge Cr, HCFeCr, FeCrSi, FeMn Alloys especially HCFeMn
  - Certs from Trusted Producer?
  - Verified by McCreath?
- Ni Powders (Sludges), Ni Electroplating & Electroless Plating.
  - ??Listed Hazardous Waste??
Misc. Contamination or Transport

• Rechargeable Batteries (LiFePO$_4$)
• Fire Resistant Hydraulic Fluid
  • Phosphate Ester / Grapple Spills / Hose Failure
• Trucks Cleaned Prior To Back-Haul?
  • TriSodium Phosphate – Cleaning Agent / Degreaser / Detergent
  • DiAmmonium Phosphate - Fertilizer
Refractories

• Phos Bonded?
  • Hearth Material
  • Slag Line (bricks)
  • Roof (bricks & mortar)
• Phosphoric Acid & Glass Phosphates
Lab Analysis

- Standards?
- Calibrations?
You Can NOT Remove S & P Simultaneously

Requires Separate Steps (Slags)

Equations:

$$5\text{CaO} + 5\text{S} \rightarrow 5\text{CaS} + 5\text{O}$$ \hspace{1cm} \text{Reducing}

$$2\text{P} + 5\text{O} \rightarrow \text{P}_2\text{O}_5$$ \hspace{1cm} \text{Oxidizing}
Tin and Lead

- Group 14 – same group as carbon
- Effects – embrittlement and hot shortness
  - lead has detrimental effects on EAF refractories @ high superheat and density
- Removal mechanism – Pb; has a high vapor pressure – oxygen blowing and/or high stirring rates in the AOD – generally remove it
- Sources – same as S, Se, Te – they are added to promote free machining
  - lead is also found in counterweights, babbitt bearings, automotive wheel weights and long terne coated roofing material
  - found in compressed powder metal parts, Sn & Zn coated material for roofing, babbits & bearings
  - red metal alloys such as Bronze (CuSn)
- Mill requirements
  Tin – 0.025% max
  Lead – 0.0010% max, compounds are toxic
Boron

- Group 13
- Effects – ability to increase hardenability in carbon steels @ 0.002% and ability to control hot shortness and improve creep properties in Ni-Mo stainless steels
- Removal mechanism – B generally oxidized, and only partially recovered in the AOD
- Sources – high Boron steels (greater than 3% B) are manufactured as “metallic glasses” as substitutes for Si electrical steel
  - “Dameron”
Copper

- Group 11
- Effects – detrimental to surface quality and hot working ability
- “Ambidextrous”, added to 301 & 201 for deep draw-ability
- Removal mechanism – Cu is essentially **NOT** removed from steel
- Affects – Cu is added to steels to increase corrosion resistance or promote hardening, e.g.17-4 PH is a precipitation hardening grade; “Corten” is a weathering structural carbon steel
- Sources – Monels (Ni/Cu alloys), electric motors, wiring, etc. (automotive scraps) revert sink stock, brass (CuZn), & bronze (CuSn)
- Mill requirements
  - 0.50% max unless otherwise specified
Copper (continued)

- Apparent copper concentration
- e.g. 1,000 lbs Cu/200,000 lbs scrap = 0.50% Cu
- @ 96% EAF yield
- ~ 1000 lbs Cu/192,000 lbs liquid steel ~ **0.52% Cu**
Eliminating Residual Penalties

• Rather than eliminating residuals to avoid penalties how about repurposing residual elements where they do no harm?
• Eliminating residual penalties by creating new scrap grades that give so called “harmful” elements a useful home. For example:
  • 201+Cu
  • 301+Cu
  • Cu allowed in both up to 1%
Radiation Detection

• Radiation detection are direct functions of geology & physics.
• Time & Distance are the 2 biggest variables in the detection & identification of radioactive contamination.
• The likelihood of identifying contamination is increased the closer to the material the detector is located.
• Conversely, the further from the material the detector is located, the greater the likelihood that contamination will not be identified.
• The duration of scanning also impacts likelihood of detection of contamination. The greater amount of time spent scanning the material, the greater the likelihood of identifying contamination.
• Identifying the most likely areas of contamination requires visual inspection.
The inverse square law is used for calculating the deterioration of radioactive energy as the detector gets further from the Source.

\[
\frac{I_1}{(I_2)} = \frac{(d_2)^2}{(d_1)^2}
\]

- \(I_1\) is the initial intensity of radiation,
- \(d_1\) is the initial distance,
- \(d_2\) is the final distance, and
- \(I_2\) is the final intensity.
Scanning Methods

- Truck/Rail scale detectors
- Handheld detectors
- Grapple-mounted detectors
- Personal monitors
- Fork-truck mounted detectors
Naturally Occurring Radioactive Material

GENERALIZED GEOLOGIC RADON POTENTIAL OF THE UNITED STATES
by the U.S. Geological Survey

Geologic Radon Potential
(Predicted Average Screening Measurement)
- LOW (< 2 pCi/L)
- MODERATE/VARIABLE (2 - 4 pCi/L)
- HIGH (> 4 pCi/L)

Scale
Continental United States and Hawaii

Miles
0 100 200 300 400 500 1000 2000 3000 4000 5000
Naturally Occurring Radioactive Material
Naturally Occurring Radioactive Material

- Naturally Occurring Radioactive Material = NORM
- Where hydrocarbons are found in the Earth, NORM contamination is often found in surrounding soil.
- Background radiation levels due to high NORM concentration in certain areas makes detection more difficult.

<table>
<thead>
<tr>
<th>Location</th>
<th>Radiation Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burlington, ON</td>
<td>2 μR/hr</td>
</tr>
<tr>
<td>Chicago, IL</td>
<td>5 μR/hr</td>
</tr>
<tr>
<td>Houston, TX</td>
<td>5 μR/hr</td>
</tr>
<tr>
<td>Louisville, KY</td>
<td>9 μR/hr</td>
</tr>
<tr>
<td>Los Angeles, CA</td>
<td>8 μR/hr</td>
</tr>
<tr>
<td>Mobile, AL</td>
<td>6 μR/hr</td>
</tr>
<tr>
<td>Port Vue, PA</td>
<td>7 μR/hr</td>
</tr>
</tbody>
</table>

Material that may be found in Burlington, ON, may be **invisible** due to the background in Port Vue, PA.
Conclusions

• Scrap supply always flows to where demand is the greatest.
• Scrap demand is a function of cost, quality and consistency.
• In these times of variable raw material prices (and therefore supply) and increasing residual element buildup, what’s important for the steel maker and scrap supplier alike is not only, what’s IN the scrap blend, but also, what has been left OUT.
• In a commoditized market “Quality is Rewarded”.
Real World

- “Net” Market Price = Technical Settlement x Commercial Terms
- 0.05% by weight = 1 lb per ton
- 0.10% by weight = 1 kg per tonne
- You cannot mix BIG numbers and LITTLE numbers

For Example:

<table>
<thead>
<tr>
<th>Element</th>
<th>Actual</th>
<th>SpecAim</th>
<th>Excess</th>
<th>Dilution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr</td>
<td>20%</td>
<td>18%</td>
<td>2%</td>
<td>11.11%</td>
</tr>
<tr>
<td>Ni</td>
<td>9%</td>
<td>8%</td>
<td>1%</td>
<td>12.5%</td>
</tr>
<tr>
<td>Cu</td>
<td>0.6%</td>
<td>0.5%</td>
<td>0.1%</td>
<td>20%</td>
</tr>
<tr>
<td>P</td>
<td>0.06%</td>
<td>0.045%</td>
<td>0.015%</td>
<td>33.33%</td>
</tr>
<tr>
<td>Sn</td>
<td>0.035%</td>
<td>0.025%</td>
<td>0.010%</td>
<td>40%</td>
</tr>
</tbody>
</table>
Heat #123456  
Weight 360,000 lbs

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>Cu</th>
<th>Co</th>
<th>Sn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spec Range</td>
<td>.04/.06</td>
<td>1.75/1.85</td>
<td>.035/X</td>
<td>.010/X</td>
<td>.40/.50</td>
<td>18.09/18.27</td>
<td>8.06/8.10</td>
<td>.50/X</td>
<td>.50/X</td>
<td>.50/X</td>
<td>.030/X</td>
</tr>
<tr>
<td>Aim</td>
<td>0.05</td>
<td>1.80</td>
<td>.45</td>
<td>18.18</td>
<td>8.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>Cu</th>
<th>Co</th>
<th>Sn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td>.050</td>
<td>1.70</td>
<td>.025</td>
<td>.005</td>
<td>.40</td>
<td>18.00</td>
<td>8.00</td>
<td>.25</td>
<td>.30</td>
<td>.20</td>
<td>.020</td>
</tr>
</tbody>
</table>

Material List: *(all alloys 0.050% C)*  
66.66% LC Fe Cr  
40% Fe Ni  
80% LC Fe Mn  
75% Fe Si
Factoring

- **Step 1:** Determine **Alloy Factors**
  Divide what you are aiming **AT** by what you are aiming **WITH**
  
  - Cr: Aim at 18.18 / Aim with 66.66 X 100 = 27.27
  - Ni: Aim at 8.08 / Aim with 40.00 X 100 = 20.20
  - Mn: Aim at 1.80 / Aim with 80.00 X 100 = 2.25
  - Si: Aim at .45 / Aim with 75.00 x 100 = .60

- **Step 2:** **SUM** Alloy Factors
  50.32

- **Step 3:** Determine **Fe Factor**
  Fe factor = 100 – Sum Alloy Factors
  100.00 - 50.32 = Fe Factor + 49.68
Factoring

• **Step 4:** Determine amount of each **Alloy Pure**
  Multiply both weight by lab analysis
  
  *Cr:* $360,000 \text{ lbs} \times 18.00\% = 64,800 \text{ lbs}$
  *Ni:* $360,000 \text{ lbs} \times 8.00\% = 28,800 \text{ lbs}$
  *Mn:* $360,000 \text{ lbs} \times 1.70\% = 6,120 \text{ lbs}$
  *Si:* $360,000 \text{ lbs} \times 0.40\% = 1,440 \text{ lbs}$

• **Step 5:** Determine amount of each **Alloy Equivalent**
  Divide lbs “alloy pure” by percent contained in alloy addition
  
  *Cr:* $64,800 \div 66.66\% = 97,200 \text{ lbs}$
  *Ni:* $28,800 \div 40.00\% = 72,000 \text{ lbs}$
  *Mn:* $6,120 \div 80\% = 7,650 \text{ lbs}$
  *Si:* $1,440 \div 75\% = 1,920 \text{ lbs}$

• **Step 6:** **SUM** Alloy Equivalents
  
  $178,770 \text{ lbs}$
Factoring

• **Step 7**: Determine weight of **Fe Equivalent** (all other) in bath
  Subtract alloy equivalent from bath weight
  \[360,000 \text{ lbs} - 178,770 = 181,230 \text{ lbs}\]

• **Step 8**: Determine **Minimum Tap Weight** for those materials
  Divide weight Fe equivalent (step 7) / Fe factor (Step 3)
  \[181,230 / 49.68 \times 100 = 364,794.686 \text{ lbs minimum tap weight}\]

• **Step 9**: Determine **Sum Alloy Additions**
  Subtract bath weight from minimum tap weight
  \[364,794.686 \text{ lbs} - 360,000 = 4,794.686 \text{ lbs total additions}\]
Factoring

• **Step 10**: Determine **Total Individual Alloy** amount
  Minimum tap weight X individual alloy factor / 100
  \[
  \text{Cr: } 364,794.686 \times 27.27 / 100 = 99,479.511 \\
  \text{Ni: } 364,794.686 \times 20.20 / 100 = 73,688.527 \\
  \text{Mn: } 364,794.686 \times 2.25 / 100 = 8207.880 \\
  \text{Si: } 364,794.686 \times .60 / 100 = 2,188.768
  \]

• **Step 11**: Determine each **Individual Alloy Addition**
  Total individual alloy amount (step 10) – alloy equivalent in bath (step 5)
  \[
  \text{Cr: } 99,479.551 – 97,200 = 2,279.511 \text{ lbs } 66.66\% \text{ LC Fe Cr} \\
  \text{Ni: } 73,688.527 – 72,000 = 1,688.527 \text{ lbs } 40\% \text{ Fe Ni} \\
  \text{Mn: } 8,207.880 – 7,650 = 557.880 \text{ lbs } \text{LC Fe Mn} \\
  \text{Si: } 2188.768 – 1920 = 268.768 \text{ lbs } 75\% \text{ Fe Si}
  \]
Factoring

- **Step 12:** Sum additions and **Compare** to step 9
  
  Method is self-checking.

  4794.686 lbs QED
Thanks for Closing the Recycling Loop