British Geological Survey

Risk list 2012 — Current supply risk index for chemical elements or element groups which are of economic value

Element or element group	Symbol	Relative supply risk index	Leading producer	Top reserve holder
rare earth elements	REE	9.5	China	China
tungsten	W	9.5	China	China
antimony	Sb	9.0	China	China
bismuth	Bi	9.0	China	China
molybdenum	Mo	8.6	China	China
strontium	Sr	8.6	China	China
mercury	Hg	8.6	China	Mexico
barium	Ba	8.1	China	China
carbon (graphite)	C	8.1	China	China
beryllium	Be	8.1	USA	Unknown
germanium	Ge	8.1	China	Unknown
niobium	Nb	7.6	Brazil	Brazil
platinum group elements	PGE	7.6	South Africa	South Africa
colbalt	Co	7.6	DRC	DRC
thorium	Th	7.6	India	USA
indium	In	7.6	China	Unknown
gallium	Ga	7.6	China	Unknown
arsenic	As	7.6	China	Unknown
magnesium	Mg	7.1	China	Russia
tantalum	Ta	7.1	Brazil	Brazil
selenium	Se	7.1	Japan	Russia
cadmium	Cd	6.7	China	India
lithium	Li	6.7	Australia	Chile
vanadium	V	6.7	South Africa	China
tin	Sn	6.7	China	China
fluorine	F	6.7	China	South Africa
silver	Ag	6.2	Mexico	Peru
chromium	Cr	6.2	South Africa	Kazakhstan
nickel	Ni	6.2	Russia	Australia
rhenium	Re	6.2	Chile	Chile
lead	Pb	6.2	China	Australia
carbon (diamond)	C	6.2	Russia	DRC
manganese	Mn	5.7	China	South Africa
gold	Au	5.7	China	Australia
uranium	U	5.7	Kazakhstan	Australia
zirconium	Zr	5.7	Australia	Australia
iron	Fe	5.2	China	Australia
titanium	Ti	4.8	Canada	China
aluminium	Al	4.8	Australia	Guinea
zinc	Zn	4.8	China	Australia
copper	Cu	4.3	Chile	Chile

Supply risk index runs from 1 (blue — very low risk) to 10 (red — very high risk)

Limitations and methodology are set out in accompanying notes

British Geological Survey

Risk List 2012

An update to the supply risk index for elements or element groups that are of economic value

The updated risk list provides a quick and simple indication of the relative risk in 2012 to the supply of 41 elements or element groups that we need to maintain our economy and lifestyle. The position of an element on this list is determined by a number of factors that might affect availability. These include the natural abundance of elements in the Earth's crust, the location of current production and reserves, and the political stability of those locations. ***New for 2012 recycling rates and substitutability of the elements has been considered in the analysis.*** Data sources used in the compilation of the list are internationally recognised and publicly available. ***The updated risk list contains fewer elements than the 2011 version. Eleven of the original 52 elements have been excluded from the update because of data availability and quality issues.***

The risk list highlights a group of elements for which global production is concentrated in very few countries. The restricted reserve distribution and the relatively low political stability ratings for some major producing countries combine to significantly increase risk to supply. ***This is compounded by low rates of recycling and limited substitutes for many of these elements.*** Concern over rare earth element supply has received significant attention recently and this element group remains at the top of the list. However, the list highlights other economically important metals with similar high levels of risk to supply disruption including platinum group metals (active components in auto-catalysts), niobium (used in MRI scanners and touch screens) and tungsten (a key hard metal used in almost all cutting tools). ***These elements, particularly the rare earth elements and tungsten, have medium to low recycling rates and a limited number of substitutes.*** The list also shows the current dominance of China in production of many metals and minerals. China is now the leading global producer of 22 of the 41 elements and element groups on the list (Figure 1).

As demand for metals and minerals increases, driven by relentless growth in the emerging economies in Asia and South America, competition for resources is growing. The risk list gives an indication of which elements might be subject to supply disruption, most likely resulting from human factors such as geopolitics ('haves' seeking to influence 'have nots') or resource nationalism (state influence on, or control of, production), along with events such as mine strikes and accidents. Policy-makers, industry and consumers should be concerned about supply security and the need to ensure diversified supply of primary resources. Equally important will be the need to make full use of secondary resources and recycling, and to reduce our intensity of resource use i.e. 'do more with less'.

With the exception of substitutability the list focuses on risks to supply and does not include any assessment of factors that influence demand, such as criticality of an element to a particular technology.

An in-depth discussion of the risk list methodology and limitations can be found below.

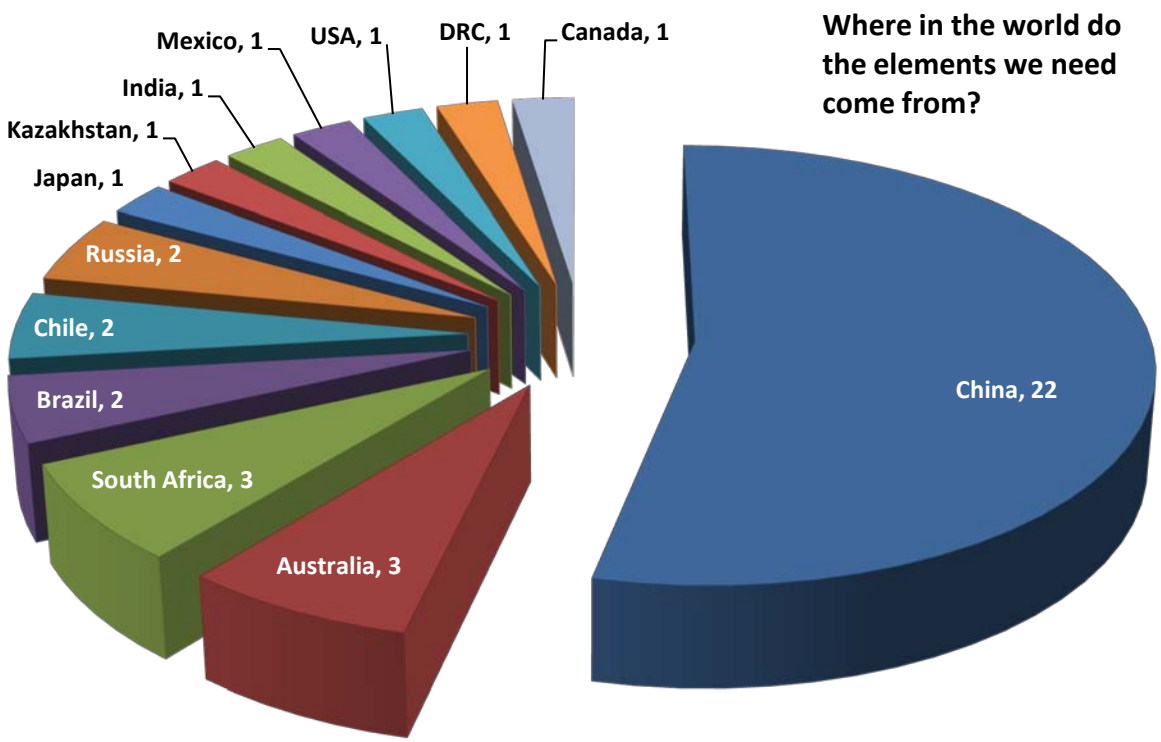

Figure 1. Chart indicates the number of times a country is the leading global producer of an element or element group of economic value. ***Source: BGS World Mineral Statisitics***

Methodology for estimating the relative risk to supply of the chemical elements

The following methodology was used to define the relative risk to supply of the following elements:

Silver (Ag); Aluminium (Al); Arsenic (As); Gold (Au); Barium (Ba); Beryllium (Be); Bismuth (Bi); Diamond; Graphite; Cadmium (Cd); Cobalt (Co); Chromium (Cr); Copper (Cu); Fluorine (F); Iron (Fe); Gallium (Ga); Germanium (Ge); Mercury (Hg); Indium (In); Lithium (Li); Magnesium (Mg); Manganese (Mn); Molybdenum (Mo); Niobium (Nb); Nickel (Ni); Lead (Pb); Platinum Group Elements (PGE - Ruthenium (Ru), Palladium (Pd), Osmium (Os), Iridium (Ir) and Platinum (Pt)) ; Rhenium (Re); Rare Earth Elements (REE - Lanthanum (La), Cerium (Ce), Praseodymium (Pr), Neodymium (Nd), Samarium (Sm), Europium (Eu), Gadolinium (Gd), Terbium (Tb), Dysprosium (Dy), Holmium (Ho), Erbium (Er), Thulium (Tm), Ytterbium (Yb) and Lutetium (Lu)); Antimony (Sb); Selenium (Se); Tin (Sn); Strontium (Sr); Tantalum (Ta); Thorium (Th); Titanium (Ti); Uranium (U); Vanadium (V); Tungsten (W); Zinc (Zn); and Zirconium (Zr).

Elements not included are those for which insufficient data exist.

An Excel spreadsheet was used to rank the above elements in terms of the relative risk to supply. The ranking system was based on seven criteria scored between 1 and 3.

- Scarcity
- Production concentration
- Reserve distribution
- Recycling Rate
- Substitutability
- Governance (top producing nation)
- Governance (top reserve-hosting nation)

A score of 1 indicates that a particular criterion has a low contribution to supply risk, while a score of 3 indicates a high risk. The scores for each criterion were summed to give an overall risk to supply, the larger the score the greater the potential risk to supply. Each criterion was given equal weight. The elements were ranked according to their score and a gradational colour scale applied such that increased risk is indicated by hotter colours.

Scarcity

Crustal abundances (Table 1) provide an indication of the scarcity of a given element on a global scale. For example, gold would be classified as high-risk due to its low crustal abundance of 0.0013 ppm, while iron would classified as low-risk with a crustal abundance of about 52,157 ppm.

The scores were allocated as follows:

1 (low) = >100 ppm
2 (medium) = >1 to 100 ppm
3 (high) = <1 ppm

Element	Abundance (ppm)	Element	Abundance (ppm)
Ag	0.055	Mn	774
Al	84,149	Mo	0.8
As	2.5	Na	22,774
Au	0.0013	Nb	8
B	11	Nd	20
Ba	456	Ni	26.6
Be	1.9	Os	0.000041
Bi	0.18	P	567
Br	0.88	Pb	11
Cd	0.08	Pd	0.0015
Ce	43	Pr	4.9
Co	26.6	Pt	0.0015
Cr	135	Re	0.000188
Cu	27	Ru	0.00057
Dy	3.6	S	404
Er	2.1	Sb	0.2
Eu	1.1	Se	0.13
F	553	Sm	3.9
Fe	52,157	Sn	1.7
Ga	16	Sr	320
Gd	3.7	Ta	0.7
Ge	1.3	Tb	0.6
Hg	0.03	Th	5.6
Ho	0.77	Ti	4136
I	0.71	Tm	0.28
In	0.052	U	1.3
Ir	0.000037	V	138
K	15,025	W	1
La	20	Yb	1.9
Li	16	Zn	72
Lu	0.3	Zr	132
Mg	28,104		

Table 1 - Average total crustal abundance of the elements included in this study. Data from Rudnick and Gao (2003).

Production concentration

Where the production of a given commodity is concentrated in a few countries this can increase the risk to supply. For example, about 84 per cent of the world's tungsten is currently sourced from China. The BGS' World Mineral Production data (2006-2010) were used to identify the top three producing countries and the percentage of world supply for which the leading country is responsible.

The percentage production for the top three countries was scored as follows:

1 (low) = <33.3 %
2 (medium) = >33.3 to 66.6 %
3 (high) = >66.6 %

Reserve distribution

Mineral deposits are unequally distributed across borders and concentration of reserves in a few countries poses an increased risk to short-term supply. For example, about 97 per cent of the world's reserves of niobium are found in Brazil. We have used mineral reserve distribution data from the USGS to provide an indication of the potential for short-term supply disruption. *Mineral Reserves* are effectively 'working inventories' that are continually revised and updated in light of numerous factors pertaining to mining, metallurgy, economics, marketing, law, and the environment (USGS, 2010). USGS' Commodity Summaries (2012) reserves data were used to identify the three countries contributing the largest share to global reserves and the percentage of the world reserves held by the top country.

The percentage of the global reserves held by the top three countries was scored as follows:

1 (low) = <33.3 %
2 (medium) = >33.3 to 66.6 %
3 (high) = >66.6 %

Where USGS data are unavailable an arbitrary score of 2 was allocated. For example, beryllium, arsenic, germanium, indium, and gallium are allocated a score of 2 since reserve information is unavailable. USGS reserve data are also unavailable for uranium. However, reserve data for 2009, available from the World Nuclear Authority (WNA), are used in this study.

Recycling rate (recyclability)

The recycling rate of a given commodity may either contribute to, or reduce risk to supply. A higher recycling rate might, for example, lead to a reduction in demand for primary resources. Currently, about 50 per cent of the world's iron is recycled, whilst the recycling rate of beryllium is approximately less than one per cent. The United Nations Environment Programme (UNEP) report on 'Recycling Rates of Metals' (2011) was used to identify the recycling rates of 42 commodities.

The recycling rate was scored as follows:

1 (high) = >30 %
2 (medium) = >10 to 30 %
3 (low) = <10 %

Where data are unavailable an arbitrary score of 2 was allocated. For example, fluorspar, diamond, graphite, uranium, and thorium are allocated a score of 2 since recycling rate information is unavailable.

Substitutability

The substitutability (the potential for one commodity to take the place of another in a given application) of a given commodity may either contribute to, or reduce risk to supply. The availability of suitable substitutes for a given commodity may, for example, lead to a reduction in demand for

primary resources. Currently substitutes for the rare earth elements are very limited. However, several substitutes exist for copper, such as silver, aluminium, fibre optics, steel, and even plastics for some applications. The University of Augsburg report on 'Materials Critical to the Energy Industry' (2011)[1] and the EU Raw Materials Initiative report 'Defining Critical Raw Materials' (2008)[2] were used to identify the substitutability of 31 commodities.

1 = Low[1] *or* <0.3[2]
2 = Medium[1] *or* 0.3 to 0.7[2]
3 = High[1] *or* >0.7[2]

Where data are unavailable an arbitrary score of 2 was allocated. For example, arsenic, gold, bismuth, diamond, mercury, lead, selenium, tin, strontium, and zirconium are allocated a score of 2 since substitutability information is unavailable.

Governance indicators

The political stability of a producing country, or country in which large reserves are held, may impact upon the supply of mineral commodities e.g. supplies may be interrupted by war, government intervention, famine or other forms of unrest. A political stability score was derived from World Bank governance indicators (2011), for both the leading producing country, and for the country with the largest reserves. The World Bank website provides percentile rank information for 213 countries on six different criteria: voice and accountability; political stability; government effectiveness; regulatory equality; rule of law; and control of corruption. Only political stability was considered as part of this study.

Countries with a political stability percentile of <33.3 per cent were scored 3, those with a percentile between >33.3 and 66.6 per cent were scored 2 and those with a percentile of >66.6 per cent were scored 1.

For each commodity an individual political stability score for both the leading global producer and for the chief reserve holder were scored as follows:

1 (high) = >66.6 %
2 (medium) = >33.3 to 66.6 %
3 (low) = <33.3 %

For example, China (with a WB percentile rank of 24.1) is the leading producing country for rare earth elements, and also has the largest share of global reserves, earning it a score of 3 in both cases, while Brazil (with a WB percentile rank of 48.1) is the leading producing country of niobium, and also has the largest share of global reserves, giving it a score of 2 in both cases.

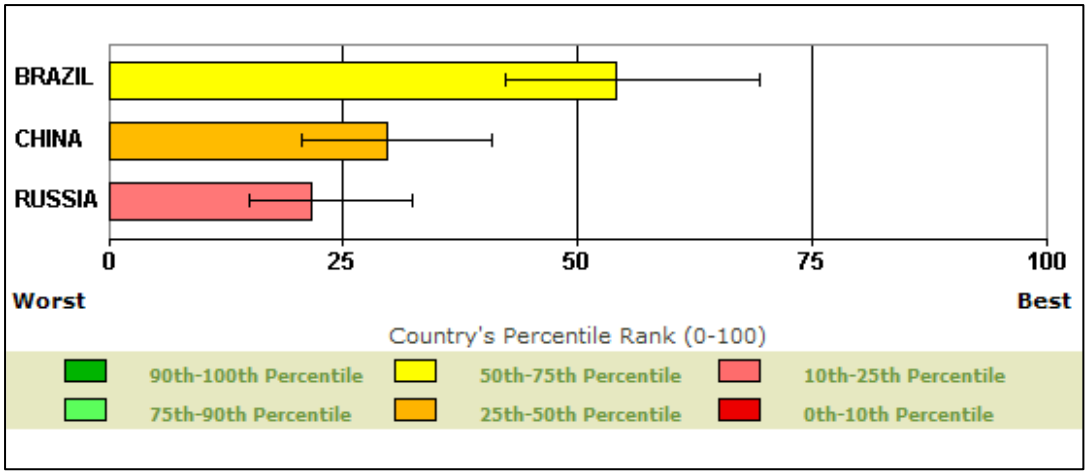

Figure 2 - Political stability indicators for Brazil, China and Russia. Data from the World Bank after Kaufmann *et al.* (2011).

Supply risk

An integrated supply risk was calculated by combining the scores for each of the seven criteria. This is illustrated for two elements, rare earth elements and copper, in Table 2.

Category	Rare Earth Element Score		Copper Score	
	Value	Score	Value	Score
Recycling rate (%)	<10	3	>30	1
Substitutability	H	3	L	1
Crustal abundance (ppm)	0.3	3	27	2
Reserve distribution (%)	50	2	28	1
Production concentration (%)	97	3	34	2
Political stability (top reserve holder)	24.1	3	67.5	1
Political stability (top producing country)	24.1	3	67.5	1
Total		**20**		**9**
Supply Risk Index (Total/2.1)		**9.5**		**4.3**

Table 2 - The calculation of a supply risk index.

Aggregate scores were divided by 2.1 to produce a simple supply risk index from 1 (very low risk) to 10 (very high risk). For example, copper has an initial aggregate score of 9. This is divided by 2.1 to give a score of 4.3. This shows that copper has a lower relative risk to supply compared to REE with a score of 9.5. Below is the final ranked output list with gradational colour scale such that increased risk is indicated by hotter colours (Table 3).

Element or Element Groups	Relative Supply Risk Index	Top Producer	Top Reserve Holder
REE	9.5	China	China
W	9.5	China	China
Sb	9.0	China	China
Bi	9.0	China	China
Mo	8.6	China	China
Sr	8.6	China	China
Hg	8.6	China	Mexico
Ba	8.1	China	China
C (graphite)	8.1	China	China
Be	8.1	USA	Unknown
Ge	8.1	China	Unknown
Nb	7.6	Brazil	Brazil
PGE	7.6	South Africa	South Africa
Co	7.6	DRC	DRC
Th	7.6	India	USA
In	7.6	China	Unknown
Ga	7.6	China	Unknown
As	7.6	China	Unknown
Mg	7.1	China	Russia
Ta	7.1	Brazil	Brazil
Se	7.1	Japan	Russia
Cd	6.7	China	India
Li	6.7	Australia	Chile
V	6.7	South Africa	China
Sn	6.7	China	China
F	6.7	China	South Africa
Ag	6.2	Mexico	Peru
Cr	6.2	South Africa	Kazakhstan
Ni	6.2	Russia	Australia
Re	6.2	Chile	Chile
Pb	6.2	China	Australia
C (diamond)	6.2	Russia	DRC
Mn	5.7	China	South Africa
Au	5.7	China	Australia
U	5.7	Kazakhstan	Australia
Zr	5.7	Australia	Australia
Fe	5.2	China	Australia
Titanium (Rutile, Ilmenite, and Leucoxene)	4.8	Canada	China
Al	4.8	Australia	Guinea
Zn	4.8	China	Australia
Cu	4.3	Chile	Chile

Table 3 - The relative supply risk index. Risk is scaled between 1 (blue) and 10 (red), hotter colours indicate a greater risk to supply.

Limitations to the methodology

Previous studies of this nature have included information pertaining to the environment, supply and demand, TMR (total material requirements), and climate change. This study omits many of these factors. For instance, we have not taken into account the potential impact of supply disruptions e.g. mercury is little used therefore the impact would be less than for an interruption to the supply of platinum group elements.

IMPORTANTLY - this represents a 'snapshot' in time and does not take in to account future issues and supply-demand scenarios. The minerals market is not static, new reserves are continually added in response to drivers such as demand and advances in technology. In the future recycling is likely to contribute an increasing share to the global market and substitutability may also increase as new technologies are delivered.

Crustal abundance values do not take into account crustal dispersion, nor do they account for the tendency of an element to become economically concentrated.

Where more than one mineral source exists for a given element e.g. titanium occurring in rutile, leucoxene and ilmenite, all sources have been combined to give a total.

Where appropriate, groups of elements have been combined and dealt with as a single commodity e.g. platinum group elements and rare earth elements. For these grouped elements a worst case scenario has been taken in terms of the crustal abundance e.g. lutetium at 0.3 ppm has been used to calculate the crustal abundance risk for rare earth elements rather than cerium at 43 ppm. Likewise, iridium 0.000037 ppm has been used to calculate the crustal abundance risk for platinum group elements rather than palladium at 0.0015 ppm.

Certain commodities have been used as a proxy for a given element; this approach may mean that not all sources of an element have been included in the production and reserve calculations (Table 4).

Element	Proxy
Fluorine	Fluorspar - CaF_2
Carbon	Coal, diamonds, and graphite
Barium	Barytes - $BaSO_4$
Beryllium	Beryl - $Be_3Al_2(SiO_3)_6$
Titanium	Rutile and Ilmenite - TiO_2 and $FeTiO_3$
Magnesium	Magnesite - $MgCO_3$
REE	Rare Earth Oxides (REO)

Table 4 - Proxy data used in the calculation of production and reserve concentrations for selected elements.

Where primary production data for a given commodity is limited other sources of data have been included (Table 5).

Element	Data Source
Indium	BGS estimates
Gallium	USGS production 'capacity'
Germanium	U.S. imports
Thorium	Monazite concentrate production
Selenium	Selenium metal production

Table 5 - Data sources used where production data for a given commodity are limited or non-existent.

Mineral resources[3] have been omitted from this study as there are no reliable comprehensive data on distribution or volumes.

Elements that have little or no commercial use have been omitted from this study e.g. polonium, astatine, and radium. Likewise, synthetic or 'manufactured' elements have also been omitted e.g. elements of atomic number 95 to 114, and hydrogen. Elements naturally occurring in a gaseous state are also not included e.g. the Noble gases, oxygen and nitrogen because the criteria used are unsuitable for assessing the supply risk of these elements. Production and reserve information for some of the minor metals e.g. scandium, yttrium, caesium, tellurium, thulium, and rubidium is unavailable because they are commonly produced as by-products or co-products of other metals. For example, yttrium is often associated with rare earth element-bearing minerals; scandium is found in trace amounts in minerals such as beryl, garnet and wolframite; caesium is often a by-product of lithium extraction; and tellurium, along with selenium, is a common by-product of nickel and copper ore extraction.

Definitions

1. *Reserves* - a 'mineral reserve' is the part of the resource which has been fully geologically evaluated and is commercially and legally mineable. Reserves may be regarded as 'working inventories', which are continually revised in the light of various 'modifying factors' related to mining, metallurgy, economics, marketing, law, the environment, communities, government, etc, etc (USGS, 2010).

2. *Resources* - a 'mineral resource' is a natural concentration of minerals or a body of rock that is, or may become, of potential economic interest as a basis for the extraction of a mineral commodity. A resource has physical and/or chemical properties that make it suitable for specific uses and it is present in sufficient quantity to be of intrinsic economic interest. It encompasses 'mineral reserve' and 'reserve base' plus other identified resources which could be exploited in the future if required according to the economic situation (USGS, 2010).

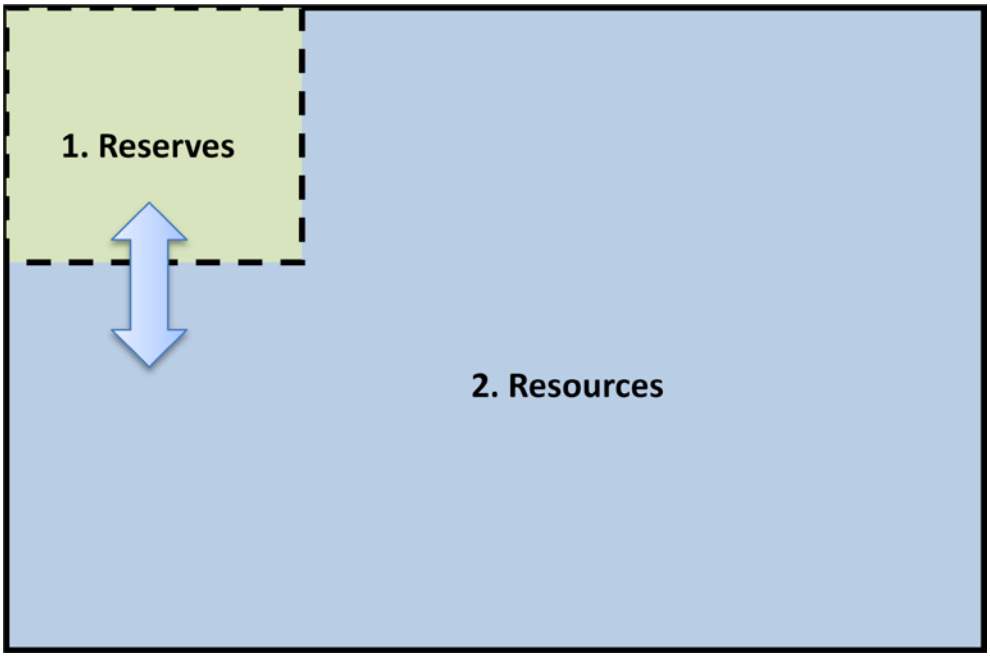

Figure 3 - Graphical representation of the relationship between reserves and resources.

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