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Chromium—A National Mineral Commodity Perspective

By John F. Papp

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Chromium—A National Mineral Commodity Perspective

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Summary

This report contains the 23 Power Point slides from a presentation made by the author at the meeting of the Washington, DC Section of the Society for Mining, Metallurgy, and Exploration, Inc. held in Washington, DC, on January 9, 2007.

Slide 1. Why have a talk about chromium? The short answer is that stainless steel requires chromium, and stainless steel is ubiquitous in industrial and military applications. The longer answer is, of course, the rest of this presentation.

Chromium—A national mineral commodity perspective

Presented at the January 9, 2007
meeting of the Washington, DC Section
of the
Society for Mining, Metallurgy, and Exploration, Inc.

By John F. Papp
U.S. Geological Survey

Slide 2. Strategic importance of a commodity is measured in amount by net import reliance (NIR) and apparent consumption (AC), and relatively by NIR as a fraction or percent of AC. AC is the amount of material consumed by a country annually, measured in tons for the major metals. (NIR is net imports plus stock decreases or minus stock increases, and AC is domestic production plus NIR.) NIR is the amount of a nation's AC that was not domestically sourced. NIR, as a fraction or percentage of AC, expresses the degree to which a nation is import dependent. A large NIR relative to AC indicates large dependence on foreign sources.

Consumption, production, resource, trade, and use, collectively are sometimes called materials flow. These quantitative characteristics are affected by geology, geography, geopolitics, engineering factors (e.g., material performance), economics (e.g., material cost relative to benefit), and price. Some of these factors for chromium are as follows.

Chromium
(commodity factors)

- Commodity importance
  - Net import reliance
    - Stocks
    - Trade
  - Apparent consumption
    - Production
    - Net import reliance
- Geography, geology, and geopolitics
  - Resources
  - Production
  - Consumption
- Price

Slide 3. Domestic reserves amount to about 0.1 million metric tons (Mt) of contained chromium compared with consumption of about 0.5 Mt of chromium per year. World chromium reserves are about 200 Mt of contained chromium compared with consumption of about 5.8 Mt of chromium per year. World reserves are more than 30 times the current rate of world production.

"Consumption" is traditional terminology used by the U.S. Geological Survey. Chromium is not literally consumed when it is used to make stainless steel. It is more accurately described as becoming an "in-use stock," improving our standard of living while waiting to be recycled.

Chromium commodity information

- Reserves (chromite ore reserves)
  - Domestic: 0.113 Mt (Cr)
  - World: > 200 Mt (Cr)
- Production and processing (chromite ore)
  - Domestic: none
  - World: 5.8 Mt/yr (Cr in chromite ore)
- Consumption (of chromium)
  - Domestic: ~0.5 Mt/yr (Cr)

Slide 4. Since the USGS started monitoring and reporting apparent consumption and net import reliance in the Mineral Commodity Summaries publication series (about 1960), chromium apparent consumption declined to about 500 thousand metric tons of chromium per year (kt/yr (Cr)) from the historical high of about 900 kt/yr (Cr) (in 1965). Chromium net import reliance is currently about 400 kt/yr (Cr). The historical high was about 800 kt/yr (Cr) (in 1965). Net import reliance as a percentage of apparent consumption is currently about 70%. The historical high was about 85% (in 1965).

These estimates are post-1962 when secondary production was first included in the net import reliance estimate and accounted for in the form of stainless steel scrap recycled. Before 1962, net import reliance as a percent of apparent consumption reached 100% on several occasions including time periods before and after WWI and WWII.

(The materials accounted for in these apparent consumption and net import reliance estimates include the production of chromite ore (CrOre) and stainless steel scrap (SSSPrd), the trade and stocks of CrOre and ferrochromium (FeCr), chromium metal (CrMtl), and chromium chemicals (CrChm).)

Chromium apparent consumption (AC) and net import reliance (NIR)

- Apparent consumption
  - Current: 500 kt/yr (Cr)
  - Historical high: 900 kt/yr (Cr) (1965)
- Net import reliance
  - Current: 400 kt/yr (Cr)
  - Historical high: 800 kt/yr (Cr) (1965)
- Net import reliance as a percentage of apparent consumption
  - Current: 70%
  - Historical high: 85% (1965)

Note: Materials include CrOre, FeCr, CrMtl, CrChm, & SSSPrd; after 1962.

Slide 5. The United States is reliant on the imported chromium. This slide shows the (2001-05) average amount of NIR, AC, and the NIR as a fraction of AC by material for several commercially traded chromium materials used by domestic industry. (For the purpose of this slide, AC and NIR by material is domestic production plus net trade of that material. Chromium is as reported in the Mineral Commodity Summaries and includes National Defense Stockpile changes.)

There was no domestic mining during this time period and the United States now satisfies most of its chromium needs via ferrochromium, so chromite ore NIR was not large; however, NIR as a percent of AC was 100%. The United States produces a small amount of ferrochromium; however, it produces a large amount of stainless steel scrap—an alternate source of chromium for steelmaking. FeCr NIR was 230 kt/yr (Cr), and NIR as a fraction of AC 0.50.

Domestic chromium metal production is not reported to avoid revealing company proprietary information. CrMtl NIR was 9 kt/yr (Cr), and NIR as a fraction of AC ranged from 0.75 to 1.00. NIR exceeded domestic production capacity by more than a factor of 3.

Averaged over all materials during the time period, chromium NIR was 330 kt/yr (Cr), and NIR as a percent of AC was 70%.

U.S. net import reliance

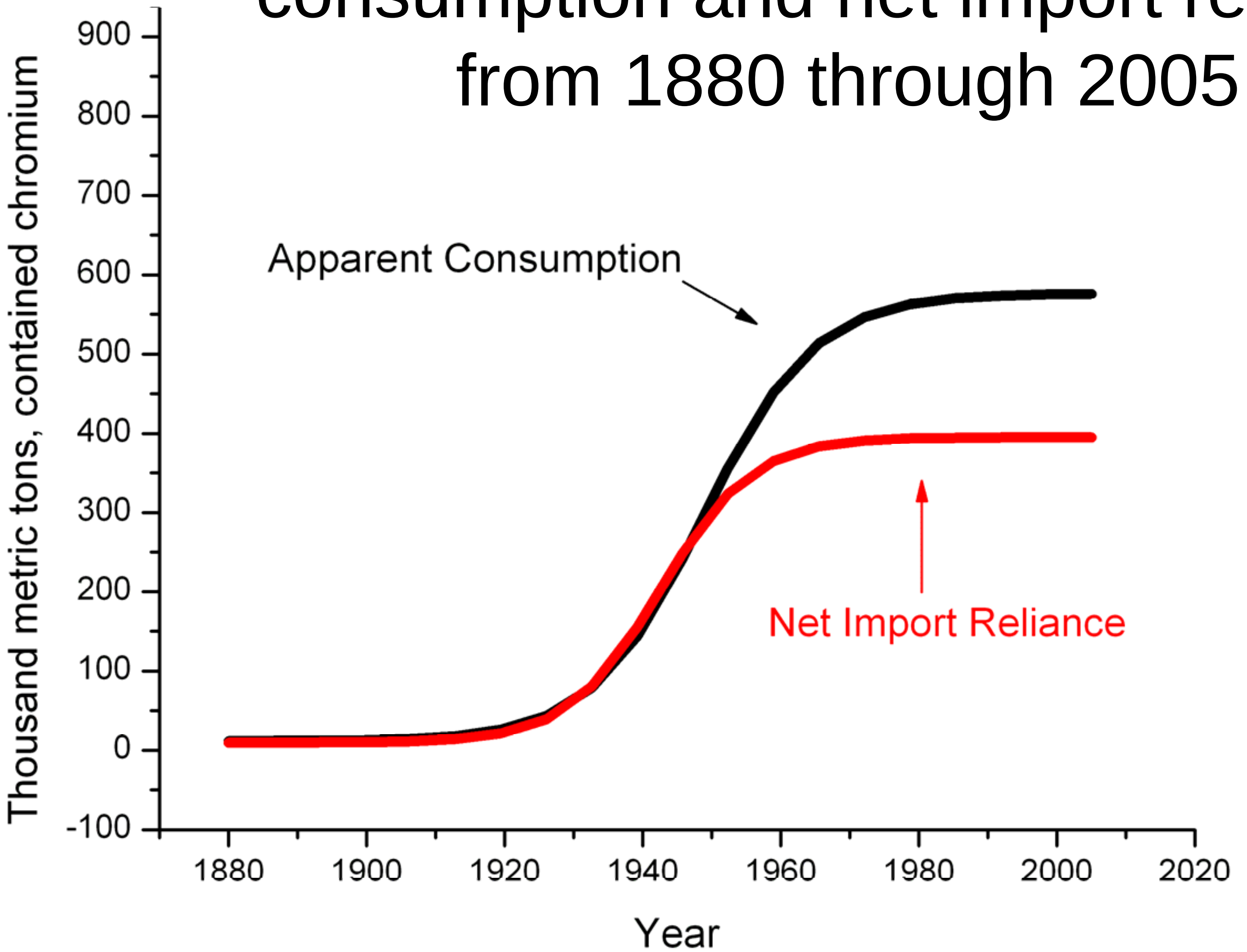
	NIR	AC	Ratio
Material	kt/yr (Cr)	kt/yr (Cr)	NIR/AC
CrOre	30	30	1.0
FeCr	230	450	0.50
CrMtl	9	9-12	0.75-1.00
Chromium	330	480	0.70

Note: 2001-05 average.

Slide 6. This slide shows the trend of U.S. chromium apparent consumption and that of net import reliance from 1880 through 2005. Since 1880, chromium net import reliance has increased from about 5 kt/yr (Cr) to about 400 kt/yr (Cr) today. Over the same time period, chromium apparent consumption has increased from 5 kt/yr (Cr) to over 500 kt/yr (Cr) today.

After about 1950, domestic chromite ore production, which ended in 1961, and stainless steel scrap production, which started in 1962, contributed to the difference between chromium apparent consumption and net import reliance shown here. (The trend line does not reflect data scatter such as the historical high values reported in a previous slide.)

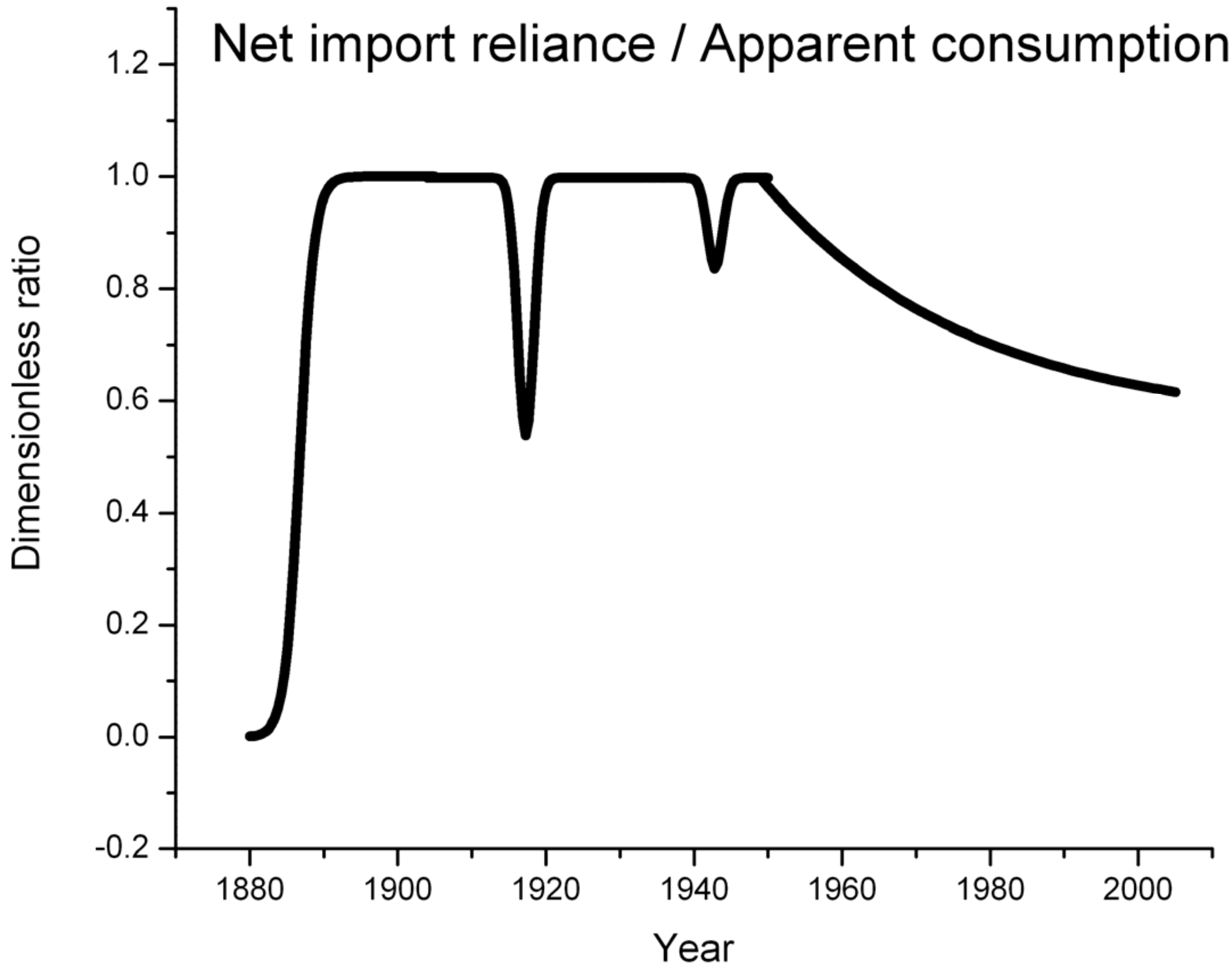
Historical trend of chromium apparent consumption and net import reliance from 1880 through 2005



Slide 7. Net import reliance as a percentage of apparent consumption over the same time period (1880 to 2005) has declined from 100% to about 70%. Significant deviations from 100% import dependence occurred before 1890, and in ~1920, ~1945, and ~1960 as a result of domestic chromite ore mining.

Declining net import reliance since 1962 resulted from increasing consumption of stainless steel scrap to produce stainless steel mill products, reflecting a trend in the steel industry to substitute scrap for mined materials--a practice that reduced production cost, including that of energy and materials.

(The apparent consumption and net import reliance computations included chromite ore, ferrochromium, and chromium metal stocks and trade, and chromite ore and recycled stainless steel scrap production.)


Net import reliance / Apparent consumption
Dimensionless ratio
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
1880
1900
1920
1940
1960
1980
2000
Year

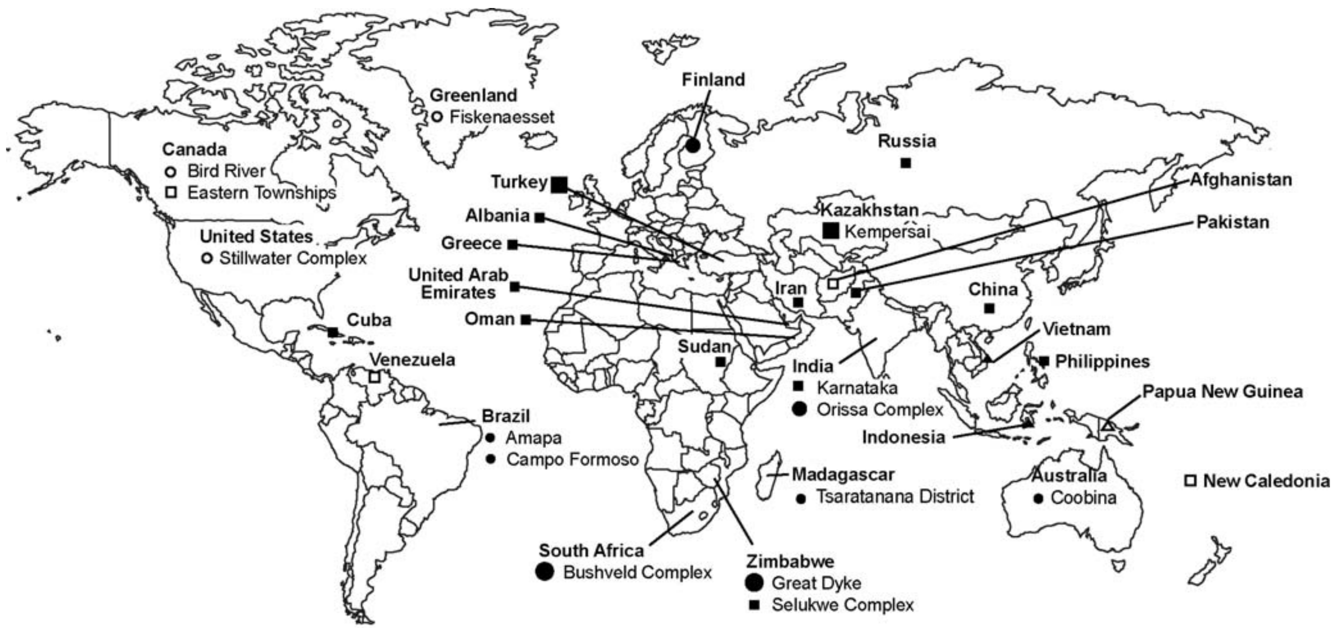
Slide 8. This slide shows the geographic location and distribution of major chromite ore deposits along with their deposit type, size, and mining status.

Chromite ore deposits were created when magma intruded the earth's crust. Chromite ore deposits are classified by type into stratiform, podiform, and lateritic deposits. Stratiform deposits, indicated by circles, or podiform deposits, indicated by squares, were formed depending on the rate of cooling and subsequent environmental conditions. The distribution of chromite ore deposits shows that economically recoverable resources are geographically concentrated in the Eastern hemisphere.

The major deposits are in India, Kazakhstan, and South Africa, all in the Eastern hemisphere. In the Western hemisphere, there are significant producing deposits in Brazil and Cuba. The major producing stratiform chromite ore deposits are in southern Africa and India; the major producing podiform deposits are in Kazakhstan and Turkey. Most world resources and production are from stratiform deposits.

This slide was made a few of years ago. If it were made today, it would show the chromite ore deposit near Coos Bay, OR, where mining started in 2006.

World chromium resources



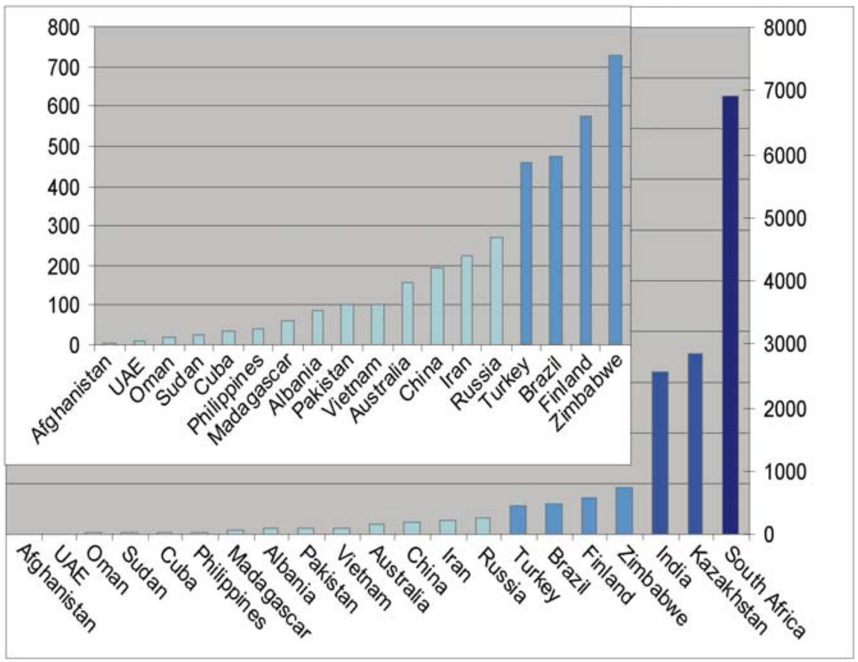
Explanation: Geologic Deposit Type

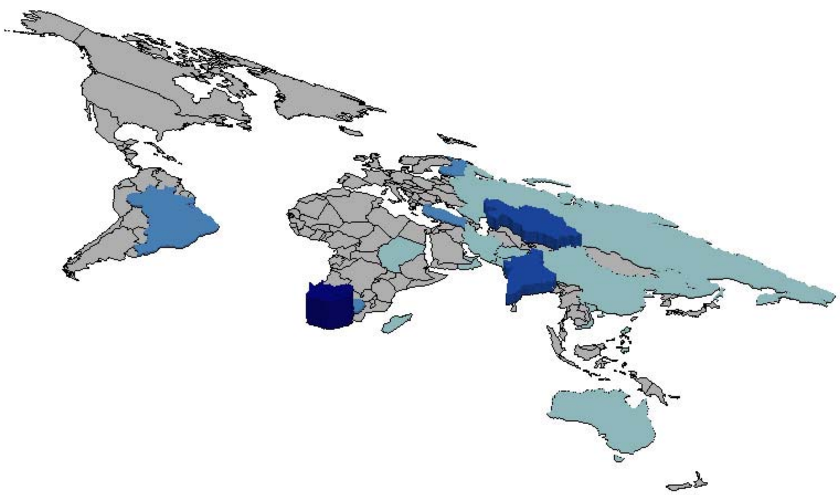
Stratiform			Podiform			Laterite		
Symbol		Resources (Mt-Cr[1])	Symbol		Resources (Mt-Cr[1])	Symbol		Resources (Mt-Cr[1])
Nonproducing	Producing		Nonproducing	Producing		Nonproducing	Producing	
○	●	> 70	□	■	> 70	None	None	> 70
○	●	30 - 70	□	■	30 - 70	None	None	30 - 70
○	●	< 30	□	■	< 30	△	▲	< 30

[1]Million tons chromium

Slide 9. This slide shows (2001-05) average annual chromite ore production by country in the bar chart and geographically on a world map. The slide shows that South Africa is the leading world chromite ore producing country followed by Kazakhstan and India. Together, they (South Africa, Kazakhstan, and India) accounted for about 80% of world production (averaged over the time period). In the Western hemisphere, Brazil is the leading chromite ore producer.

Average annual chromite production



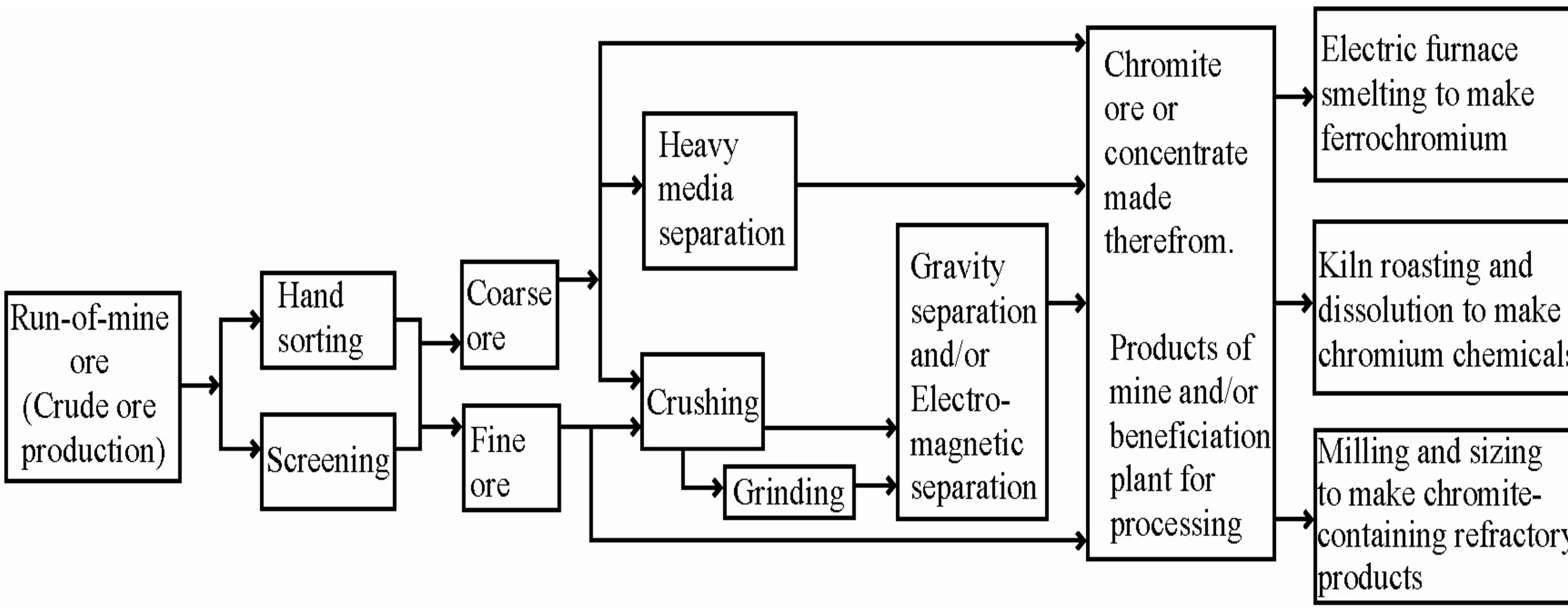


Units: Thousand metric tons, marketable chromite ore.

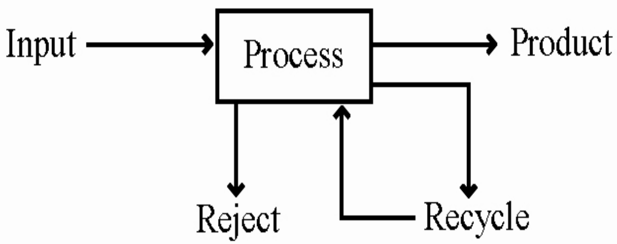
Note: United States chromite production is expected to reach 0.04 Mt/yr after 2006.

Slide 10. This slide shows chromite ore material flow from mining, on the left, through various stages of industrial processing moving to the right. Once mined, the chromite ore is beneficiated at the mine site and then shipped to a chromium chemical-, chromite refractory-, or chromium ferroalloy-producing plant. Most chromite, over 90%, is converted into ferrochromium, which is used to introduce chromium into alloys, primarily stainless steel, or to make chromium metal. Sometimes, a single beneficiation plant is fed by several mines; however, it is more common that beneficiation takes place at the mine site where the beneficiation process is tailored to the mine's product.

Chromite ore material flow



Note:
Not shown above are reject and recycle fraction that are associated with most processes as shown to the right.

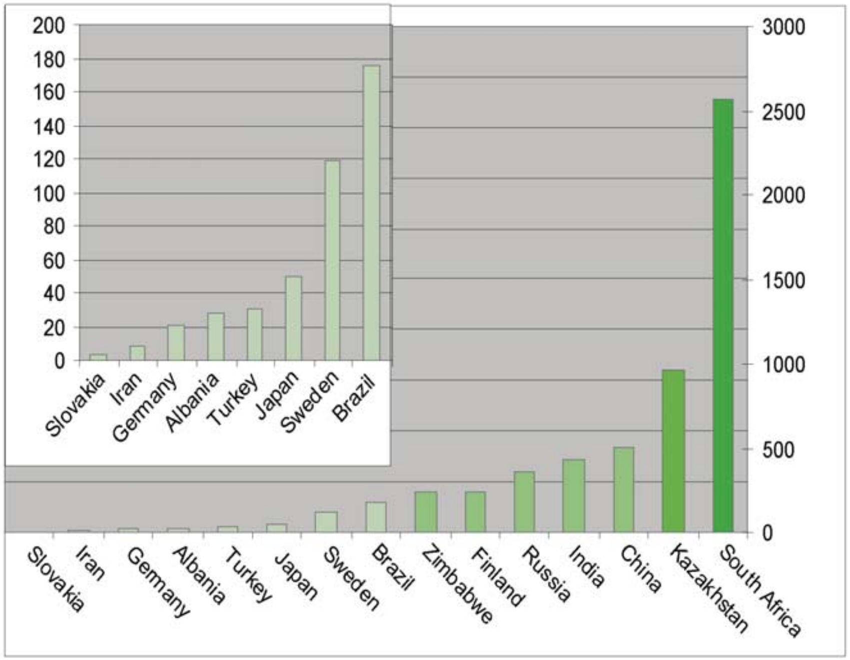


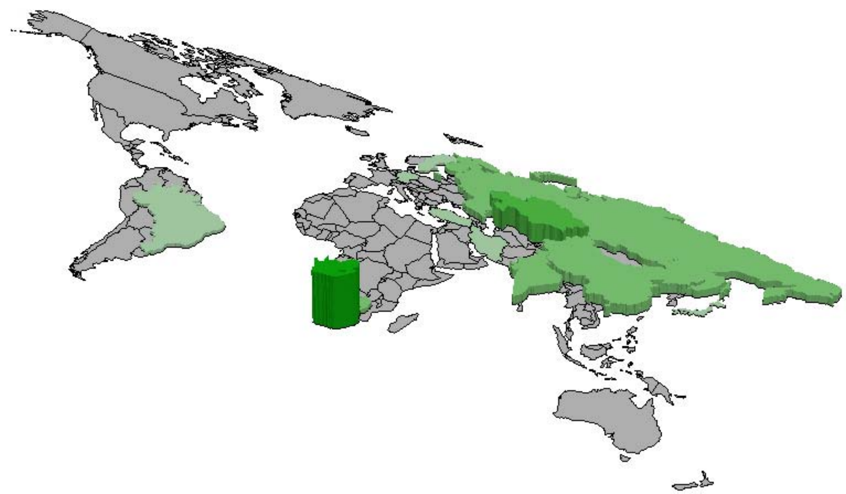
Slide 11. This slide shows (2001-05) average annual ferrochromium production, which accounts for 90% of chromite ore consumption.

Ferrochromium production is an electrical-energy intensive process that requires chromite ore, fluxes (quartzite), and carbon (e.g., coal, coke, charcoal). Ferrochromium production, like chromite ore production, is geographically concentrated in the Eastern hemisphere; however, it is more geographically distributed than is chromite ore production. The leading chromite ore producers are among the leading ferrochromium producers. Chinese ferrochromium production is based mostly on chromite ore from South Africa, India, and Kazakhstan. China has invested in the production of chromite ore and ferrochromiumin South Africa. Russian ferrochromium production is based mostly on chromite ore from Kazakhstan.

Since it takes about 2.5 tons of chromite ore to make 1 ton of ferrochromium, significant transportation cost savings can be made by producing the ferrochromium near to the source of chromite ore. New ferrochromium plants are built above chromite ore deposits to minimize transportation cost.

Average annual ferrochromium production





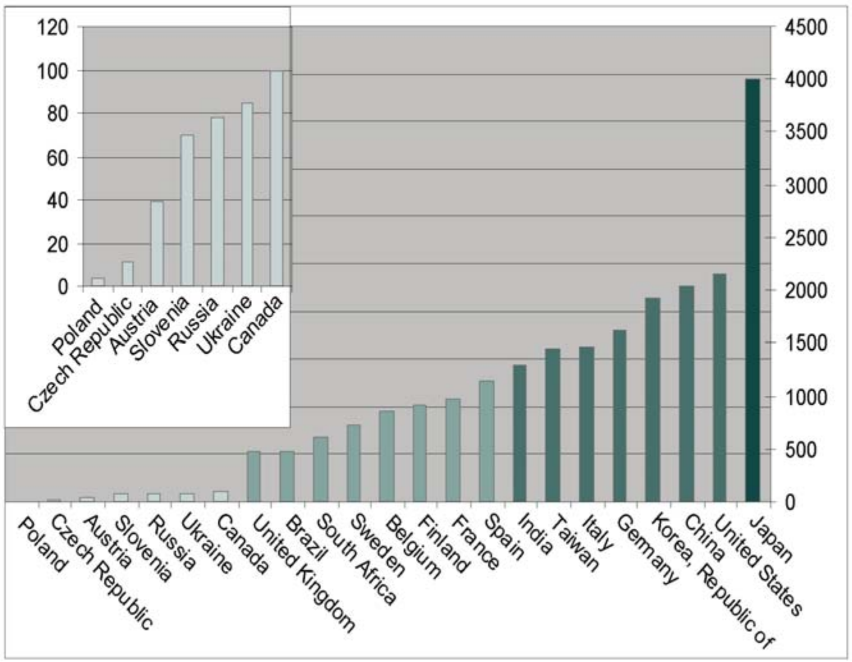
Units: Thousand metric tons, gross weight.

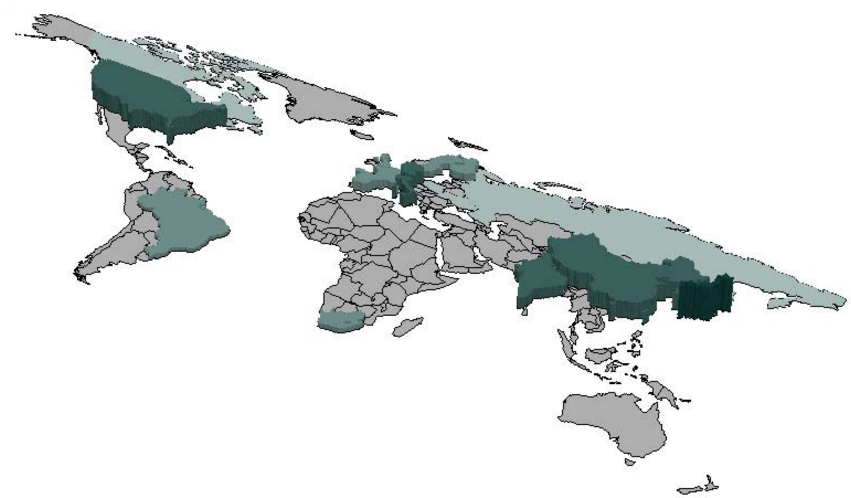
Note: 2001-05 average U.S. net imports were 352,000 kt/yr.

Slide 12. About 80% of ferrochromium is used to make stainless steel (based on reported U.S. consumption of chromium ferroalloys and metal in 2005). This slide shows that the geographic distribution of stainless steel producers differs substantially from that of chromite ore and ferrochromium producers; however, some of those upstream producers are among the stainless steel producers. Major stainless steel producing plants are located in Asia, Europe--including Scandinavia, and the Americas. In Europe, stainless steel is produced in Austria, Belgium, England, Finland, France, Germany, and Sweden. In Asia, China, Japan, and Korea are leading producers. In the Americas, Brazil and the United States produce stainless steel.

Stainless steel contains about 17% chromium (based on American Iron and Steel Institute reported U.S. production by grade). If all of the chromium came from ferrochromium, one ton of ferrochromium would be required to produce 3 to 3.5 tons of stainless steel; however, some chromium comes from recycled stainless steel scrap. The stainless steel industry produces mill products; bars, plates, rods, rolls, and sheets in a variety of sizes.

Average annual stainless steel production

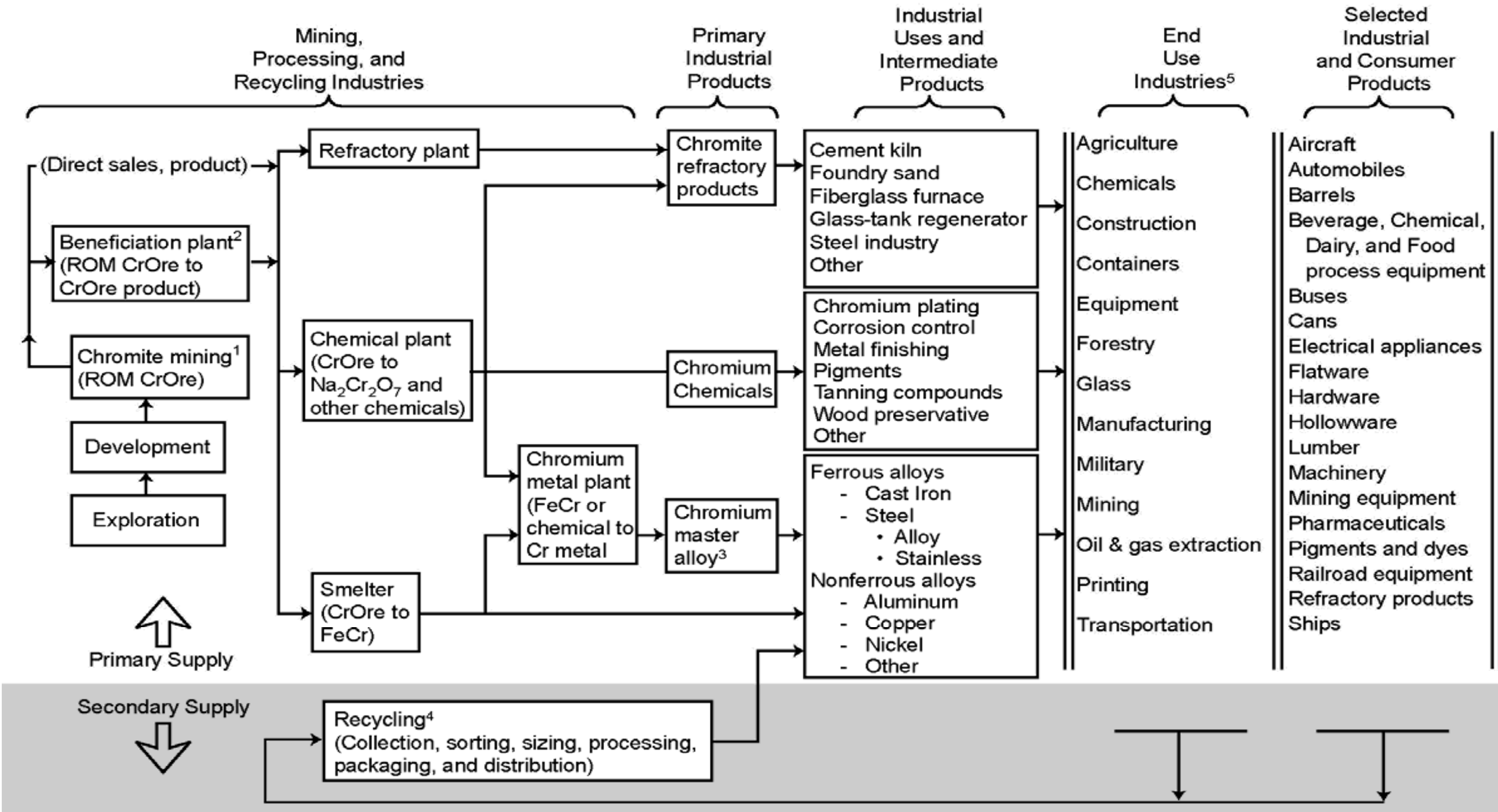




Units: Thousand metric tons, gross weight.

Slide 13. This chromium material flow slide shows mining, at the left, through end uses, at the right. Recycling is indicated at the bottom. Stainless steel is used in a wide variety of industries and in a wide variety of products. Stainless steel mill products are used to make parts, which are incorporated in components, which are incorporated in industrial and consumer goods. Stainless steel finds its way into many products.

Chromium material flow to end uses



Notes:

CrOre = Chromite ore
FeCr = Ferrochromium
$Na_2Cr_2O_7$ = Sodium dichromate
ROM = Run-of-Mine

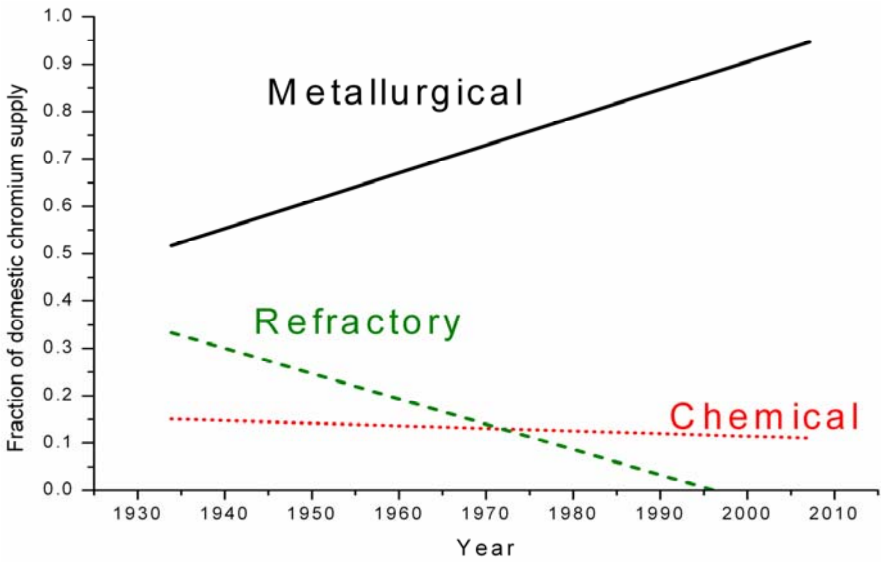
[1] Mining includes screening and hand sorting.
[2] Beneficiation includes crushing, grinding, and separation techniques including gravimetric, heavy media, magnetic, and spiral.
[3] Master alloy is an alloy used as a feed stock to produce other alloys.
[4] Chromium materials derived from industrial processing and post consumer goods.
[5] Based on North American Industrial Classification system.

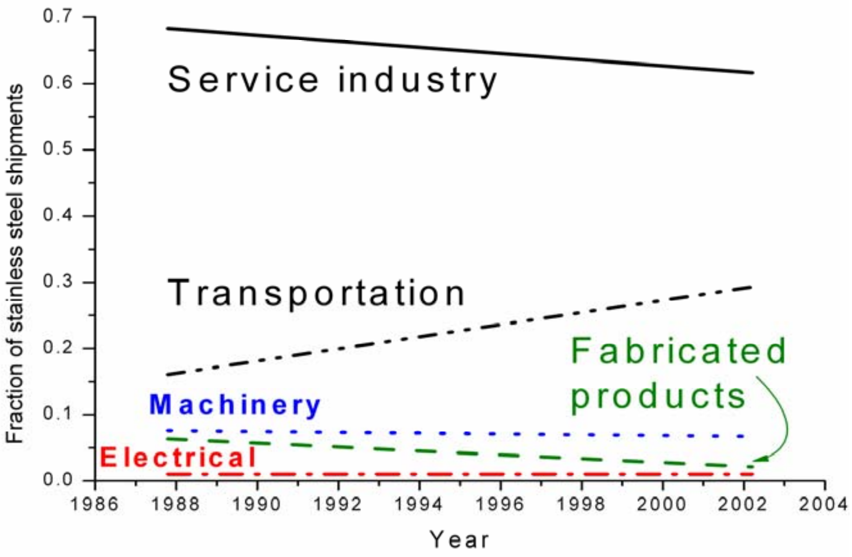
Slide 14. On the left is the trend of the distribution of U.S. chromium consumption by major markets from 1930 through 2010 (based on data from 1940 through 2001) and, on the right, is the trend of stainless steel shipments among metallurgical markets from 1988 through 2002 (based on data from 1989 through 2001). Metallurgical means feed materials that end up in metal alloys. Refractory means materials used to make furnace linings or heat exchangers. Chemical means feed materials that end up in chemicals. This distribution is not representative of other countries because the United States is one of the few countries that produces chromium chemicals.

As pointed out above, most chromium ends up in stainless steel. Using the distribution of stainless steel to represent all metallurgical uses, these distributions may be combined to get …

U.S. chromium consumption

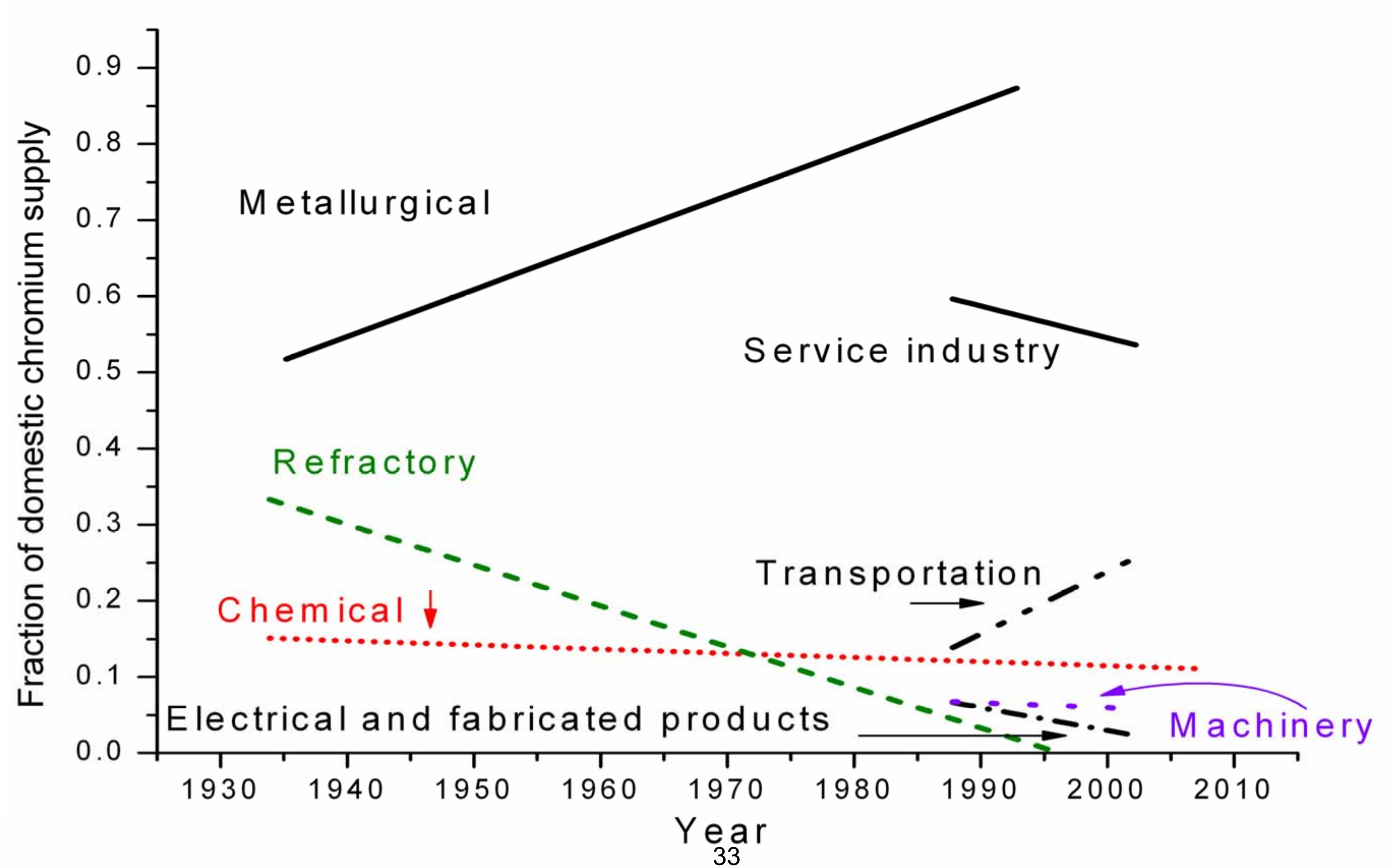
among major markets and metallurgical markets





Slide 15. U.S. chromium distribution by market. One may observe that (1) metallurgical use dominates the domestic market, just as it does internationally; that (2) refractory use was historically significant but is now very small; and that (3) chemical use is declining slowly. The slide shows that the service industry has dominated the metallurgical market since the late 1980s but is declining, and there is growing use by the transportation industry. The data seem to show that the transportation industry may bypass the service industry and source its stainless steel purchases from domestic stainless steel producers.

U.S. chromium use by market

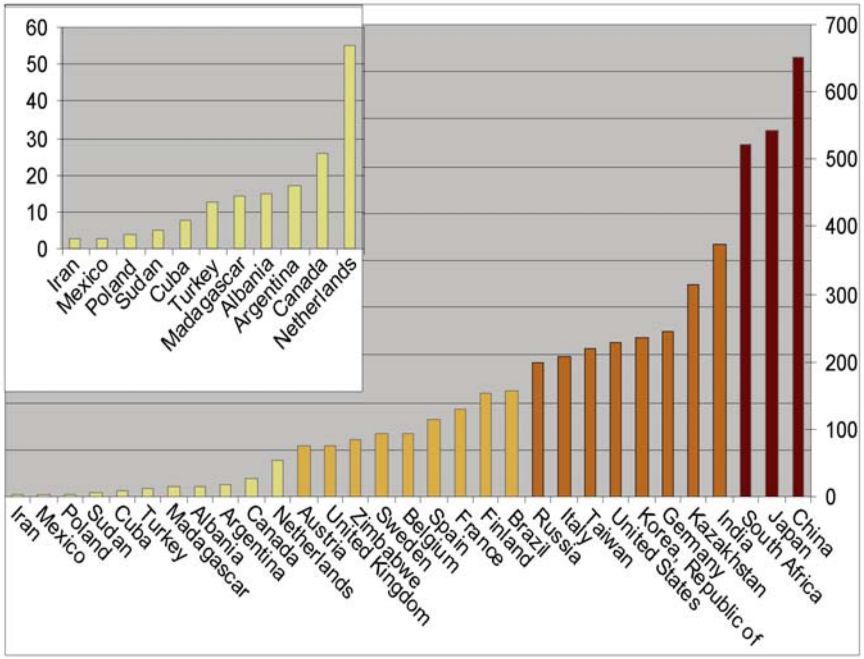


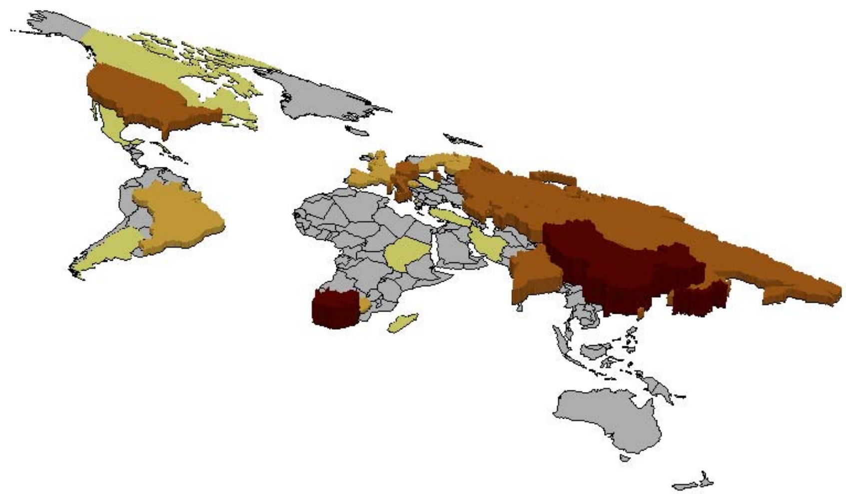
Slide 16. This slide shows (2001-05) average annual chromium consumption. It shows that (1) chromium consumption is more geographically distributed than ferrochromium or chromite ore production is and that (2) China and Japan are leading chromium consumers. Stainless steel producing countries play a leading role among chromium consumers.

Anthropogenic chromium material cycle analysis (Johnson, 2006) was applied at the global, regional, and country level; accounting for 98% of chromite ore and more than 99% of stainless steel production among 9 regions containing 54 countries. These countries accounted for 94% of the global gross domestic product and 77% of the world's population. The study found that chromium-containing material flow into in-use stocks was proportional to chromium flow into use by country and region. The leading flows into use (in descending order of amount) by region were Europe, Asia, and North America. The study found that "metal goods and other uses" and "industrial machinery" dominated end uses in the leading regions and "industrial waste, end-of-life vehicles, and other uses" dominated discard flows. Measured in contained chromium, Africa was the leading net exporter of chromium-containing materials, while Asia dominated finished-product trade to North America.

(For the purpose of comparing consumption among countries, consumption was computed as chromite ore production plus net trade of chromite ore, ferrochromium, and chromium metal. In other words, recycling and stock changes used as part of the domestic apparent consumption estimate had to be ignored because such information is not available for most countries.)

Average annual chromium consumption





Units: Thousand metric tons, contained chromium.

Slide 17. When the U.S. economy dominated the world economy in the post-World War II period, it was said "When the United States sneezes, the rest of the world catches a cold." in reference to the economic impact of the United States on the world economy. World economic changes were driven by domestic U.S. policies and politics. Strikes, inflation, strong economy, and weak economy in the United States affected most other free world economies, because they depended on the U.S. economy. As this slide shows, China has displaced the United States as the leading chromium consuming and stainless steel producing nation. Events in China are now likely to have major impact on, if not dominate, the chromium industry.

(As pointed out previously, in 2005 over 90% of the chromite ore mined in the world ended up in ferrochromium, and in the U.S. about 80% of reported consumption ended up in stainless steel. Assuming that the U.S. use of ferrochromium is representative of world use, about 75% of chromium production ended up in stainless steel. Most chromium goes into the metallurgical industry as an alloying element, and most of that goes into stainless steel.)

World chromium consumption

- “China is now the leading user of stainless steel in the world.”(Nickel Magazine)
- China is now the leading user of chromium in the world.
- 1996–2006 Stainless steel production trend
  - China increased ~5X
  - India, Finland increased > 2X
  - Belgium, Brazil, Italy, Kazakhstan, Republic of Korea, and Taiwan increased < 2X
  - Germany, Japan, Spain, US -small change
  - France, Sweden, UK -decreased

Slide 18. The major marketplace chromium-containing material (chromite ore, ferrochromium, and chromium metal) values are documented in trade statistics and prices, in trade journals. U.S. trade (quantity and value) of chromite ore was first reported (in the Minerals Yearbook chromium chapter) in 1884; ferrochromium, in 1915; and chromium metal, in 1946; permitting one to compute unit values for those materials since those years.

Trade journals have monitored chromite ore, ferrochromium, and chromium metal prices continually since about 1950.

Chromium value & price

	Year first reported	
Material	Value	Price
Chromite ore	1884	~1950
Ferrochromium	1915	~1950
Chromium metal	1946	~1950

Value: Mass-weighted average value of U.S. imports.
Price: As reported in trade journals.

Slide 19. These values are unit value of U.S. imports. Price is from trade journals. Prices and values are similar by material and show a similar progression with increasing processing. In other words (based on dollars per unit of contained chromium), ferrochromium is about three times the cost of chromite ore, and chromium metal is about six times the cost of ferrochromium.

Judging from these values and prices, the U.S. appears to be importing less costly grades of chromite ore; higher than median cost grades of ferrochromium; and the most costly grades of chromium metal.

Chromium value & price in 2005

Material	Value	Price
Chromite ore	$437	$523
Ferrochromium	1,425	1,241 – 1,221
Chromium metal	8,007	4,935 – 8,165

CrOre:FeCr ~ 1:3.

FeCr:CrMtl ~ 1:6.

Units: $/metric ton, contained Cr.

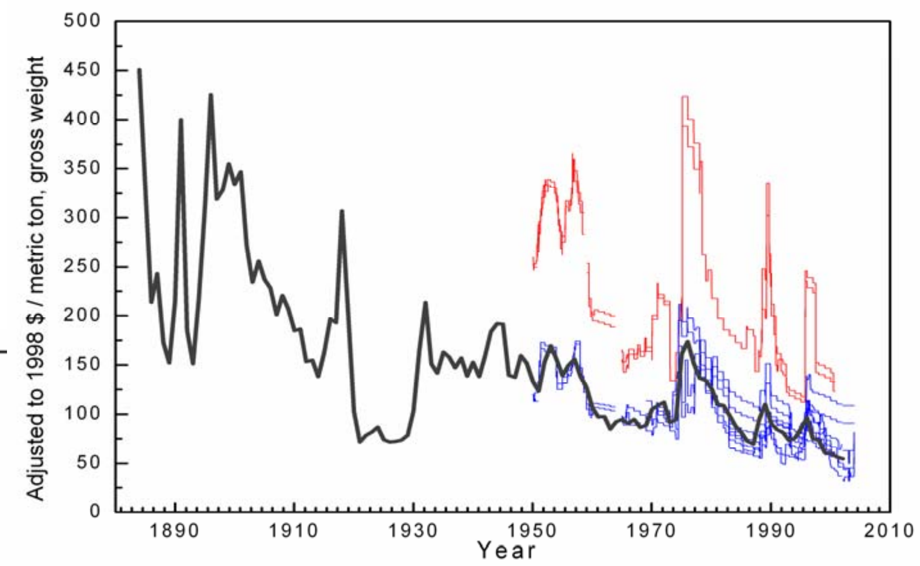
Value: Mass-weighted average value of U.S. imports.

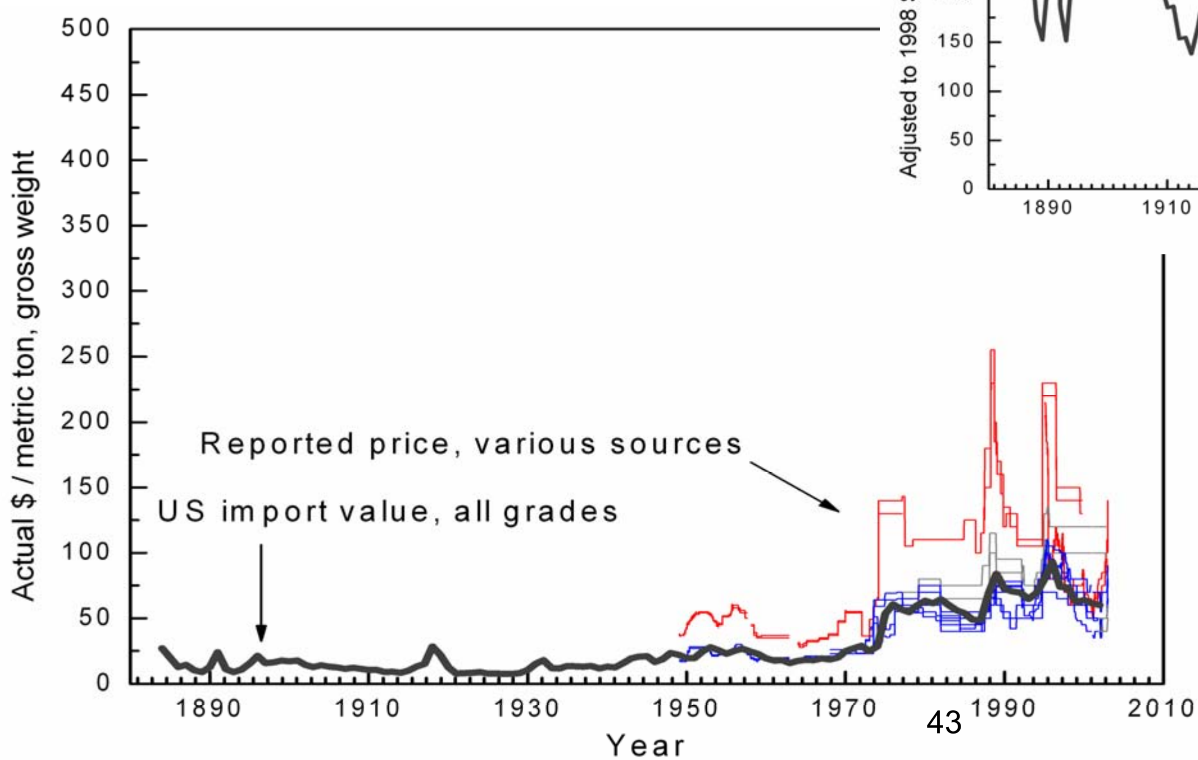
Price: As reported in trade journals.

Slide 20. On the left are chromite ore prices and import values in actual dollars from about 1900 to the present. On the right are the same data adjusted to constant (1998) dollars. The leading suppliers of chromite ore to the United States during this time period were South Africa and Turkey.

Turkish prices are shown in red; South African, in blue. The wide black line is import value averaged over all grades. The price of chromite ore reported by use or from countries other than South Africa or Turkey are shown in gray. The United States imported more South African ore than Turkish ore. As a result, the average import value is nearer to the South African price. The slide shows (1) that mass-weighted average import value reflects reported prices and trade, (2) the mass-weighted average import value reflects reported price trend, and (3) the price of chromite ore today, adjusted for inflation, is less than it was during the Great Depression.

Historical price and value trend of chromite ore





Blue: South Africa.
Red: Turkey.
Black: Import value.

Slide 21. U.S. chromium supply travels over long supply routes because resources and production are in the Eastern hemisphere. The major producers of chromite ore and ferrochromium are politically and economically dynamic nations. The United States is chromium import dependent and that dependence has shifted from chromite ore to ferrochromium.

There are no substitutes for chromium in its major end use–stainless steel. Stainless steel is not stainless steel without chromium. Of course, one can substitute stainless steel scrap for ferrochromium. One can also substitute other metal alloys for stainless steel; however, either cost or performance is compromised.

Observations / Conclusions

- Resources and production are mostly in the Eastern hemisphere.
- U.S. chromium imports travel over long supply routes.
- Geopolitical situation
  - Producers: India, Kazakhstan, South Africa
  - Consumers: China, Europe, United States
- Chromium comes from politically and economically dynamic areas.
- The United States is import dependent for chromium.
- U.S. net import reliance has shifted from CrOre to FeCr.
- Substitutes in chromium's major end use –None.

Slide 22. From 2001 through 2005, World chromium production has grown at an average annual rate of about 12%, as has U.S. apparent consumption; however, U.S. net import reliance has grown only 3%.

A chromium-materials stockpile might be used to provide material needed by industry in the event of a national emergency until new mines can be brought into production. Since the dissolution of the USSR in 1991, the United States has been selling off chromium materials from the National Defense Stockpile. If there is no threat that would cause industry to increase production of machinery or military equipment faster than new mines could be developed, and resources are adequately distributed so that security of supply is not a problem, then high stockpile levels would not be needed.

Observations / Conclusions (continued)

- World and U.S. Market – growing.

	Average annual growth (2001-05)
WP	12%
AC	12%
NIR	3%

Note: WP – World chromite ore production. AC – U.S. chromium apparent consumption. NIR – U.S. net import reliance.

Slide 23.

References

This work was supported by the Minerals Resources Program, U.S. Geological Survey.

Robert Callaghan prepared the bar charts, world maps, and material flow figures.

American Iron & Steel Institute, 2006, 2005 Quarterly production of stainless and heat-resisting steel (AIS104, 4th quarter), June.

International Chromium Development Association, 2006, Statistical Bulletin: Paris, France, 45 p.

Johnson, Jeremiah, 2006, Contemporary chromium flows from mining to recycling: International Chromium Development Association Meeting 2006, Cape Town, South Africa, February 22-24, Presentation, [unpaginated].

Nickel Magazine, 2006, China's Challenge: Nickel Magazine, v. 21, no. 4, July, p. 3.

Papp, J.F., 2006, Chromite, *in* Industrial Minerals and Rocks—Commodities, Markets, and Uses, 7th Edition: Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, p. 309-333.

Papp, J.F., 2004, Chromium use by market in the United States: Proceedings of the Tenth International Ferro Alloys Congress, 1-4 February, Cape Town, South Africa. *http://minerals.usgs.gov/minerals*