Oryx Stainless
Research Series

Key raw materials nickel, chrome and iron: Limited availability despite sufficient geological reserves?

September 2012

What are the relevant criteria for the determination of the criticality of nickel, chrome and iron?

A study by
Prof. Dr. Matthias Finkbeiner,
Chair of Sustainable Engineering,
Technische Universität Berlin
on behalf of
Oryx Stainless

TU berlin — SUSTAINABLE ENGINEERING

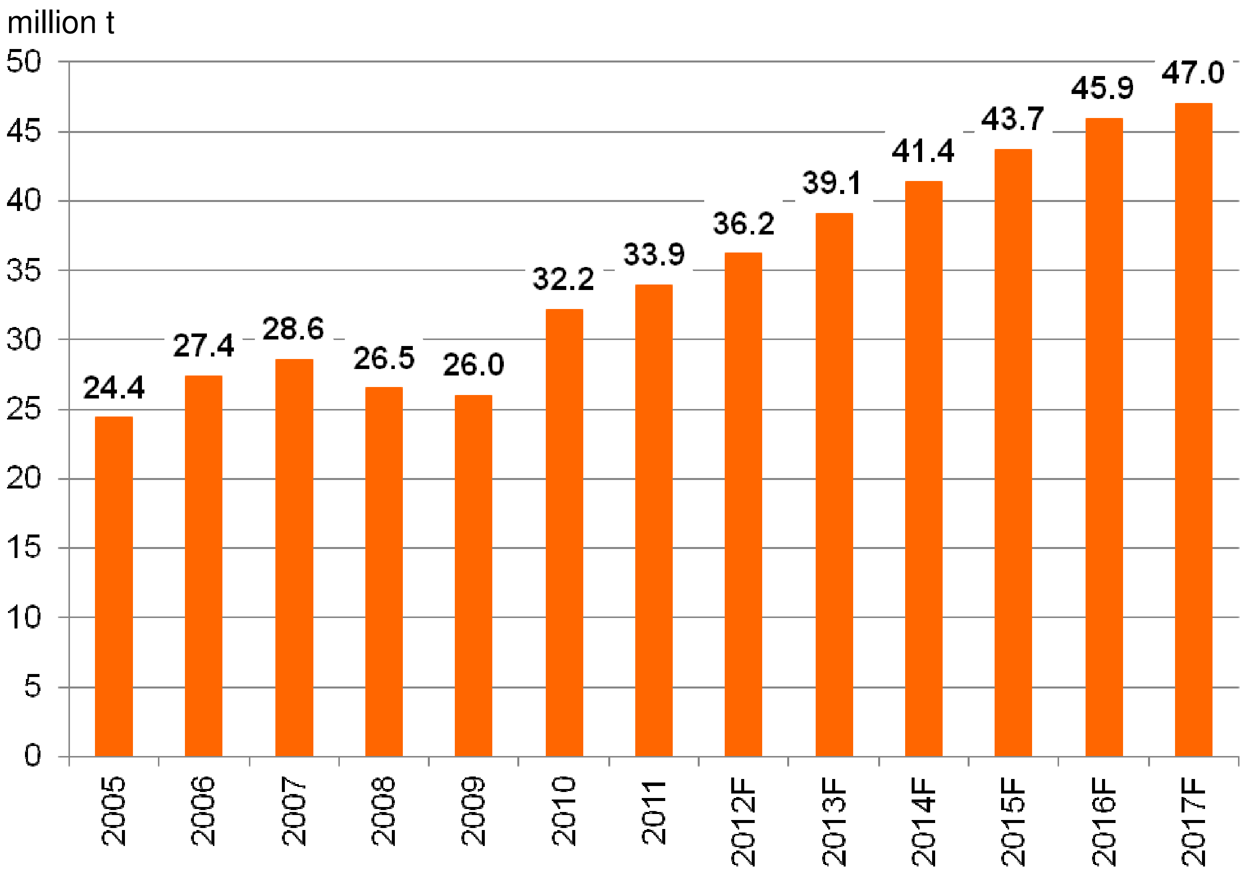
ORYX STAINLESS
A BRAND OF THE KMR GROUP

1. **Market environment and starting point**
2. Study – Models and Methods
3. Results
4. Conclusion
5. Research Team
6. About Oryx Stainless

ORYX STAINLESS

A BRAND OF THE KMR GROUP

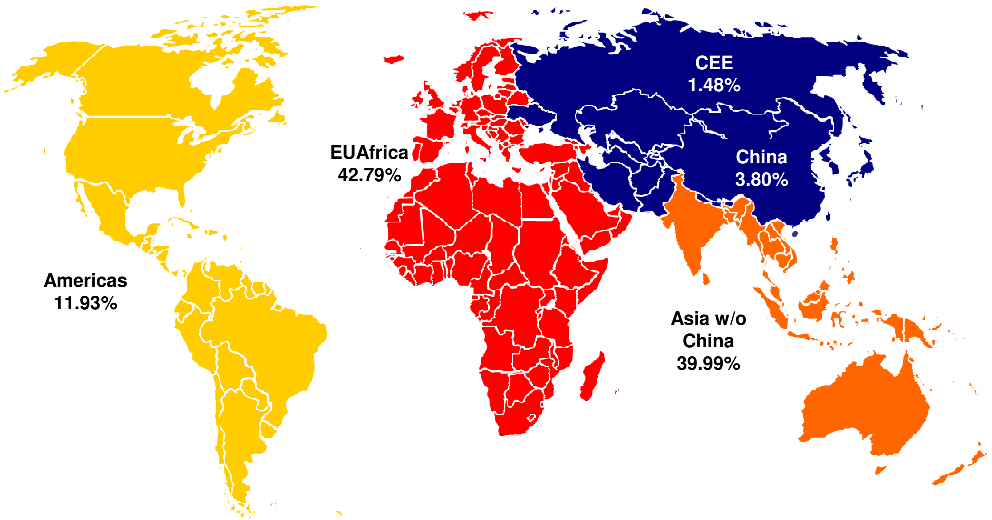
Stainless steel production continues to grow



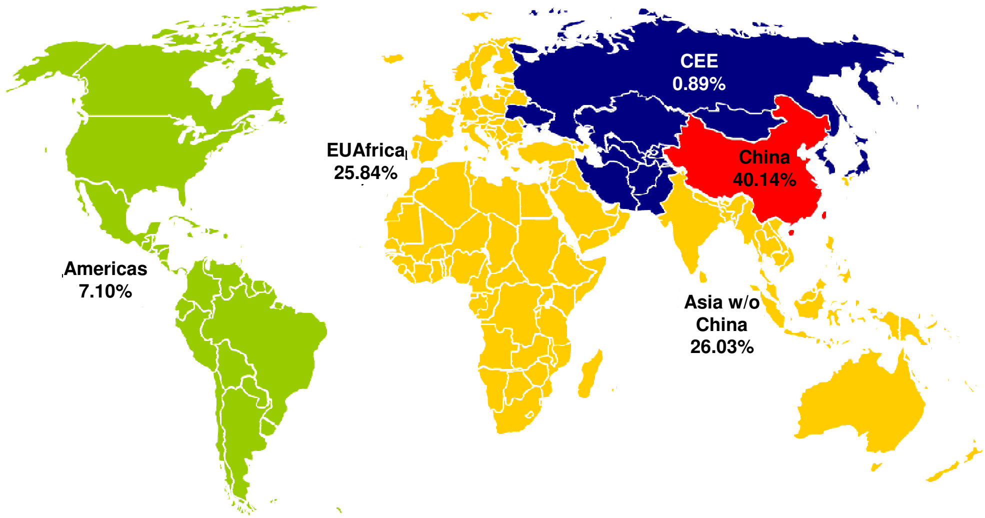
Source: ISSF, INSG, Macquarie Research, May 2012

Growth mainly stimulated by China

Worldwide stainless steel production 2001: 19.1 million t



Worldwide stainless steel production 2012E: 36.2 million t

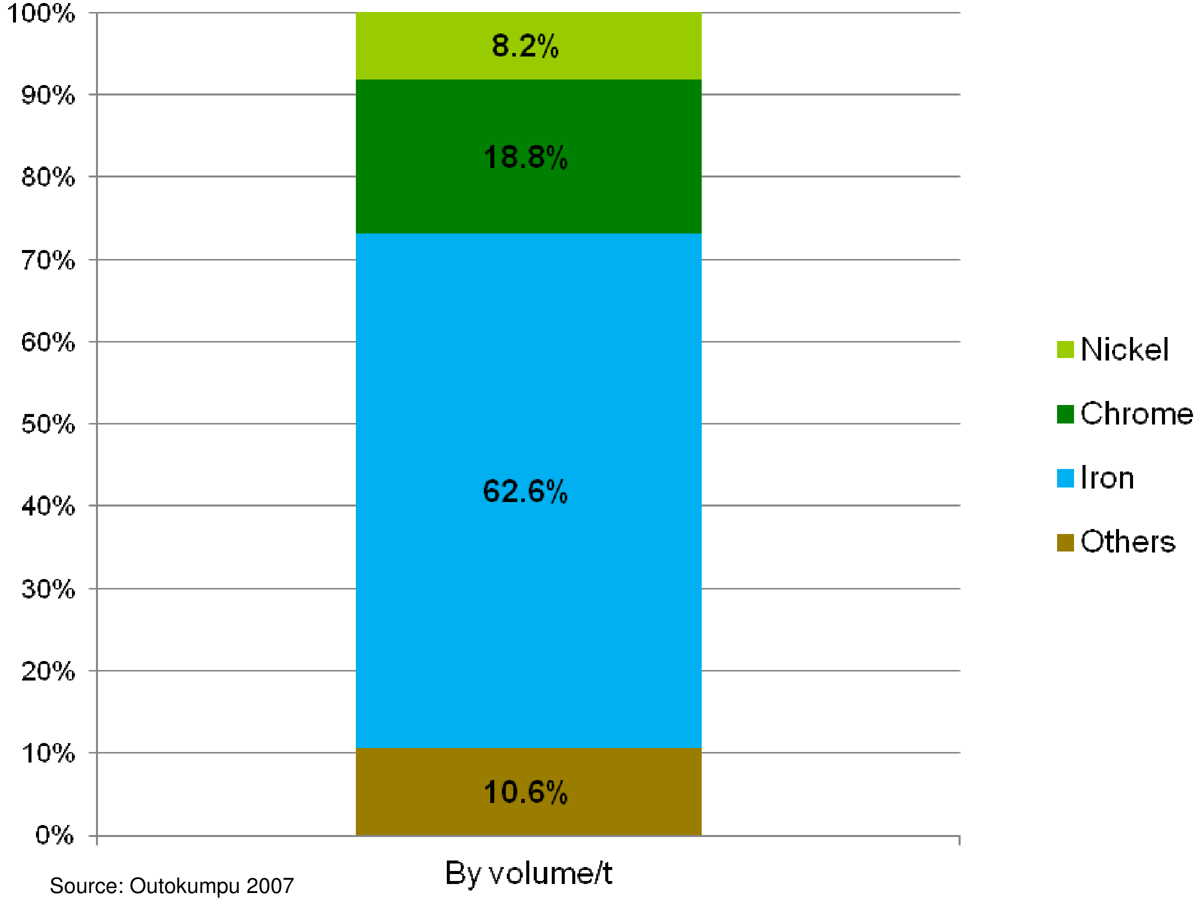


Share of world production

- > 40%
- > 30%
- > 10%
- > 5%
- < 5%

Source: ISSF, Macquarie Research

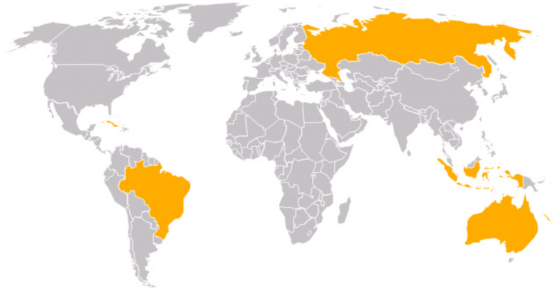
Main components of stainless steel: Nickel, chrome and iron



Source: Outokumpu 2007

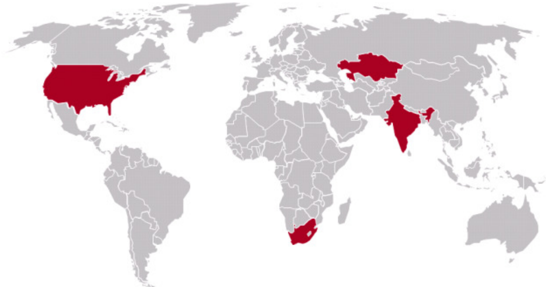
Strong (but limited) geological reserves

Worldwide resources of nickel*



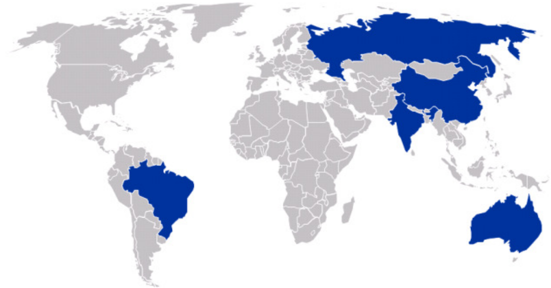
	Production (t)	Reserves (t)
Australia	180,000	24,000,000
New Caledonia	140,000	12,000,000
Brazil	83,000	8,700,000
Russia	280,000	6,000,000
Cuba	74,000	5,500,000
Indonesia	230,000	3,900,000
South Africa	42,000	3,700,000
Canada	200,000	3,300,000
China	80,000	3,000,000
Madagascar	25,000	1,600,000
Philippines	230,000	1,100,000
Dom. Republic	14,000	1,000,000
Colombia	72,000	720,000
Botswana	32,000	490,000
Other Countries	100,000	4,600,000

Worldwide resources of chrome*



	Production (tsd. t)	Reserves (tsd. t)
Kazakhstan	3,900	220,000
South Africa	11,000	200,000
India	3,800	54,000
United States	NA	620
Other Countries	5,300	NA

Worldwide resources of iron (content)*



	Production (mio. t)	Reserves (mio. t)
Australia	480	17,000
Brazil	390	16,000
Russia	100	14,000
China	1,200	7,200
India	240	4,500
Venezuela	16	2,400
Canada	37	2,300
Sweden	25	2,200
Ukraine	80	2,100
United States	54	2,100
Iran	30	1,400
Kazakhstan	24	1,000
Mauretania	11	700
South Africa	55	650
Mexico	14	400
Other countries	50	6,000

* five highest reserve countries

Source: US Geological Survey, 2012

Access to and availability of raw material more important in times of “resource wars”

But is it really all about geological resources and availability?

I. Market environment and starting point

II. Study – Models and Methods

III. Results

IV. Conclusion

V. Research Team

VI. About Oryx Stainless

ORYX STAINLESS
A BRAND OF THE KMR GROUP

Task of the study

Beyond the geological availability, are there other criteria which are relevant for the determination of the criticality?

What are the most important criteria for the determination of the criticality?

- Scientific study on which factors beyond geological reserves are relevant to the availability of the primary raw materials for the stainless steel production
- Focus on nickel, chrome and iron

How much does the availability of raw materials differ when economic aspects other than geologic availability are taken into account?

What is the most critical component of stainless steel under economic aspects?

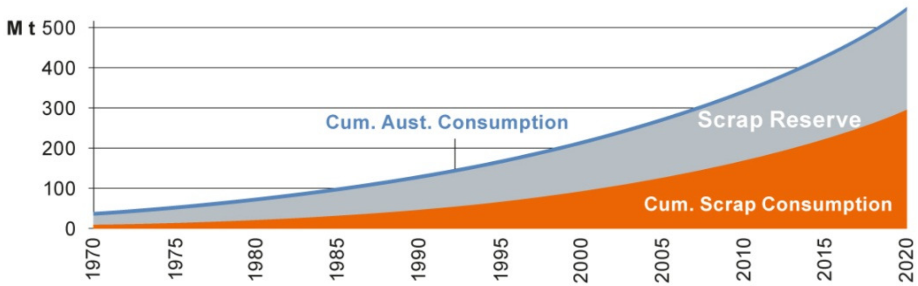
Only limited research on factors beyond geological availability so far

- Raw material availability is influenced by many factors
- New challenges
  - Longer supply chains due to specialization and outsourcing
  - Geographically dispersed supply chains as a result of globalization
  - Higher risk of disruption due to increasing complexity of supply
  - Monolithic control of resources or changes in government policies
- Research on the actual criticality beyond the geological availability for selected raw materials only; strong focus on presumably scarce raw materials like lithium or rare earth elements
- Key components of stainless steel were not the focus of earlier research
- Nickel, chrome and iron: Focus mainly on geological resources
- Black box new material class stainless steel scrap – the important nickel, chrome and iron resource

Key factor new raw material class stainless steel scrap

- Today on average 50% stainless steel scrap used for each ton of new stainless steel
  - Purchase price advantage over primary raw material
  - Lower processing costs, e.g. due to higher energy efficiency
  - Environmental advantage over primary raw material due to CO_2 savings

in M t	1980	2000	2009	2010	2020
Cumulated austenitic consumption	66.1	207.6	320.7	335.5	543.1
Cumulated scrap consumption	20.2	91.4	157.4	167.2	296.9
Scrap reserve	45.9	116.3	163.3	168.3	246.2



Source: Heinz H. Pariser

Several institutions are currently beginning to assess additional aspects beyond geological availability

NATIONAL RESEARCH COUNCIL

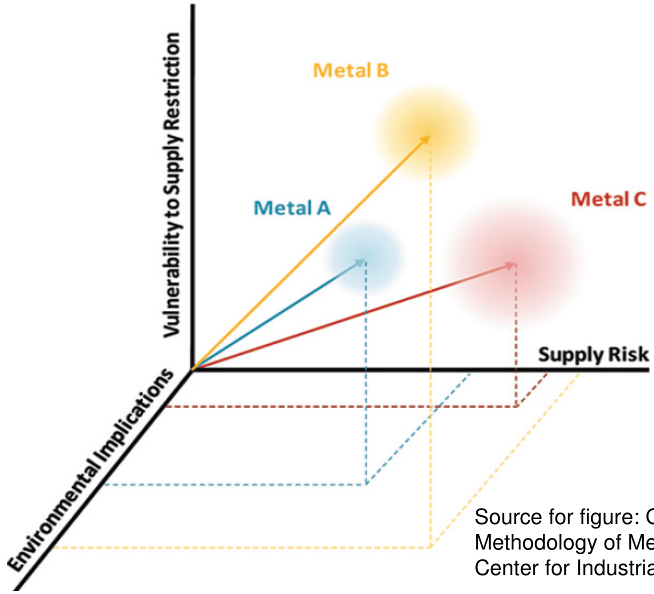
EUROPEAN COMMISSION

VDI

Yale University Center for Industrial Ecology
YALE SCHOOL OF FORESTRY & ENVIRONMENTAL STUDIES

KFW

IZT
Institut für Zukunftsstudien und Technologiebewertung
Institute for Futures Studies and Technology Assessment



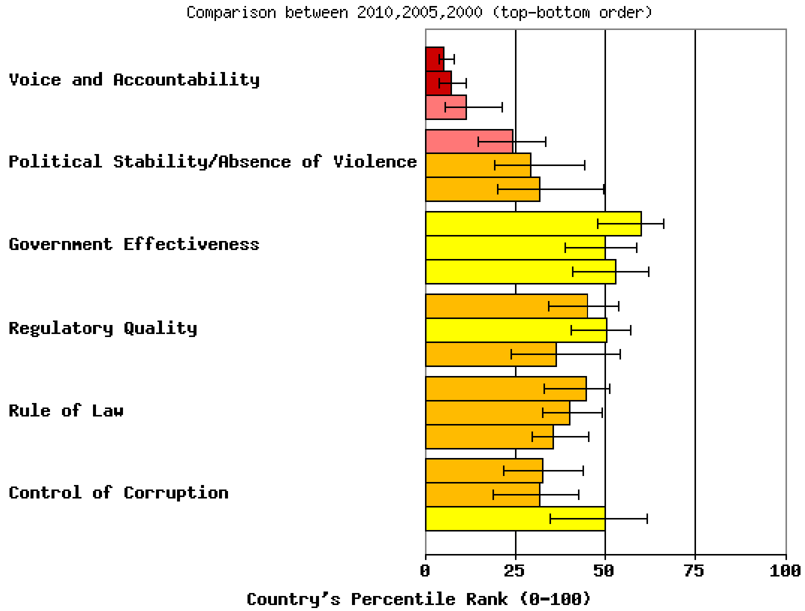
Source for figure: Graedel et al. (2011): Methodology of Metal Criticality Determination, Center for Industrial Ecology, Yale University

- Different approaches and different criteria = different results for material criticality
- Which aspects are quantified and how?
- Corporate, national or global approach
- Relevance of aspects: short-, medium-, long-term
- Validity of indicators

The TU Berlin approach: The relevant aspects for assessing the criticality of materials

Recycling rate	Recycled content of a material
Reserve-to-production ratio	Geological availability (displaying current production technologies)
Country concentration	Reserve concentration in certain countries
Company concentration	Concentration of production/extraction activity in certain companies
Political stability	Stability and safety associated with a country
Demand growth	Assumed increase of demand in future
Barriers to trade	Percentage of production subject to trade barriers

$$H := \sum_{i=1}^{N} a_i^2$$



Sources for figure: http://info.worldbank.org/governance/wgi/sc_chart.asp

The TU Berlin approach: Quantification of aspects

Aspects influencing raw material availability and indicators enabling their quantification

Aspect	Indicators	
Reserves	1/depletion time	Years→ 1/a
Recycling rate	New material content	%
Country concentration	Herfindahl Index (HHI)	Value between 0 and 1
Stability	World Bank’s World Governance Indicators (WGI), scaled	Value between 0 and 1
Company concentration	Herfindahl Index (HHI)	Value between 0 and 1
Trade barriers	Share of production under trade barriers in %	%
Expected demand growth	% per annum until 2025/2030	%
Substitutability	% substituted per year (positive and negative)	%
Companion metal fraction	% produced as by-product	%
Anthropogenic reserves	Depletion time (compared to production)	%

Limiting factor: data availability

The TU Berlin approach: Aggregation of indicators

- A “criticality threshold” is included in the assessment for the quantitative comparability of indicators
- Company “targets“ as basis for the assessment
- Offers the possibility to include the perspective of the stainless steel industry
- “Distance to target”-method

$$\text{Indicator result} = \prod_i \left(\frac{\text{current value}_i}{\text{threshold}_i} \right)$$

- For each aspect a threshold/industry target is set above criticality is expected
- All values below 1(<1) are set to equal 1 (=1) in order to prevent the compensation of critical indicator results

The TU Berlin approach: When do criteria have a critical effect on availability?

Determination of targets

Indicator		Limit		
Herfindahl Index	If the value exceeds a certain threshold, signal for substantial market concentration	<	0.1	<
Worldwide Governance Indicators	Shows the quality of governance (e.g. value for Germany: 0.2)	<	0.33	<
Demand growth	Expected demand growth	<	0.01	<
Trade barriers	Percentage of the annual output affected by trade barriers	<	0.25	<
New raw material content	Based on the objective with regard to recycling	<	0.25	<
Reserve-to-production ratio	Amount of reserves divided by the amount used per annum	<	40	<

Source: TU Berlin

I. Market environment and starting point

II. Study – Models and Methods

III. Results

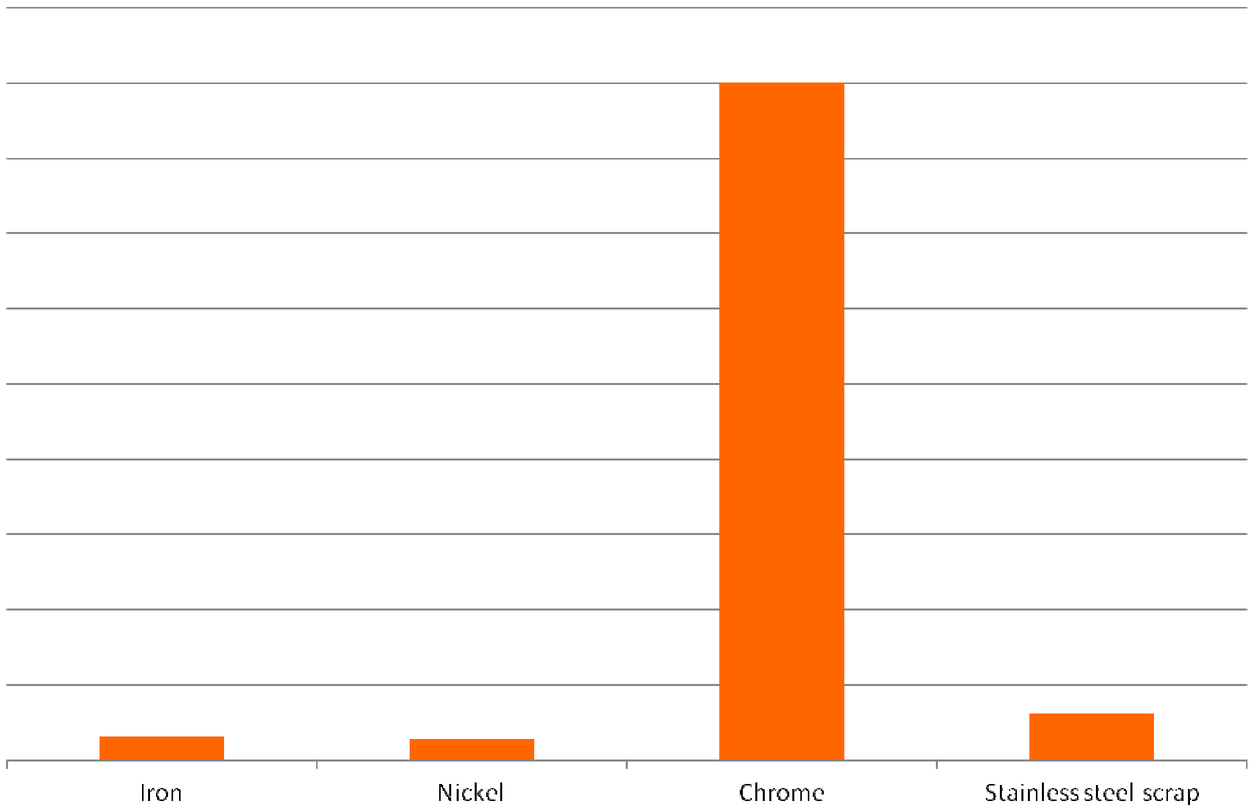
IV. Conclusion

V. Research Team

VI. About Oryx Stainless

ORYX STAINLESS
A BRAND OF THE KMR GROUP

Chrome is the most critical raw material of all main components of stainless steel



Source: TU Berlin

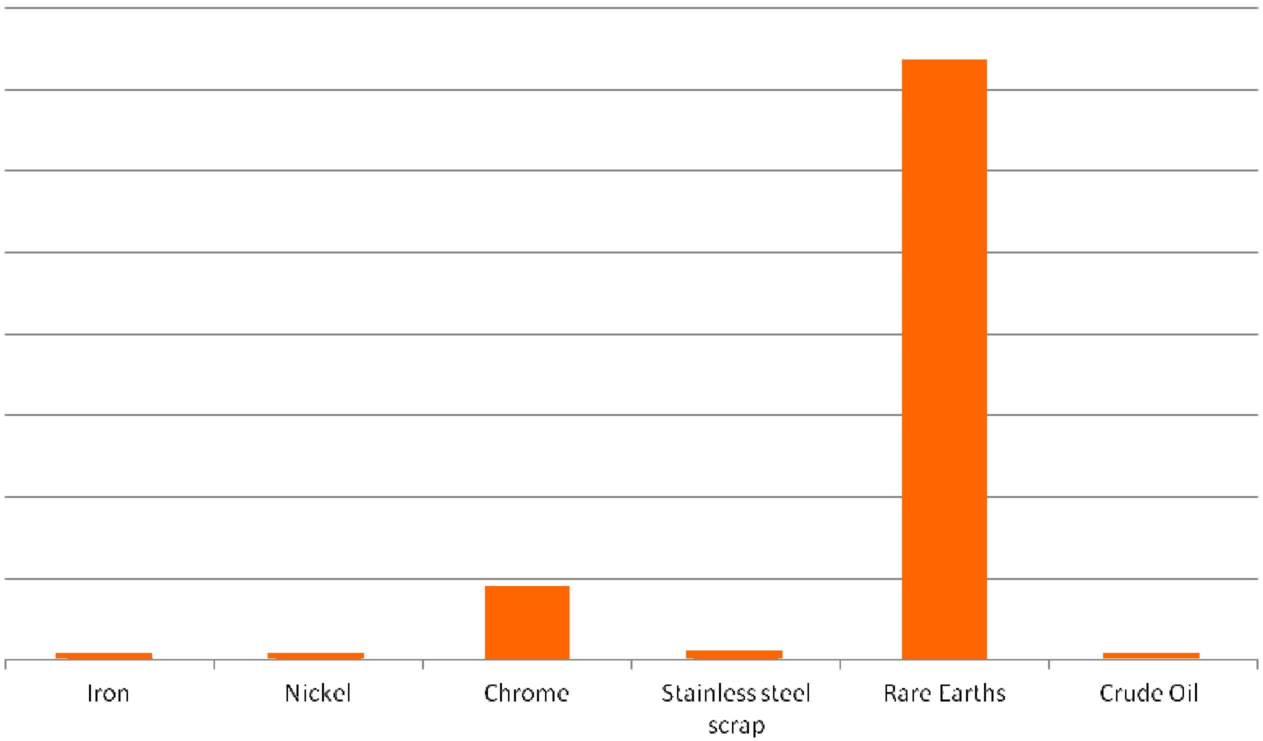
Indicators – “One size doesn‘t fit all“

- Which indicators are crucial for the results?

<table>
<tr><th>Chrome</th><th>Nickel</th><th>Iron ore</th><th>Stainless Steel Scrap</th></tr>
<tr><td colspan="4">High demand growth predictions</td></tr>
<tr><td colspan="3">High new material content</td><td>Low depletion time</td></tr>
<tr><td>Country concentration</td><td></td><td></td><td>Country concentration</td></tr>
</table>

- Results have to be viewed in relation to targets – different targets lead to different results

Chrome is far more critical than crude oil when it comes to economic aspects

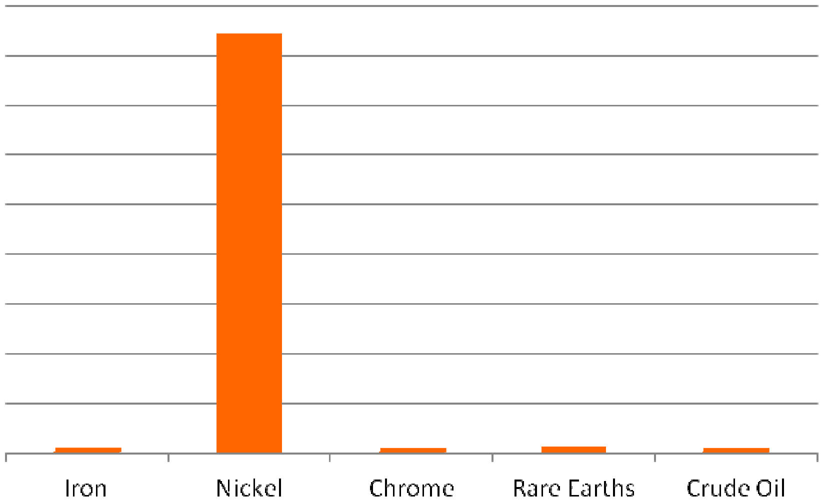


Real criticality is not reflected in public discussions

Source: TU Berlin

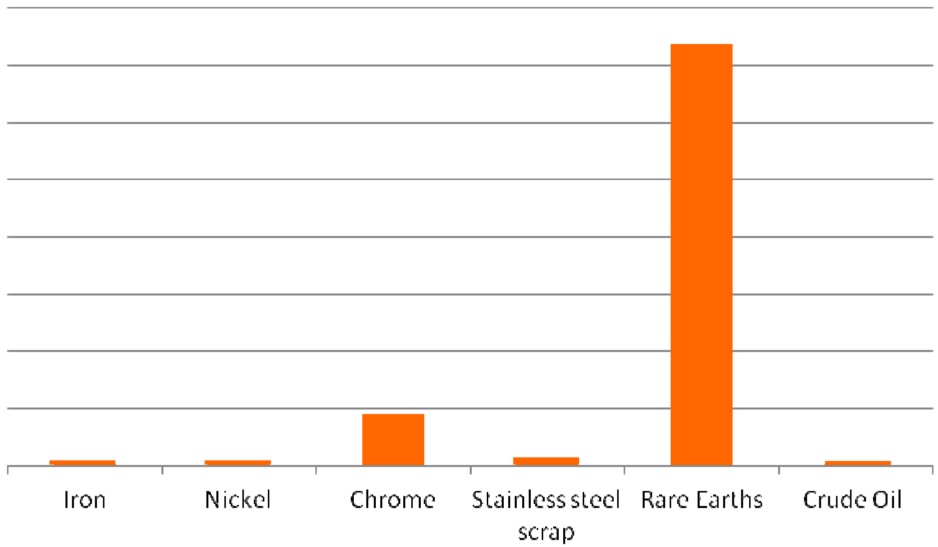
No indication regarding the “real“ availability of resources by assessing geological factors only

Geological availability only assessed by ADP*



$$^{*}ADP_{i,reserves} = \frac{\text{extraction rate i}}{(\text{reserve}_{\text{i}})^{2}} \cdot \frac{(\text{reserve antimony})^{2}}{\text{extraction rate antimony}}$$

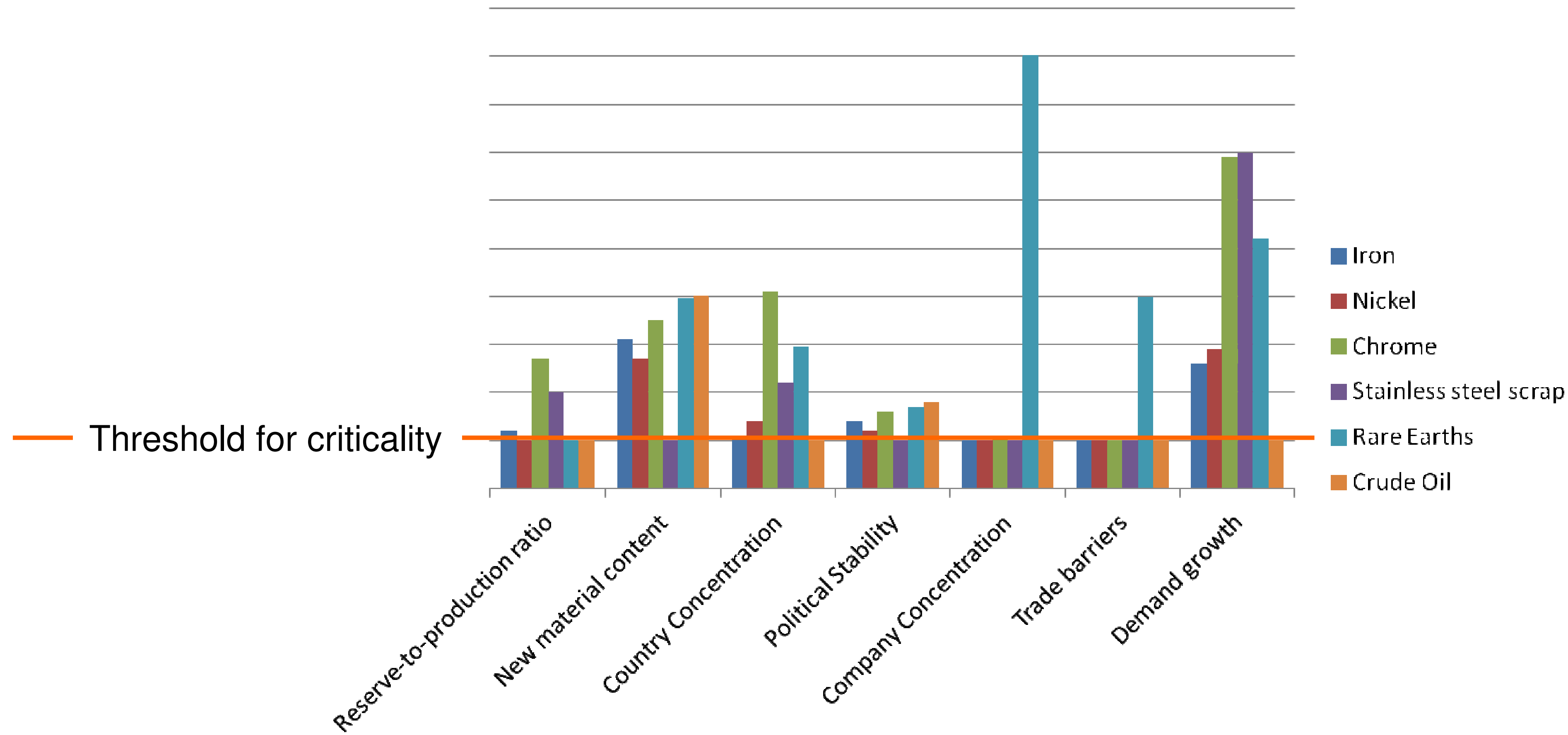
“Real“ availability based on holistic TU Berlin model



Source: TU Berlin; CML 2002

The availability of materials significantly differs when economic aspects other than geologic availability are taken into account

Increasing demand and access to scrap: Important indicators for the stainless steel industry



Raw material security: Is it really all about geological resources and availability? No!

- It is not enough to just pay attention to geological reserves. The actual availability of raw materials depends on a whole set of criteria

- In addition to increasing demand, scrap availability is critical for the stainless steel production as scrap should be considered as a raw material

- **Recycling rates must be maintained at high levels**
- **Open global markets must be developed for the most effective use of the secondary raw material scrap**
- **Supply reliability of high importance**
- **Access to sufficient and competitively priced raw materials – the success factor for the stainless steel industry in the present and the future**
- **Vulnerability of the sector or companies can be reduced or even avoided by creating alternative strategies, e.g. diversified sources of supply**

I. Market environment and starting point

II. Study – Models and Methods

III. Results

IV. Conclusion

V. Research Team

VI. About Oryx Stainless

ORYX STAINLESS

A BRAND OF THE KMR GROUP

Research team

- **Technische Universität Berlin**
  - The roots of the university go back to the year 1770
  - More than 300 professors
  - Approx. 30,000 students
- **Prof. Dr. rer. nat. Matthias Finkbeiner**
  - Head of the Chair of Sustainable Engineering
  - Teaching at Technische Universität Berlin since 2007
  - Since 2010 also Advisory Professor at Aalto University in Lahti, Finland
  - Leader of the Carbon Footprint Project of the UNEP/SETAC Life Cycle Initiative
  - Research priorities: life cycle assessment, resource efficiency, carbon footprint, water footprint, eco-design, environmental labels and certification
  - Prof. Finkbeiner was supported by the scientific assistants Laura Schneider and Markus Berger

ORYX STAINLESS

A BRAND OF THE KMR GROUP

Oryx Stainless Group

- Oryx Stainless – the internationally leading raw materials trading group
- Oryx Stainless is one of the world's leading trading organizations for raw materials employed in the stainless steel industry
- Its core business lies in handling and processing stainless steel scrap

Mülheim an der Ruhr, Germany

Dordrecht, The Netherlands

Facts & Figures

- Established: 1990
- Locations: Mülheim an der Ruhr, Germany, and Dordrecht, the Netherlands
- Oryx Stainless, a KMR Group brand, possesses a stable shareholder base that fully supports the company's long-term strategy of sustainable growth. All owners have assumed entrepreneurial responsibility within the management of the holding company or in the individual divisions
- Volume (2011): approx. 470,000 t
- Global market share: approx. 6%
- Workforce (2012): 90

Source: Oryx Stainless

Contact

Oryx Stainless Group

- Rheinstrasse 97
  D-45478 Mülheim an der Ruhr
  Phone: +49 208 5809 0
  Fax: +49 208 5809 100
- 's-Gravendeelsedijk 175
  NL-3316 AS Dordrecht
  Phone: +31 78 632 6230
  Fax: +31 78 632 6231
- info@oryxstainless.com
  www.oryxstainless.com

Technische Universität Berlin

- Prof. Dr. rer. nat. Matthias Finkbeiner
  Department of Sustainable Engineering
  Strasse des 17. Juni 135
  D-10623 Berlin
  Phone: +49 30 314 24341
  Fax: +49 30 314-21720
- matthias.finkbeiner@tu-berlin.de
  www.see.tu-berlin.de


ORYX
STAINLESS
A BRAND OF THE KMR GROUP