

# Supplementary Materials: Metal Criticality Determination for Australia, the US, and the Planet—Comparing 2008 and 2012 Results

Luca Ciacci, Philip Nuss, Barbara K. Reck, T. T. Werner and T. E. Graedel

## Numerical Results of the Criticality Parameters of the Individual Metals

**Supply Risk (medium term)**—DTM: Depletion Time (Medium Term); CF: Companion Metal Fraction; GTEM: Geological, Technological, and Economic (Medium Term); PPI: Policy Potential Index; HDI: Human Development Index; S&R: Social & Regulatory; WGI: Worldwide Governance Indicators—Political Stability & Absence of Violence/Terrorism; GSC: Global Supply Concentration; GP: Geopolitical; SRM: Supply Risk (Medium Term).

Year	Material	Supply Risk: Medium-term									
		Geological, Technological, and Economic			Social & Regulatory			Geopolitical			SRM
		DTM	CF	GTEM	PPI	HDI	S&R	WGI	GSC	GP	
2008	Aluminum	0	0	0	54	77	65	57	67	62	43
2008	Iron	14	0	7	54	73	63	60	75	67	46
2008	Nickel	51	2	26	51	79	65	56	60	58	50
2008	Copper	82	9	45	40	77	58	51	67	59	54
2008	Zinc	96	10	53	50	76	63	55	66	61	59
2008	Indium	98	100	99	51	76	64	55	82	68	77
2012	Aluminum	0	0	0	59	78	69	57	73	65	44
2012	Iron	63	0	31	55	77	66	62	80	71	56
2012	Nickel	65	2	33	59	79	69	57	66	62	55
2012	Copper	77	9	43	49	77	63	53	65	59	55
2012	Zinc	94	10	52	57	78	67	58	69	64	61
2012	Indium	98	100	99	59	80	69	54	81	67	78

**Supply Risk (long term)**—DTL: Depletion Time (Long Term); CF: Companion Metal Fraction; SRL: Supply Risk (Long Term).

Year	Material	Supply Risk: Long-term		
		DTL	CF	SRL
2008	Aluminum	0	0	0
2008	Iron	0	0	0
2008	Nickel	0	2	1
2008	Copper	39	9	24
2008	Zinc	82	10	46
2008	Indium	96	100	98
2012	Aluminum	0	0	0
2012	Iron	0	0	0
2012	Nickel	0	2	1
2012	Copper	49	9	29
2012	Zinc	85	10	47
2012	Indium	97	100	98

**Environmental Implications (National and Global)—EI: Environmental Implications.**

Year	Material	Environmental Implications
		EI
2008	Aluminum	3
2008	Iron	1
2008	Nickel	10
2008	Copper	17
2008	Zinc	3
2008	Indium	22
2012	Aluminum	3
2012	Iron	1
2012	Nickel	10
2012	Copper	17
2012	Zinc	3
2012	Indium	22

**Vulnerability to Supply Restriction (National)**—MAN: Material Asset (National Level); NE: National Economic Importance; I: Importance; SP: Substitute Performance; SAM: Substitute Availability (Medium Term); ER: Environmental Impact Ratio; IRR: Net Import Reliance Ratio; S: Substitutability; IR: Net Import Reliance; GII: Global Innovation Index; SU: Susceptibility; VSRN: Vulnerability to Supply Restriction (National Level).

Year	Material	Nation of focus	Vulnerability to Supply Restriction: National											
			Importance			Substitutability					Susceptibility			VSRN
			MAN	NE	I	SP	SAM	ER	IRR	S	IR	GI	SU	
2008	Aluminum	United States	75	76	75	47	46	29	10	33	100	29	64	58
2008	Iron	United States	94	51	72	52	43	100	53	62	13	29	21	52
2008	Nickel	United States	92	19	55	72	59	28	59	55	33	29	31	47
2008	Copper	United States	100	98	99	66	47	16	77	52	32	29	30	60
2008	Zinc	United States	100	13	57	39	45	80	48	53	72	29	50	53
2008	Indium	United States	83	0	42	56	75	49	40	55	100	29	64	54
2012	Aluminum	United States	74	62	68	47	54	30	38	43	20	40	30	47
2012	Iron	United States	93	61	77	56	44	100	47	62	11	40	25	55
2012	Nickel	United States	89	24	57	74	68	34	43	55	49	40	44	52
2012	Copper	United States	98	88	93	66	49	16	32	41	35	40	37	57
2012	Zinc	United States	99	11	55	38	46	81	18	46	72	40	56	52
2012	Indium	United States	84	0	42	56	76	49	40	55	100	40	70	56
2008	Aluminum	Australia	71	100	86	40	47	34	7	32	0	46	23	47
2008	Iron	Australia	91	58	74	53	51	100	37	60	0	46	23	53
2008	Nickel	Australia	89	6	47	66	49	10	86	53	0	46	23	41
2008	Copper	Australia	100	100	100	66	47	16	21	38	0	46	23	53
2008	Zinc	Australia	100	34	67	38	44	69	2	38	0	46	23	43
2008	Indium	Australia	80	0	40	59	75	50	10	48	100	46	73	54
2012	Aluminum	Australia	71	75	73	43	54	27	7	33	0	47	23	43
2012	Iron	Australia	91	68	79	53	46	100	38	59	0	47	23	54
2012	Nickel	Australia	87	3	45	64	56	11	80	53	0	47	23	40
2012	Copper	Australia	96	76	86	66	49	16	21	38	0	47	23	49
2012	Zinc	Australia	97	24	61	38	45	70	2	39	0	47	23	41
2012	Indium	Australia	81	0	41	55	77	50	17	50	100	47	73	55

**Vulnerability to Supply Restriction (Global)**—MAG: Material Asset (Global Level); SP: Substitute Performance; SAL: Substitute Availability (Long Term); ER: Environmental Impact Ratio; S: Substitutability; VSRG: Vulnerability to Supply Restriction (Global Level).

Year	Material	Vulnerability to Supply Restriction: Global					VSRG
		Importance MAG	Substitutability				
			SP	SAL	ER	S	
2008	Aluminum	43	44	8	34	28	36
2008	Iron	54	57	26	100	61	57
2008	Nickel	52	62	15	16	31	42
2008	Copper	64	67	14	15	32	48
2008	Zinc	61	40	8	77	42	51
2008	Indium	50	59	70	50	60	55
2012	Aluminum	45	44	10	35	29	37
2012	Iron	55	56	9	100	55	55
2012	Nickel	53	63	18	17	33	43
2012	Copper	65	67	14	16	32	48
2012	Zinc	62	40	10	79	43	52
2012	Indium	53	56	69	49	58	56

## Discussion of the Criticality Parameter Results for the Individual Metals

### 1. Aluminum

#### *Supply Risk (Medium Term)*

- Geological, Technological, and Economic indicator: no significant changes compared to 2008, indicating no supply risk issues for this metal.
- PPI and HDI indices have increased in 2012, leading to higher scores for Social & Regulatory indicators. Similarly, Global Supply Concentration, under the Geopolitical component, reached higher scores for 2012 than for 2008.
- Overall, SR (medium term) has slightly worsened (from 43 in 2008 to 44 in 2012).

#### *Vulnerability to Supply Restriction (United States)*

- Significant decreases for National Economic Importance under the Importance component, and to Import Reliance under the Susceptibility component, occur. In particular, from 2008 to 2012 the US strongly reduced its dependence on Al imports (from 100% to 20% of domestic apparent consumption).
- A higher score is computed for the Substitutability component due to increases for Substitute Availability and Import Reliance Ratios for Al substitutes. The Global Innovation Index increased from 29 to 40 over 2008–2012.
- Material Assets, Substitute Performance, and Environmental Ratio are aligned with 2008 scores.
- The US reduced its VSR for Al from 57 in 2008 to 47 in 2012.

#### *Vulnerability to Supply Restriction (Australia)*

- Compared to the US, Australia is less vulnerable to Al supply restriction. This leads to significantly lower values for the Substitutability and Susceptibility components. In particular, as Australia is a net exporter of Al as well as its major substitutes (Fe and Cu), the Import Reliance Ratio and Net Import Reliance indicators are extremely favorable for this country.
- Higher scores for Australia are, however, computed for National Economic Importance and Global Innovation Index indicators.

*Supply Risk (Long Term)*

- As for 2008, no issues for supply risk are estimated for Al in the long term. Both Depletion Time and Companion Metal Fraction indicators are given a value of 0.

*Vulnerability to Supply Restriction (Global)*

- 2012 VSR results at the global level worsened slightly compared to 2008. In particular, an increase for Al demand in end-use sectors for which Cu is a potential substitute resulted in a higher score for Substitute Availability.

**2. Iron***Supply Risk (Medium Term)*

- Geological, Technological, and Economic indicator: Depletion Time has increased significantly due to a large primary production increase (almost +40% from 2008 to 2012); no changes in Reserves were reported in 2012.
- PPI and HDI for the Social & Regulatory component and WGI and Global Supply Concentration for the Geopolitical component increased from 2008 to 2012.
- Overall, SR (medium term) has increased by about 20% (46 to 56).

*Vulnerability to Supply Restriction (United States)*

- Compared to 2008, 2012 results for the US received higher scores (i.e., higher levels of concern) for Importance, Substitutability, and Susceptibility components. This is because substantial increases occur for National Economic Importance, Substitute Performance, and Substitute Availability (due to an increase in Fe demand for end-uses in which the substitute leads to lower performance), and for the GII index.
- Lower scores are computed for indicators related to import of Fe (i.e., Net Import Reliance and Net Import Reliance Ratio) and of its substitutes, particularly Al (see aluminum for more details).

*Vulnerability to Supply Restriction (Australia)*

- Compared to the US, Australia has a higher level of concern for Importance (due to the National Economic Importance indicator) but lower levels of concern for Substitutability and Susceptibility. This is because Australia is a net exporter of Fe as well as its major substitute (Al); thus Import Reliance Ratio and Net Import Reliance indicators received lower scores than those for the US.
- Higher scores for Australia are computed for the National Economic Importance and Global Innovation Index indicators.
- The 2012 results for VSR (national) for the US and Australia show a counterbalance of the various factors, and the resulting assessment gives a similar score to both countries (i.e., 55 and 54, respectively).

*Supply Risk (Long Term)*

- As for 2008, no issues for supply risk occur for Fe in the long term. Both Depletion Time and Companion Metal Fraction indicators are given a value of 0.

*Vulnerability to Supply Restriction (Global)*

- The score for the Importance indicator has increased by a small amount from 2008 to 2012, but lower values apply for Substitute Performance and Substitute Availability at global level. Overall, the 2012 VSR (global) is slightly lower compared to 2008.

### 3. Nickel

#### *Supply Risk (Medium Term)*

- Geological, Technological, and Economic indicator: Depletion Time has increased due to a substantial increase of global primary production (about +23% from 2008 to 2012); no changes in reserve were reported to 2012.
- PPI for the Social & Regulatory component, WGI, and Global Supply Concentration for the Geopolitical component have increased from 2008 to 2012.
- Overall, SR (medium term) has increased (from 50 to 55) over 2008–2012.

#### *Vulnerability to Supply Restriction (United States)*

- Compared to 2008, 2012 results for the US show a worsening from 2008 scores. Notwithstanding a decrease for Material Asset and Net Import Reliance Ratio, all other indicators have increased. In particular, Net Import Reliance has increased (+16 points) due to a greater dependence on Ni imports for the US in 2012.
- Overall, VSR for the US increased from 47 to 52 over 2008–2012.

#### *Vulnerability to Supply Restriction (Australia)*

- Compared to the US, Australia has generally lower VSR results. A higher score is estimated for Net Import Reliance Ratio, which is part of the Substitutability indicator. It should be noted that Australia is a net exporter of Ni, which means NIR = 0%. Thus, despite the fact that NIR scores for the Ni substitutes (i.e., mainly the AISI steel series) are very close to 0%, the overall IRR goes theoretically to infinity and receives a maximum score of 100%. The US, instead, depends much more on import of Ni and of the related substitutes, but because Ni imports are around 50% of domestic apparent consumption (while Fe and Al are around 20%, on average) the overall IRR score for the US is lower than that for Australia.
- Substitute Performance and Substitute Availability indicators are lower for Australia due to a greater Ni demand for end-uses, for which good material substitutes do exist (e.g., AISI 410 in building and construction).
- For 2012, Australia's VSR is 40 versus 52 for the US.

#### *Supply Risk (Long Term)*

- As for 2008, no issues for supply risk are anticipated for Ni in the long term. The Depletion Time indicator is given a value of 1.

#### *Vulnerability to Supply Restriction (Global)*

- Some improvements for VSR (global) indicators are realized, but they are marginal compared to 2008 scores (i.e., 2012 scores are nearly equal to the 2008 results).

### 4. Copper

#### *Supply Risk (Medium Term)*

- Geological, Technological, and Economic indicator: Depletion Time has decreased because of the new Cu reserve discovery in Chile (from 550 Tg to 680 Tg, globally).
- PPI and WGI for Social & Regulatory and Geopolitical have increased in 2012. Global Supply Concentration has decreased; HDI score for 2012 equals the 2008 value.
- Overall, the SR (medium term) is little changed from 2008 to 2012.

*Vulnerability to Supply Restriction (United States)*

- Compared to 2008, VSR for the US has decreased from 60 to 57. This is mainly due to lower results for Net Import Reliance Ratio, which is positively influenced by less dependence on Al imports (see aluminum for more details), as this metal is a major substitute for Cu.
- Material Assets and National Economic Importance for Cu have also decreased for the US from 2008 to 2012; however, the Importance score remains quite high (i.e., 93).

*Vulnerability to Supply Restriction (Australia)*

- Compared to the US, Australia shows higher results for the Importance indicator, but lower scores for Substitutability and Susceptibility. Despite the fact that for the Australian economy Cu is highly important (leading to potential issues of supply restriction), there is little or no dependence on net-imports of Cu and of its major substitutes (e.g., Al). As a result, Net Import Reliance and Net Import Reliance Ratio are much lower than for the US.
- GII is greater for Australia.
- Overall, Australia is given a 2012 VSR (national) of 49 against 57 for the US.

*Supply Risk (Long Term)*

- Notwithstanding that new Cu Reserves have been discovered in Chile in 2012, according to the USGS mineral statistics, the same data source reports no changes in the total Cu reserve base, which is the same as for 2008. Using the official estimate for Cu reserve base, Supply Risk (long term) increases from 24 in 2008 to 29 in 2012. If, instead, the new Chilean Cu discovery is included in the estimate of Cu Reserve Base, no changes in Supply Risk are computed in the long term.
- Depletion Time (long term) has increased from 39 to 49.

*Vulnerability to Supply Restriction (global)*

- End-use market shares are set as for 2008 because no more recent data were found. For this reason, VSR (global scores) for 2012 equal those for 2008 (i.e., 48).

**5. Zinc***Supply Risk (Medium Term)*

- Geological, Technological, and Economic indicator: Depletion Time has slightly decreased due to a new Zn Reserves discovery (from 180 Tg in 2008 to 250 Tg in 2012, globally).
- PPI and HDI scores for the Social & Regulatory indicator have increased. Similarly, WGI and Global Supply Concentration have increased in 2012.
- Overall, SR (medium term) is little changed from 2008 to 2012.

*Vulnerability to Supply Restriction (United States)*

- Material Assets and National Economic Importance for the Importance component have slightly decreased.
- The Substitutability component has decreased due to a lower result for Net Import Reliance Ratio. This is a consequence of less dependence in 2012 from net import of aluminum, which is a major substitute for zinc applications. Net Import Reliance has not changed from 2008, as the country largely relies on net import of zinc for apparent domestic consumption.
- GII for the US has increased substantially in 2012.
- Overall, VSR for the US is little changed compared to 2008 levels.

*Vulnerability to Supply Restriction (Australia)*

- Compared to the US, Australia got higher results for Importance indicators, but somewhat lower scores for Substitutability and Susceptibility components.
- The decreased VSR results for Australia are due to the country's status as a net exporter of zinc and of its substitutes, mainly aluminum. Net Import Reliance and Net Import Reliance Ratio positively influence the VSR result for this country.
- GII is greater than that for the US.
- Overall, Australia receives a 2012 VSR (national) of 41 against 52 of the US.

*Supply Risk (Long Term)*

- Notwithstanding that a new Zn reserve has been reported for 2012 according to USGS mineral statistics, the same data source reports no changes in the total Zn Reserve Base, which is the same as for 2008. Using the official estimate for the Zn Reserve Base, Supply Risk (long term) increases slightly (from 46 to 47) as an effect of longer Depletion Time (long term). If, instead, the new Zn reserve is included in the estimate of Zn Reserve Base, Depletion Time (long term) decreases by 10 points (i.e., from 85 to 75) over 2008-2012 and, consequently, Supply Risk (long term) decreases from 46 to 43.

*Vulnerability to Supply Restriction (Global)*

- A negligible increase is computed for the Substitutability component. 2012 VSR for Zn at the global level equals the 2008 result.

**6. Indium***Supply Risk (Medium Term)*

- Geological, Technological, and Economic indicator confirms for 2012 levels of high concerns for In.
- Overall, SR (medium term) has little increased from 2008 (i.e., 77) to 2012 (i.e., 78).

*Vulnerability to Supply Restriction (United States)*

- Material Assets for the Importance component have slightly increased.
- The Substitutability component has remained constant, reflecting the country's reliance on net-import of this metal.
- GII for the US has increased substantially in 2012.
- Overall, VSR for the US has little increased from 54 in 2008 to 56 in 2012.

*Vulnerability to Supply Restriction (Australia)*

- Compared to the US, Australia got similar results for the almost all VSR metrics (but in Australia's favor) over 2008–2012.
- Australia has world's largest reserves of zinc and bauxite from which indium and gallium (which is a potential good substitute of indium in solder and alloys applications, electrical components and semiconductors manufacturing) are mainly extracted. The current Australian indium and gallium refinery capacity is however very limited and constraints the exploitation of this potential. As a result, indium criticality is greater than that would likely occur should extensive indium recovery meet high prospective for improving this co-product processing in this country.
- GII is greater than that for the US.
- Overall, Australia receives a 2012 VSR (national) of 55, which is close to 56 of the US.

*Supply Risk (Long Term)*

- Based on known in reserves, Supply Risk of indium is very high, confirming concerns and challenges to meet the future demand of this metal worldwide.

*Vulnerability to Supply Restriction (Global)*

- A small increase is computed for the VSR indicator from 2008 (i.e., 55) to 2012 (i.e., 56).