# **British Geological Survey**

Risk list 2011 — Current supply risk index for chemical elements or element groups which are of economic value

antimory         Sh         8.5         China           platinum group isloments         PGE         8.5         South Africa           mercury         Hg         8.5         China           langstan         W         8.5         China           rare earth elements         REE         8.0         China           inchum         Nb         8.0         Brazil           strottium         Sr         7.5         China           bismuth         Bi         7.0         China           bismuth         Bi         7.0         China           tortum         Th         7.0         India           bronne         1         6.5         Dhile           indum         Ra         6.5         Dhile           indum         In         8.5         China           germanium         Ge         6.5         USA           hellum         Ba         6.5         USA           nadydeburn         Mo         6.0         China           indum         Sa         6.0         China           startalum         Ta         6.0         Prou           tartalum         Ta	Element or element group	Symbol	Relative supply risk index	Leading producer	
PGE         8.5         South Africa           mercury         Hg         8.5         China           ungsten         W         8.5         China           rare carbl elements         REE         8.0         Brazil           situntum         Sr         7.5         China           bisruth         Bi         7.0         India           bisruth         Bi         7.0         India           bromine         Br         7.0         India           bromine         Br         7.0         India           bromine         Br         7.0         USA           carbon (graphite)         C         7.0         Chilo           indium         Re         6.5         Chilo           jodne         1         8.5         Chilo           indum         Re         6.5         USA           nehnum         Re         6.5         USA           nolydenum         Me         6.0         China           silver         Ag         6.0         China           silver         Ag         6.0         China           silver         Ag         6.0         Ehra	antimony	Sb	8.5 China		
mercury         Hg         8.5         China           tungsten         W         8.5         China           rae earth elements         REE         8.0         Brazil           strontium         Nb         8.0         Brazil           strontium         Sr         7.5         China           bismuth         Bi         7.0         India           transine         Br         7.0         USA           carbin (graphite)         C         7.0         USA           carbin (graphite)         C         7.0         China           findium         In         6.5         China           indium         In         6.5         China           germanum         Be         6.5         USA           berlium         Be         6.5         USA           hellum         He         6.5         USA           hellum         He         6.5         USA           infum         Sin         6.0         China           gasentic         As         6.0         China           straintum         Ta         6.0         Revanda           magnases         Mn         5.5 <td>platinum group elements</td> <td>PGE</td> <td>8.5</td> <td colspan="2">South Africa</td>	platinum group elements	PGE	8.5	South Africa	
Lungsten         W         8.5         China           rare earth elements         REE         8.0         China           inbibum         Nb         8.0         Brazil           strontum         Sr         7.5         China           bisruth         Bi         7.0         India           thorium         Th         7.0         USA           carbon (graphita)         C         7.0         USA           carbon (graphita)         C         7.0         USA           indium         Re         6.5         China           indium         Re         6.5         China           indium         In         6.5         China           germanium         Ge         6.5         USA           helium         In         6.6         USA           molydenum         Mo         6.0         China           in         Sn         6.0         China           silver         Ag         6.0         Peru           tantalum         Ta         6.0         Reado           rangenesium         Mg         5.5         China           margenesium         Mg         5.5	mercury	Hg	8.5	China	
Tare earth elements         REE         8.0         China           nicklum         Nb         8.0         Brazil           stonnium         Sr         7.5         China           bisnuth         Bi         7.0         China           bisnuth         Bi         7.0         China           thorium         Th         2.0         India           bromine         Br         7.0         USA           catoon (graphite)         C         7.0         China           indium         Re         6.5         Chila           indium         In         6.5         China           germanium         Go         6.5         USA           permanum         Go         6.5         USA           nelybdenum         Mo         6.0         China           infum         Be         6.5         USA           nelybdenum         Mo         6.0         China           infum         Ba         6.0         China           infum         Ba         6.0         China           isker         Ag         6.0         Peru           tattalum         Ta         6.0 <t< td=""><td>tunasten</td><td>W</td><td>8.5</td><td>China</td></t<>	tunasten	W	8.5	China	
Inibitum         Nb         8.0         Brazil           strontium         Sr         7.5         China           bismuth         Bi         7.0         China           thorium         Th         7.0         India           bromine         Br         7.0         USA           caton (graphte)         C         7.0         China           rhenium         Re         6.5         Chile           indum         In         6.5         China           germanium         Ge         6.5         USA           berylitim         Be         6.5         USA           nalybdenum         Mo         6.0         China           infum         Be         6.5         USA           marsenic         As         6.0         China           arsenic         As         5.0         China<	rare earth elements	REE	8.0	China	
strontlym         Sr         7.5         China           bismuth         Bi         7.0         China           thorium         Th         7.0         India           bromine         Br         7.0         USA           carbon (graphile)         C         7.0         China           rhenium         Re         6.5         Chile           indim         In         6.5         Chile           indim         In         6.5         China           germanium         Ge         6.5         China           peryllum         Be         6.5         USA           helfurn         He         6.0         China           in         Sn         6.0         China           isin         Sn         6.0         Revenda           anaganese         Mn         5.5         China           marganese         Mn         5.5         China           gold         Au         5.5         China           cabinum         Co         5.5         DRC           gold         Au         5.5         China           cabard         P         5.0         China <td>niobium</td> <td>Nh</td> <td>8.0</td> <td>Brazil</td>	niobium	Nh	8.0	Brazil	
bismuth         Bi         7.0         China           thorium         Th         7.0         USA           carbon (graphite)         C         7.0         USA           carbon (graphite)         C         7.0         USA           carbon (graphite)         C         7.0         USA           indium         Re         6.5         Chile           indium         In         6.5         Chile           indium         Be         6.5         USA           hellum         Be         6.5         USA           hellum         He         6.5         USA           hellum         Mo         6.0         China           arsenic         As         6.0         China           arsenic         As         6.0         Rwanda           inagenese         Mn         5.5         DRC           gold         Au         5.5         DRC           cobalt         Co         5.5         DRC           cobalt         Co         5.5         DRC           gold         Au         5.5         Australia           cadium         Ca         5.5         Australia	strontium	Sr	7.5	China	
thoriumTh7.0IndiabronineBr7.0USAcarbon (graphite)C7.0OhinaheniumRe6.5ChileindianIn6.5ChileindiumIn6.5ChileindiumGa6.5ChileindiumGa6.5USAheliumHe6.5USAheliumHe6.5USAheliumMo6.0ChinatinSn6.0ChinatinSn6.0PerutartatumTa6.0RwandamagnesiumMg5.5OhinacobaltCo5.5DRCgoldAu5.5OhinacathiumCd5.5OhinamagnesiumMg5.5OhinacathiumCd5.5OhinalithiumLi5.5AustraliacathiumCa5.5OhinalithiumLi5.5AustraliacathiumCa5.5OhinalithiumLi5.5AustralialithiumLi5.5AustralialithiumLi5.5ChinalithiumLi5.5ChinalithiumLi5.5ChinalithiumLi5.5ChinalithiumLi5.5ChinalithiumLi5.5ChinalithiumLi5.5China </td <td>hismuth</td> <td>Bi</td> <td>7.0</td> <td>China</td>	hismuth	Bi	7.0	China	
bromineBr7.0USAcarbon (graphite)C7.0ChinarheniumRe6.5ChileindineI6.5ChileindineIn6.5ChileindiumIn6.5ChinagermaniumGe6.5USAheryliumBe6.5USAheliumHe6.5USAheliumHe6.5USAheliumHe6.5USAinSn6.0ChinaatsanicAs6.0PerutantalumTa6.0PerutantalumTa6.0RwandamanganeseMn5.5ChinacobaltCo5.5DRCgoldAu5.5ChinacatoriumCd5.5ChinacatoriumCa5.5ChinaphosphorousP5.0ChinaphosphorousP5.0ChinaboronBa4.5TurkyyvaradiumCr4.5ChinapoptastimK4.5ChinaboronBa4.5ChinacatoriumCa5.5ChinaptosphorousP5.0ChinaptosphorousP5.0ChinaptosphorousF4.5ChinaptosphorousF4.5ChinacatoriumGa4.5ChinacatoriumGa4.5	thorium	Th	7.0	India	
Carbon (graphite)         C         7.0         China           Indium         Re         6.5         Chile           Iodine         I         6.5         Chile           Indium         In         6.5         China           germanium         Ge         6.5         Dhina           beryllum         Be         6.5         USA           helium         He         6.5         USA           molybdenum         Mo         6.0         China           sin         Sn         6.0         China           siner         Ag         6.0         China           silver         Ag         6.0         Peru           tartalum         Ta         6.0         Rwanda           maganese         Mn         5.5         China           maganesium         Mg         5.5         China           cobalt         Co         5.5         DRC           gold         Au         5.5         China           fithium         Li         5.5         Australia           cadmium         Ca         5.5         China           bergium         Ba         5.0         China	bromine	Br	7.0	USA	
Answer         Re         6.5         Chile           Indium         In         6.5         Chile           Indium         In         6.5         China           gernanium         Ge         6.5         China           beryllium         Be         6.5         USA           helium         He         6.5         USA           helium         He         6.5         USA           helium         He         6.0         China           tin         Sn         6.0         China           silver         Ag         6.0         Peru           tartalum         Ta         6.0         Rwanda           magaese         Mn         5.5         China           cobalt         Co         5.5         DPC           gold         Au         5.5         China           cadmium         Cd         5.5         DPC           gold         Au         5.5         China           cadium         Ca         5.5         China           phosphorous         P         5.0         China           phosphorous         P         5.0         China	carbon (graphite)	С	7.0	China	
Indian         In         6.5         China           indium         In         6.5         China           germanium         Ge         6.5         China           germanium         Ge         6.5         USA           helium         He         6.5         USA           helium         He         6.5         USA           motydodrum         Mo         6.0         China           tin         Sn         6.0         China           arsenic         As         6.0         Peru           tartalum         Ta         6.0         Rwanda           magnesium         Mg         5.5         China           readmium         Mg         5.5         China           cobalt         Co         5.5         DRC           gold         Au         5.5         China           cathum         Cd         5.5         China           lithium         Li         5.5         China           cathum         Ca         5.5         China           bron         Ca         5.5         China           bron         Ba         5.0         China      b	rhenium	Be	6.5	Chile	
IndiumIn6.5ChinagermaniumGe6.5ChinaberylliumBe6.5USAheliumHe6.5USAmolybdenumMo6.0ChinatinSn6.0ChinaarsenicAs6.0PerutartalumTa6.0PerutartalumTa6.0RwandamagnesiumMg5.5ChinacobaltCo5.5DRCgoldAu5.5ChinacadmiumCd5.5ChinacadmiumCd5.5ChinacadmiumCd5.5ChinacadmiumCa5.5ChinacadadumCa5.5ChinacadadumCa5.5ChinacadadumCa5.5ChinacadadumCa5.5ChinabarlumBa5.0ChinabarlumBa5.0ChinabarlumZr4.5AustraliacalciumV4.5RussiabarlumGa4.5ChinabarlumGa4.5ChinaprossiumK4.5CanadagalliumGa4.5ChinapotassiumK4.5ChinafluorineF4.5Chinacarbon (ccal)C4.5Chinacarbon (ccal)C4.5Chinacarbon (clamadumNi4.0 </td <td>iodine</td> <td></td> <td>6.5</td> <td>Chile</td>	iodine		6.5	Chile	
Instructure         Instructure         Instructure           germanium         Ge         6.5         China           beyllium         He         6.5         USA           heljum         He         6.5         USA           inin         Sn         6.0         China           tin         Sn         6.0         China           arsenic         As         6.0         Peru           tantalum         Ta         6.0         Rwanda           magnesic         Mn         5.5         China           magnesium         Mg         5.5         China           cobalt         Co         5.5         DRC           gold         Au         5.5         China           cadmium         Cd         5.5         China           cadium         Cd         5.5         China           cadium         Cd         5.5         China           phosphorous         P         5.0         China           boron         B         4.5         Turkey           zirconium         Zr         4.5         Australia           vanadium         V         4.5         China	indium	 In	6.5	China	
generation         Be         6.5         USA           helium         He         6.5         USA           nolybdenum         Mo         6.0         China           tin         Sn         6.0         China           arsenic         As         6.0         China           silver         Ag         6.0         Peru           tartalum         Ta         6.0         Rwanda           maganese         Mn         5.5         China           gold         Au         5.5         China           cobalt         Co         5.5         China           cadmium         Cd         5.5         China           cadium         Cd         5.5         China           cadium         Cd         5.5         China           cadium         Cd         5.5         China           fithium         Li         5.5         Australia           cadium         Ca         5.5         China           brono         Ba         5.0         China           barum         Ba         5.5         Turkey           zirconium         Zr         4.5         Australia     <	germanium	ែខ	6.5	China	
Bellium         Bellium         He         6.5         USA           molybdenum         Mo         6.0         China         1           tin         Sn         6.0         China         1           arsenic         As         6.0         China         1           silver         Ag         6.0         Peru         1           tantalum         Ta         6.0         Rwanda         1           magnese         Mn         5.5         China         1           cobalt         Co         5.5         DRC         1           gold         Au         5.5         China         1           cadmium         Cd         5.5         China         1           cadium         Ca         5.5         China         1           cadium         Ca         5.5         China         1           phosphorous         P         5.0         China         1           barium         Ba         4.5         Turkey         2           ariconium         Zr         4.5         Australia         1           vanadium         V         4.5         China         1	bervllium	Be	6.5	LISA	
No.         So.         So.         So.         So.           ining         No         6.0         China           arsenic         As         6.0         China           silver         Ag         6.0         Peru           tantalum         Ta         6.0         Rwanda           maganese         Mn         5.5         China           cobalt         Co         5.5         DRC           gold         Au         5.5         China           cobalt         Co         5.5         DRC           gold         Au         5.5         China           cadmium         Cd         5.5         China           lithium         Li         5.5         Australia           cadium         Ca         5.5         China           barium         Ba         5.0         China           barium         Ba         5.0         China           barium         Ba         5.0         China           barium         Ba         5.0         China           barium         Ba         4.5         Turkey           zirconium         Zr         4.5         Australia	helium	He	6.5	LISA	
InterpretationInterpretationinSn6.0ChinaarsenicAs6.0ChinasilverAg6.0PerutantalumTa6.0RwandamanganeseMn5.5ChinacobaltCo5.5DRCgoldAu5.5ChinacobaltCo5.5DRCgoldAu5.5ChinacadmiumCd5.5ChinalithiumLi5.5ChinalithiumCa5.5ChinalithiumCa5.5ChinaphosphorousP5.0ChinabariumBa5.0ChinabariumBa5.0ChinabariumBa4.5TurkeyzirconiumZr4.5AustraliavanadiumV4.5CanadagalliumGa4.5ChinapotasiumK4.5CanadagalliumGa4.5ChinacopperCu4.5Chinacarbon (coal)C4.5ChinariccZn4.0ChinaseleniumS3.5Chinacarbon (diamods)C4.0RussiasulphurS3.5ChinairionFe3.5Chinacarbon (diamods)C4.0RussiasulphurS3.5ChinairionFe3.5China </td <td>molyhdenum</td> <td>Mo</td> <td>6.0</td> <td>China</td>	molyhdenum	Mo	6.0	China	
AnAsCoChinaarsenicAs6.0ChinasilverAg6.0PerutantalumTa6.0RwandamagneseMn5.5ChinamagnesiumMg5.5ChinacobaltCo5.5DRCgoldAu5.5ChinacadmiumCd5.5ChinacadmiumCd5.5ChinacadmiumCa5.5ChinacadmiumCa5.5ChinacalciumCa5.5ChinaphosphorousP5.0ChinabariumBa5.0ChinaboronB4.5TurkeyzirconiumZr4.5RussialeadPb4.5ChinapotassiumK4.5ChinagalliumGa4.5ChinafluorineF4.5ChinacopperCu4.5ChinaseleniumSe4.5ChinacopperCu4.5Chinacarbon (coal)C4.0ChinarickelNi4.0Russiacarbon (diamods)C4.0ChinasodiumNa4.0Chinacarbon (diamods)C4.0ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5China <td>tin</td> <td>Sn</td> <td>6.0</td> <td>China</td>	tin	Sn	6.0	China	
Disord         Ag         GO         Peru           tantalum         Ta         6.0         Rwanda           maganese         Mn         5.5         China           cobalt         Co         5.5         China           cobalt         Co         5.5         DRC           gold         Au         5.5         China           cadmium         Cd         5.5         China           cadmium         Ca         5.5         China           barium         Ca         5.5         China           barium         Ba         5.0         China           boron         B         4.5         Turkey           zirconium         Zr         4.5         Australia           vanadium         V         4.5         Russia           lead         Pb         4.5         China           goltassium         K         4.5         China <td>arsenic</td> <td>Δs</td> <td>6.0</td> <td>China</td>	arsenic	Δs	6.0	China	
AndTagCoRwandamanganeseMn5.5ChinamagnesiumMg5.5ChinacobaltCo5.5DRCgoldAu5.5ChinacadmiumCd5.5ChinalithiumLi5.5ChinacadmiumCa5.5ChinacadmiumCa5.5ChinalithiumLi5.5ChinacalciumCa5.5ChinaphosphorousP5.0ChinabariumBa5.0ChinaboronB4.5TurkeyzirconiumZr4.5AustraliavanadiumV4.5RussialeadPb4.5ChinapotassiumK4.5ChinafuorineF4.5ChinacopperCu4.5ChinacopperCu4.5Chinacarbon (coal)C4.5ChinanickelNi4.0Russiacarbon (diamonds)C4.0ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5China	silvor	Λα	6.0	Poru	
IndicationIndicationmanganeseMin5.5ChinaregressiumMg5.5ChinacobaltCo5.5DRCgoldAu5.5ChinacadmiumCd5.5ChinaithiumLi5.5AustraliacalciumCa5.5ChinaphosphorousP5.0ChinabariumBa5.0ChinaboronB4.5TurkeyzirconiumZr4.5AustraliavanadiumV4.5RussialeadPb4.5ChinapotassiumK4.5CanadagalliumGa4.5ChinafloorineF4.5ChinacopperCu4.5ChinagalliumGa4.5ChinafloorineF4.5ChinacopperCu4.5Chinacarbon (coal)C4.5ChinaincZn4.0ChinauraniumU4.0KazakhstannickelNi4.0ChinasodiumNa4.0ChinasodiumS3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5Chinairon	tantalum	Ta	6.0	Bwanda	
InterpretationMin3.3ChinamagnesiumMg5.5ChinacobaltCo5.5DRCgoldAu5.5ChinacadmiumCd5.5ChinacadmiumCd5.5ChinailthiumLi5.5ChinacalciumCa5.5ChinaphosphorousP5.0ChinabariumBa5.0ChinaboronB4.5TurkeyzirconiumZr4.5AustraliavanadiumV4.5ChinapotassiumK4.5ChinagolaliumGa4.5ChinagalliumGa4.5ChinafluorineF4.5ChinacopperCu4.5Chinacarbon (coal)C4.5ChinazincZn4.0ChinauraniumU4.0KazakhstannickelNi4.0Russiacarbon (diamonds)C4.5ChinasodiumNa4.0ChinasodiumNa4.0ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5China </td <td>mangangan</td> <td>Mn</td> <td>5.5</td> <td colspan="2"></td>	mangangan	Mn	5.5		
IndependentIndependentcobaltCo5.5DRCgoldAu5.5ChinacadmiumCd5.5ChinalithiumLi5.5AustraliacalciumCa5.5ChinaphosphorousP5.0ChinabariumBa5.0ChinaboronB4.5TurkeyzirconiumZr4.5AustraliavanadiumV4.5RussialeadPb4.5ChinapotassiumK4.5ChinagallumGa4.5ChinafluorineF4.5ChinacopperCu4.5ChinagalumGa4.5ChinafluorineF4.5ChinacopperCu4.5ChinaseleniumSe4.5ChinazincZn4.0ChinauraniumU4.0RussiauraniumU4.0RussiachlorineCl4.5ChinazincZn4.0ChinauraniumNi4.0RussiauraniumNa4.0ChinasodiumNa4.0Chinacarbon (caal)C4.0Chinacarbon (camonds)C4.0Chinacarbon (diamonds)C4.0ChinaironFe3.5ChinaironFe3.5China	manganese	Ma	5.5	China	
ColarColColColgoldAu5.5ChinaithiumCd5.5ChinalithiumLi5.5AustraliacalciumCa5.5ChinaphosphorousP5.0ChinabariumBa5.0ChinaboronB4.5TurkeyzirconiumZr4.5AustraliavanadiumV4.5RussialeadPb4.5ChinagollumGa4.5ChinagoltumK4.5CanadagalliumGa4.5ChinafluorineF4.5ChinacopperCu4.5ChinacopperCu4.5Chinacarbon (coal)C4.5ChinanickelNi4.0RussiachlorineCl4.0Chinaicarbon (diamonds)C4.0ChinasulphurS3.5ChinaironFe3.5ChinaironFe3.5ChinaironAA.0ChinaironFe3.5ChinaironAA.0ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5Chinairon <td>cobalt</td> <td>Co</td> <td>5.5</td> <td></td>	cobalt	Co	5.5		
gudAd3.3ChinacadmiumCd5.5ChinalithiumLi5.5AustraliacalciumCa5.5ChinaphosphorousP5.0ChinabariumBa5.0ChinaboronB4.5TurkeyzirconiumZr4.5AustraliavanadiumV4.5RussialeadPb4.5ChinagulumGa4.5ChinagulumGa4.5ChinagulumGa4.5ChinagulumGa4.5ChinagulumGa4.5ChinafluorineF4.5ChinacopperCu4.5Chinacarbon (coal)C4.5ChinazincZn4.0ChinainckelNi4.0RussiachlorineCl4.0ChinainckelNi4.0ChinasodiumNa4.0ChinasodiumNa4.0ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe3.5ChinaironFe <td>aold</td> <td>C0</td> <td>5.5</td> <td>China</td>	aold	C0	5.5	China	
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Supply risk index runs from 1 (blue — very low risk) to 10 (red — very high risk) Copyright NERC 2011

Limitations and methodology are set out in accompanying notes

# A new supply risk index for chemical elements or element groups which are of economic value

The risk list gives a quick and simple indication of the relative risk in 2011 to the supply of the 52 chemical elements or element groups which we need to maintain our economy and lifestyle. The position of an element on this list is determined by a number of factors which might impact on supply. These include the abundance of elements in the Earth's crust, the location of current production and reserves, and the political stability of those locations. Data sources used in the compilation of the list are internationally recognised and publicly available.

The risk list highlights a group of elements where global production is concentrated in a very few countries. The restricted supply base and the relatively low political stability ratings for some major producing countries combine to significantly increase risk to supply. Restriction on the availability of rare earth elements has received a good deal of attention recently and this group features close to 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 component in autocatalysts), niobium (used in MRI scanners and touch screens) and tungsten (key hard metal used in almost all cutting tools). The list also shows the current importance of China in production of many metals and minerals. China is now the leading global producer of 28 of the 52 elements and element groups on the list (and as shown in 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 which elements might be subject to supply disruption, most likely from human factors such as geopolitics ('haves' seeking to influence 'have nots') or resource nationalism (state control of production), along with events such as strikes and accidents. Policy-makers, industry and consumers should be concerned about supply risk and the need to diversify supply from Earth resources, from recycling more and doing more with less, and also about the environmental implications of burgeoning consumption.

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 or how easy it is to substitute that element with another.

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



### 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:

Ag; Al; As; Au; B; Ba; Be; Bi; Br; C (coal, diamond and graphite); Ca; Cd; Cl; Co; Cr; Cu; F; Fe; Ga; Ge; He; Hg; I; In; K; Li; Mg; Mn; Mo; Na; Nb; Ni; P; Pb; PGE (Ru, Pd, Os, Ir and Pt) ; Re; REE (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu); S; Sb; Se; Sn; Sr; Ta; Th; Ti; U; V; W; Zn; and 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 four criteria scored between 1 and 5.

- Scarcity
- Production concentration
- Reserve base distribution
- Governance

A score of 1 indicates that a particular criterion has a low contribution to supply risk, while a score of 5 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:

>100 to 1000 ppm
>10 to 100 ppm
>1 to 10 ppm
>0.1 to 1 ppm
<0.1 ppm

Where data are unavailable an arbitrary score of 2 was allocated. For example, He is allocated a score of 2 since crustal abundance data is unavailable.

Element	Abundance (ppm)	Element	Abundance (ppm)
Ag	0.055	Mn	774
Al	84,149	Мо	0.8
As	2.5	Na	22,774
Au	0.0013	Nb	8
В	11	Nd	20
Ва	456	Ni	26.6
Ве	1.9	Os	0.000041
Bi	0.18	Р	567
Br	0.88	Pb	11
Cd	0.08	Pd	0.0015
Ce	43	Pr	4.9
Со	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	Та	0.7
Ge	1.3	Tb	0.6
Hg	0.03	Th	5.6
Но	0.77	Ti	4136
-	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 83 per cent of the world's tungsten is currently sourced from China. The BGS' <u>World Mineral Production data (2005-2009)</u> 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:

0 to 30 %
>30 to 45 %
>45 to 60 %
>60 to 75 %
>75 %

#### Reserve base distribution

It is important to assess where elements might be sourced in the future. However, for many elements the global distribution of resources is poorly known, while reserves<sup>1</sup> are often localised. Accordingly we have used reserve base<sup>2</sup> distribution data from the USGS to provide an indication of future sources of supplies. Where the reserve base of a given commodity is concentrated in a few countries this leads to increased risk to future supplies. For example, nearly 87 per cent of the world's reserve base of niobium is found in Brazil. The USGS' Commodity Summaries (2009) reserve base data were used to identify the three countries contributing the largest share to the global reserve base and the percentage of the world reserve base held by the top country.

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

1 (low)	0 to 30 %
2 (medium-low)	>30 to 45 %
3 (medium)	>45 to 60 %
4 (medium-high)	>60 to 75 %
5 (high)	>75 %

Where data are unavailable an arbitrary score of 2 was allocated. For example, Be, As, Na, S, In, Cl, Ca and Ge are allocated a score of 2 since reserve base information is unavailable. Reserve base data are also unavailable for coal; however, reserve data for 2008 are available from the Energy Information Administration (EIA).

### **Governance indicators**

The political stability of a producing country 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 combined overall political stability score was calculated, using World Bank (WB) governance indicators, for the leading three producing countries. 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.

A combined overall political stability value was calculated by summing the individual political stability scores for the three leading global producers for each element and scored as follows:

0 to 2
3 to 4
5 to 6
7 to 8
9

For example, the three leading producing countries for REE are China, Brazil and Russia. Their combined political stability factor would be calculated thus: China (WB percentile rank is 29.7 = 3), Brazil (WB percentile rank is 54.2 = 2), and Russia (WB percentile rank is 21.7 = 3), as shown in Figure 2. Combining these scores gives a combined political stability factor of 8 which equates to an overall score of 4 (medium-high risk).



Figure 2. Political stability indicators for Brazil, China and Russia. Data from the World Bank after Kaufmann et al. (2010).

#### Supply risk

An integrated supply risk was calculated by combining the scores for each of the four criteria. This is illustrated for two elements, iron and niobium, in Table 2.

Category	Iron Score Niobium Score		m Score	
	Value	Score	Value	Score
Crustal abundance (ppm)	56,300	1	8	3
Reserve base distribution (%)	21.4	1	86.7	5
Production concentration (%)	39.1	2	95.8	5
Political Stability	6	3	6	3
Total		7		16
Supply Risk Index (Total/ 2)		3.5		8

**Table 2.** The calculation of a supply risk index.

Aggregate scores were divided by 2 to produce a simple supply risk index from 1 (very low risk) to 10 (very high risk). For example, iron has an initial aggregate score of 7. This is divided by 2 to give a score of 3.5. This shows that iron has a lower relative risk to supply compared to niobium with a score of 8.

#### Limitations to the methodology

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

**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. Also recycling is likely to contribute an increasing share to the global market in the future.

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. Ti 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 a single commodity e.g. PGE and REE. For these grouped elements a worst case scenario has been taken in terms of the crustal abundance e.g. Lu at 0.3 ppm has been used to calculate the crustal abundance risk for REE rather than Ce at 43 ppm. Likewise, Ir 0.000037 ppm has been used to calculate the crustal abundance risk for PGE rather than Pd at 0.0015 ppm.

## **British Geological Survey**

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 base calculations (Table 3).

Element	Ргоху
Sodium	Halite - NaCl (+ sea salt and brine)
Calcium	Lime - CaO
Fluorine	Fluorspar - CaF <sub>2</sub>
Carbon	Coal, diamonds, and graphite
Barium	Barytes - BaSO <sub>4</sub>
Beryllium	Beryl - $Be_3Al_2(SiO_3)_6$
Boron	Borate
Potassium	Potash - K <sub>2</sub> O content
Titanium	Rutile and Ilmenite - TiO <sub>2</sub> and FeTiO <sub>3</sub>
Magnesium	Magnesite - MgCO <sub>3</sub>
REE	Rare Earth Oxides (REO)

 Table 3 - Element proxies used in production and reserve base calculations.

Mineral resources<sup>3</sup> have been omitted from this study since resources are not measured and the global distribution is poorly defined.

Elements that have little or no commercial use have been omitted from this study e.g. Po, At, and Ra. Likewise, synthetic or 'manufactured' elements have also been omitted e.g. elements of atomic number 95 to 114, and H. Elements naturally occurring in a gaseous state are also not included e.g. the Noble gases, O and N because the criteria used are unsuitable for assessing the supply risk of these elements. Production and reserve base information for some of the minor metals e.g. Sc, Y, Cs, Te, Tl, and Rb is unavailable because they are commonly produced as by-products or as co-metals. For example, Y is often associated with REE-bearing minerals; Sc is found in trace amounts in minerals such as beryl, garnet and wolframite; Cs is often a by-product of Li extraction; and Te, along with Se, 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).
- Reserve Base the 'reserve base' includes the 'mineral reserve' plus those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics. It has been a widely utilised concept. However, publication of reserve base estimates was discontinued in 2010 (USGS, 2010).

## **British Geological Survey**

3. Resources - a 'mineral resource' regroups all identified resources. It 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, the reserve base and resources.

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