

Material Scarcity

– in Search of Solutions –

Endangered Elements
- Metals and Phosphorus -

The Elements

<div>food & life</div>																		<div>2</div> <div>He</div> <div>4.0026</div>																			
<div>1</div> <div>H</div> <div>1.0079</div>																				<div>10</div> <div>Ne</div> <div>20.180</div>																	
<div>3</div> <div>Li</div> <div>6.941</div>		<div>4</div> <div>Be</div> <div>9.0122</div>																<div>9</div> <div>F</div> <div>18.998</div>		<div>18</div> <div>Ar</div> <div>39.948</div>																	
<div>11</div> <div>Na</div> <div>22.990</div>		<div>12</div> <div>Mg</div> <div>24.305</div>																<div>17</div> <div>Cl</div> <div>35.453</div>		<div>36</div> <div>Kr</div> <div>83.80</div>																	
<div>19</div> <div>K</div> <div>39.098</div>		<div>20</div> <div>Ca</div> <div>40.078</div>																<div>35</div> <div>Br</div> <div>79.904</div>		<div>54</div> <div>Xe</div> <div>131.29</div>																	
<div>37</div> <div>Rb</div> <div>85.468</div>		<div>38</div> <div>Sr</div> <div>87.62</div>		<div>39</div> <div>Y</div> <div>88.906</div>		<div>40</div> <div>Zr</div> <div>91.224</div>		<div>41</div> <div>Nb</div> <div>92.906</div>		<div>42</div> <div>Mo</div> <div>95.94</div>		<div>43</div> <div>Tc</div> <div>[98]</div>		<div>44</div> <div>Ru</div> <div>101.07</div>		<div>45</div> <div>Rh</div> <div>102.91</div>		<div>46</div> <div>Pd</div> <div>106.42</div>		<div>47</div> <div>Ag</div> <div>107.87</div>		<div>48</div> <div>Cd</div> <div>112.41</div>		<div>49</div> <div>In</div> <div>114.82</div>		<div>50</div> <div>Sn</div> <div>118.71</div>		<div>51</div> <div>Sb</div> <div>121.76</div>		<div>52</div> <div>Te</div> <div>127.6</div>		<div>53</div> <div>I</div> <div>126.90</div>		<div>54</div> <div>Xe</div> <div>131.29</div>			
<div>55</div> <div>Cs</div> <div>132.91</div>		<div>56</div> <div>Ba</div> <div>137.33</div>		<div>57-70</div> <div>*</div>		<div>71</div> <div>Lu</div> <div>174.97</div>		<div>72</div> <div>Hf</div> <div>178.49</div>		<div>73</div> <div>Ta</div> <div>180.95</div>		<div>74</div> <div>W</div> <div>183.84</div>		<div>75</div> <div>Re</div> <div>186.21</div>		<div>76</div> <div>Os</div> <div>190.23</div>		<div>77</div> <div>Ir</div> <div>192.22</div>		<div>78</div> <div>Pt</div> <div>195.07</div>		<div>79</div> <div>Au</div> <div>196.97</div>		<div>80</div> <div>Hg</div> <div>200.59</div>		<div>81</div> <div>Tl</div> <div>204.38</div>		<div>82</div> <div>Pb</div> <div>207.2</div>		<div>83</div> <div>Bi</div> <div>208.98</div>		<div>84</div> <div>Po</div> <div>[209]</div>		<div>85</div> <div>At</div> <div>[210]</div>		<div>86</div> <div>Rn</div> <div>[222]</div>	
<div>87</div> <div>Fr</div> <div>[223]</div>		<div>88</div> <div>Ra</div> <div>[226]</div>		<div>89-102</div> <div>**</div>		<div>103</div> <div>Lr</div> <div>[260]</div>		<div>104</div> <div>Rf</div> <div>[261]</div>		<div>105</div> <div>Db</div> <div>[262]</div>		<div>106</div> <div>Sg</div> <div>[266]</div>		<div>107</div> <div>Bh</div> <div>[264]</div>		<div>108</div> <div>Hs</div> <div>[277]</div>		<div>109</div> <div>Mt</div> <div>[268]</div>		<div>110</div> <div>Uu</div> <div>[271]</div>		<div>111</div> <div>Uu</div> <div>[272]</div>		<div>112</div> <div>Uu</div> <div>[273]</div>		<div>114</div> <div>Uu</div> <div>[285]</div>											

food & life

lights

batteries

solar panels

magnets

catalysts

* Lanthanide series

** Actinide series

- Serious threat in next 100 years
- Rising threat from increasing use
- Limited availability future risk to supply
- Abundant element
- Formed by radioactive decay
- Insufficient information



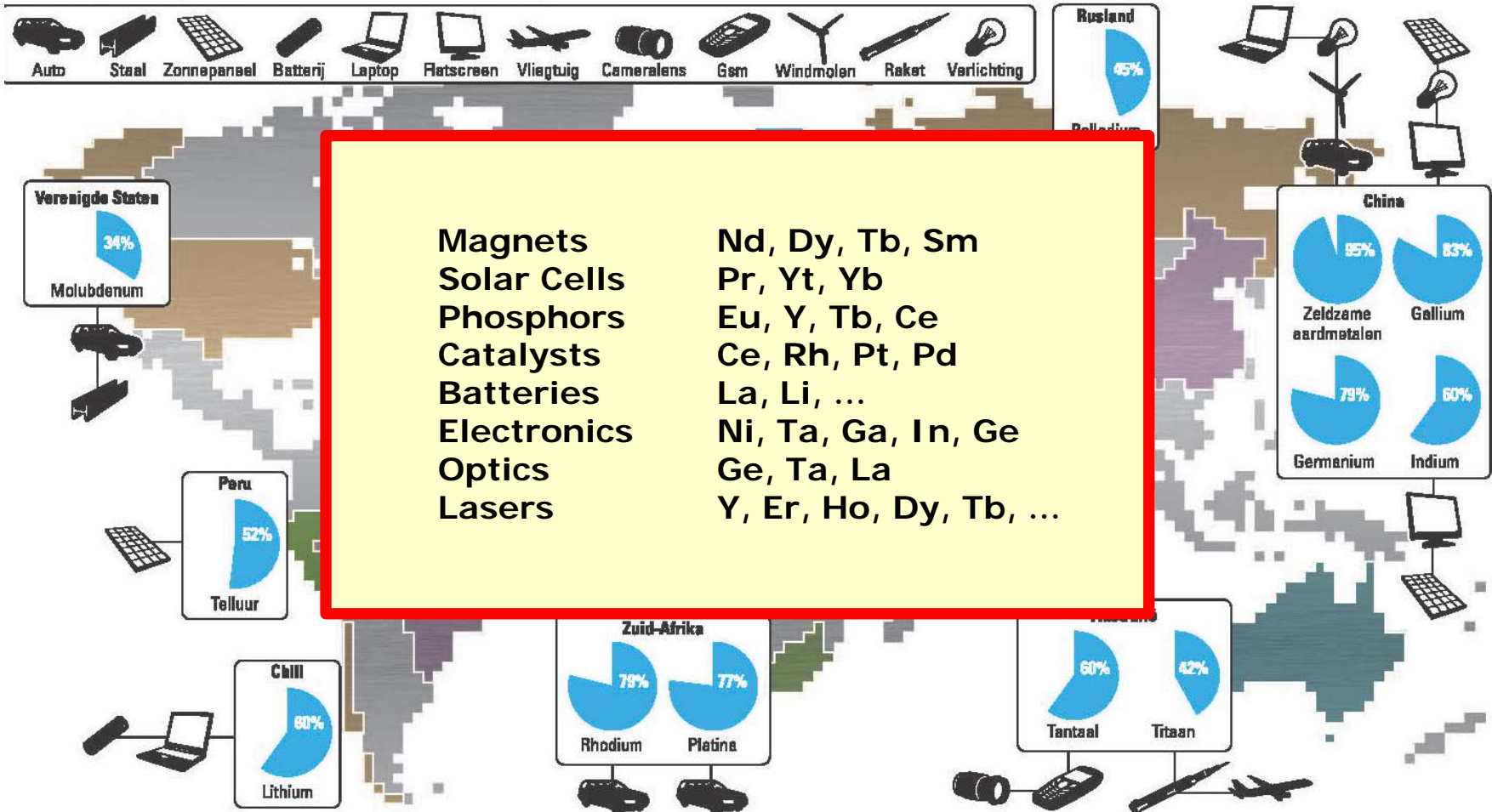
China dominates the rare earth metals

NRC-Handelsblad January 16, 2010

Hybrid cars, flat screens, and solar panels contain rare (earth) metals. Most are obtained from China and unstable regions. The Western world is vulnerable.

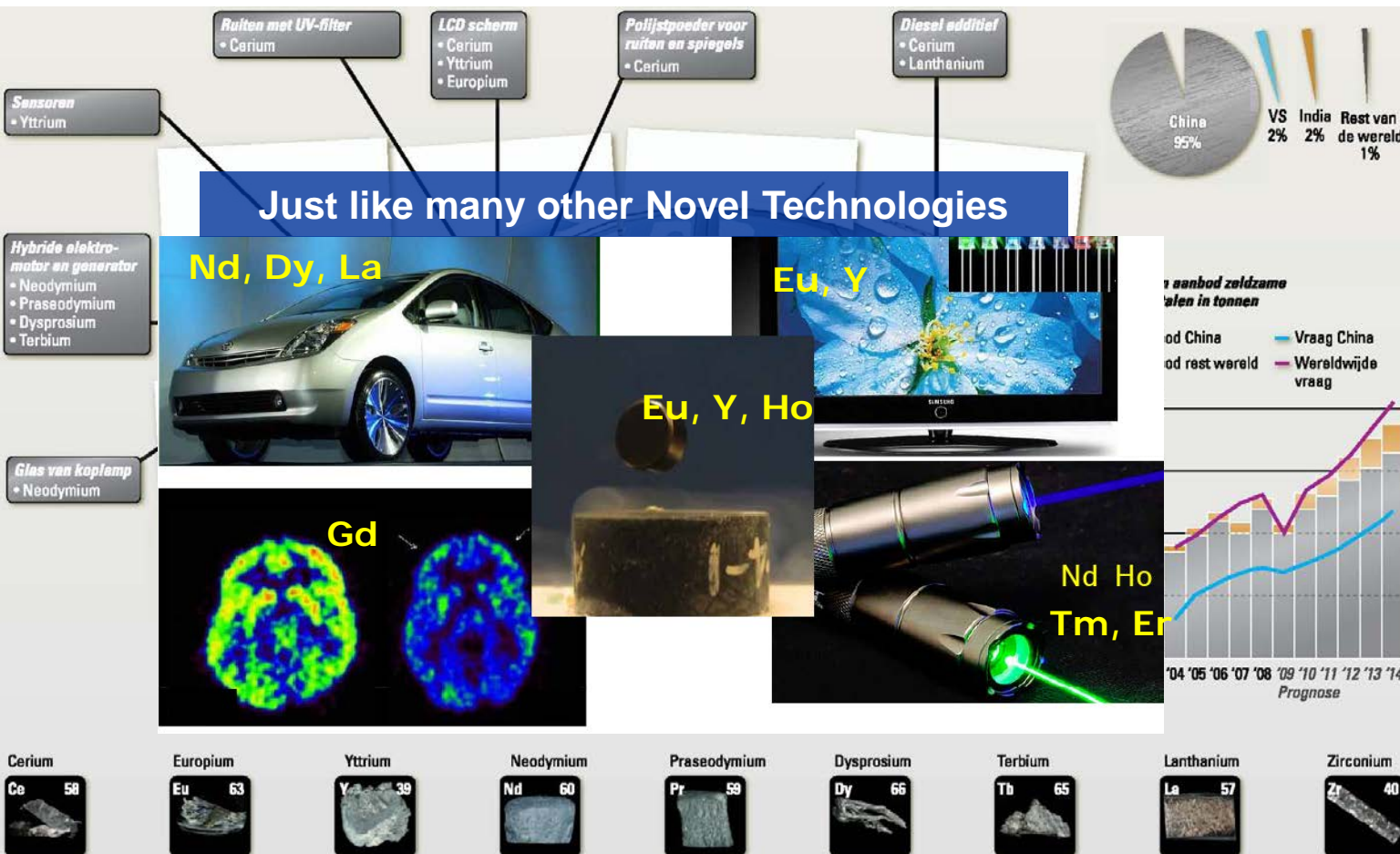
Europa afhankelijk van rest van de wereld voor kritische metalen

De taartdiagrammen geven het aandeel aan van de totale wereldproductie



Without rare earth metals, no car

NRC-Handelsblad January 22, 2010



Neodymium

500 g

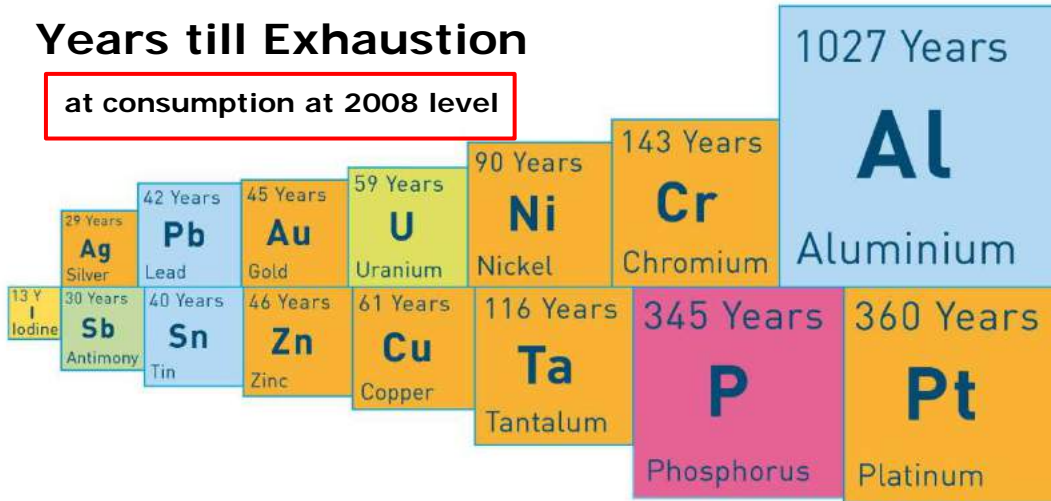
Toyota Prius
Mercedes S 400

200 kg

Windturbine 16m

Years till Exhaustion

at consumption at 2008 level



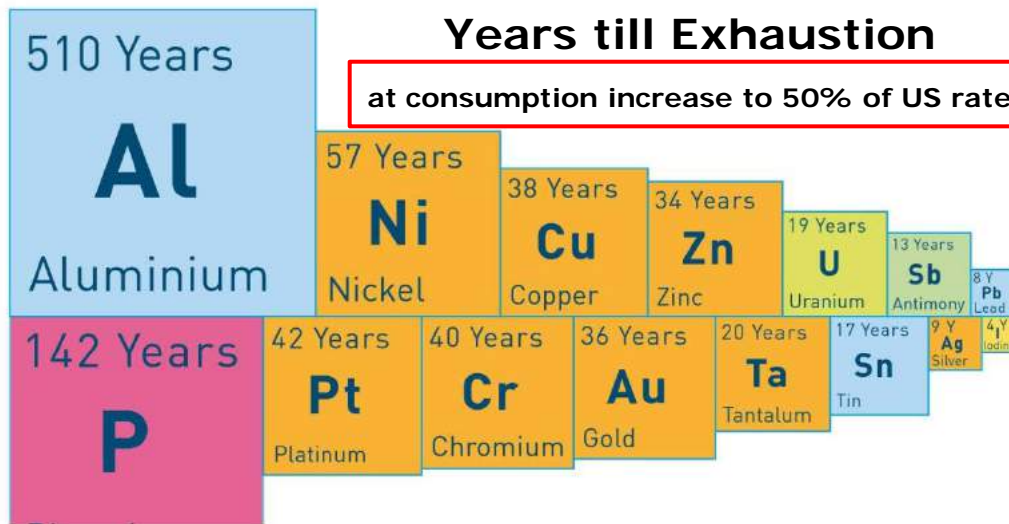
Scarcity of Minerals

A strategic security issue!

The Hague Centre for Strategic Studies 02 | 01 | 10

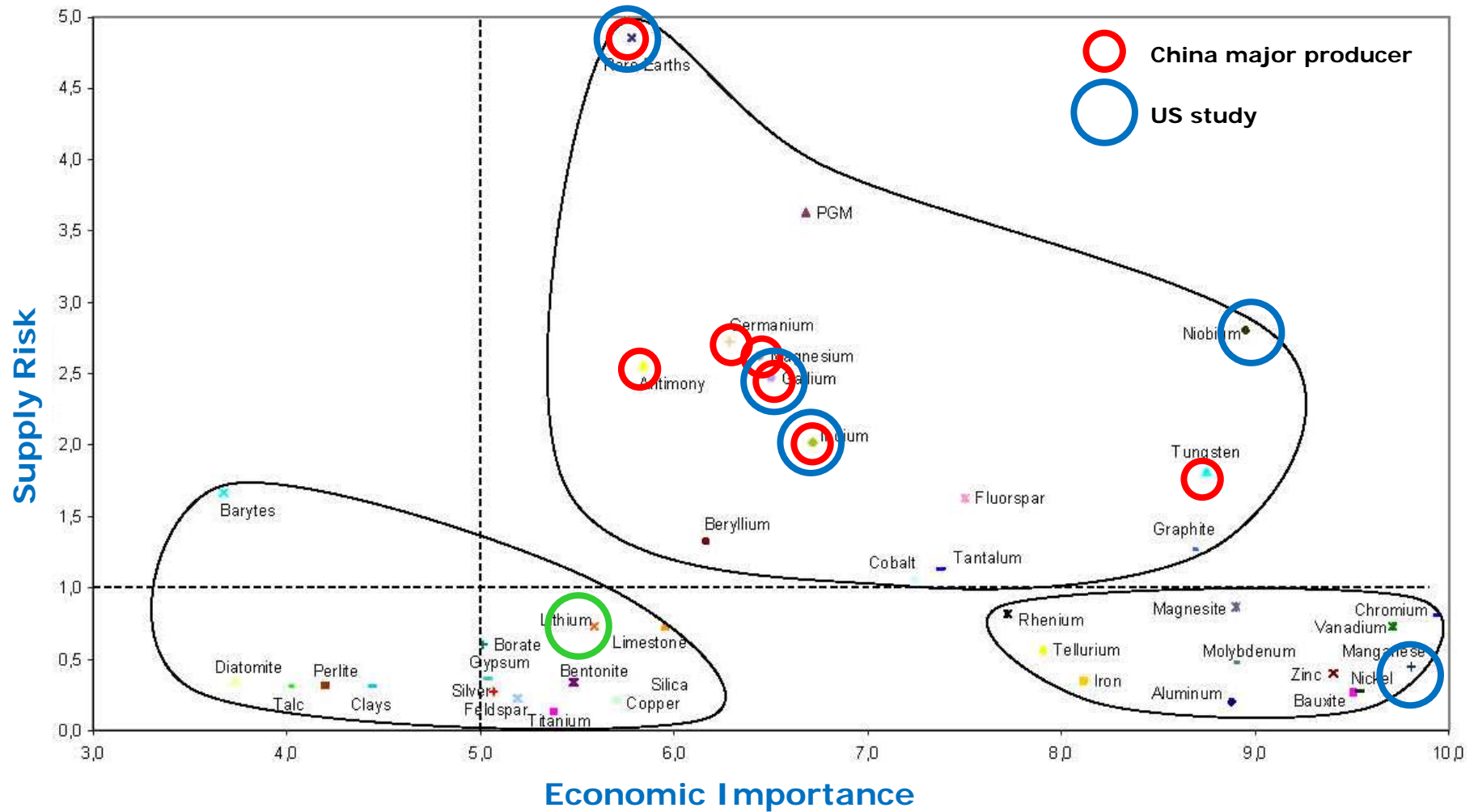
Years till Exhaustion

at consumption increase to 50% of US rate



War on Unobtanium

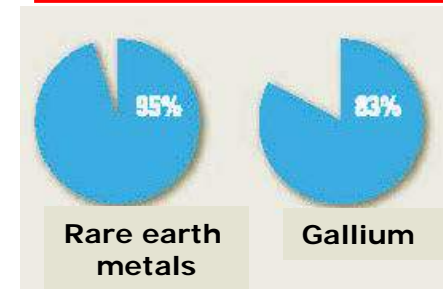
EU Critical Materials List



Scarcity of Minerals

MINERAL	SHARE ¹	EXPORT QUOTA (2010)	MAIN APPLICATIONS
DYSPROSIUM	99%	Full export ban	Permanent magnet (electrical vehicles; windturbines)
LANTHANUM	95%	ca. 9.000 tonnes ²	NiMH battery (electrical vehicles)
NEODYMIUM	95%	ca. 5.000 tonnes ³	Permanent magnet (electrical vehicles; windturbines)
ANTIMONY	87%	57.500 tonnes	Semiconductors, alloys
TUNGSTEN	84%	14.300 tonnes	High-performance cutting tools
GALLIUM	83%	-	Semiconductor (space defense)

Chinese share of world production



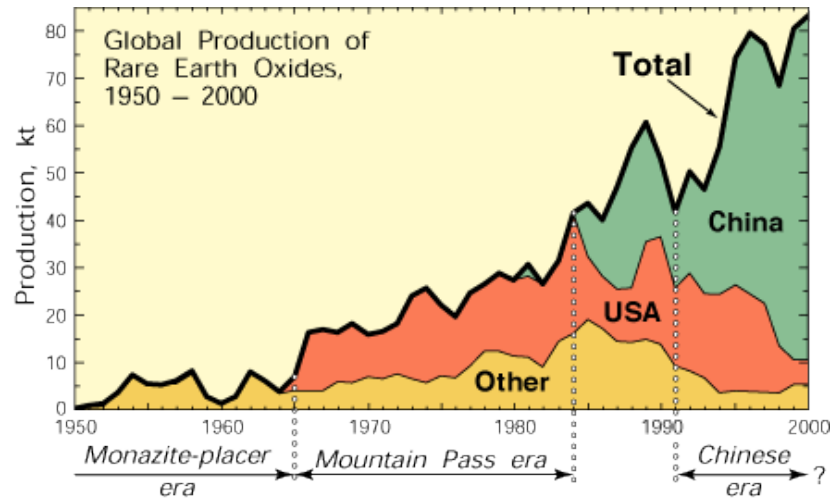
China's Rare Earth Element Export Quotas

	Export Quotas (Tonnes Rare Earth Oxides)	Annual Change
2005	65,609	-
2006	61,821	-6%
2007	59,643	-4%
2008	56,939	-5%
2009	50,145	-12%
2010	30,258	-40%
2011	30,184	-0.24%

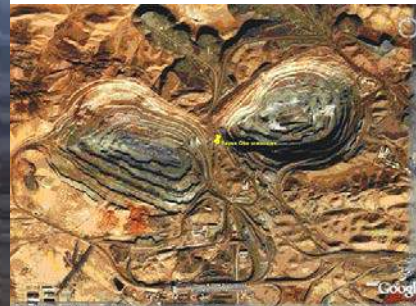
China keeps rare earth metals for itself
(NRC – Dutch Newspaper)

(Source: Kingsnorth 2010 and Scott 2011)

Scarcity of Minerals - China



Bayan Obo Mine, Inner Mongolia the largest worldwide



Scarcity of Minerals - non-China

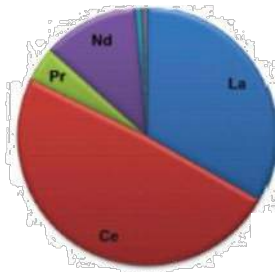
Source:
IMCOA 2009

Deposit	Resource (million tonnes)
Bayan Obo	1,460
Kvanevfjeld Greenland	215
Mountain Pass	20
Nechalacho	65
Mt Weld	12

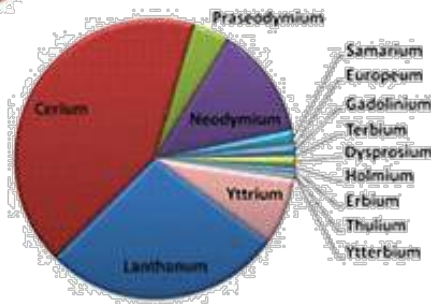


Relative Abundance of Rare Earth Elements

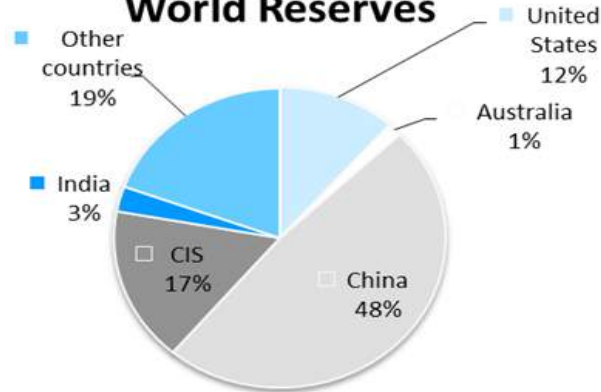
Mt Pass



Kvanevfjeld



World Reserves



World Reserves in million tons (USGS 2012)

United States	13
Australia	1.6
China	55
CIS	19
India	3.1
Other countries	22
Total	114

Rare Earths & Precious Metals

Scandium, Yttrium, and the Lanthanides

Hydrogen 1 1.0079					
Lithium 3 6.941	Beryllium 4 9.0122				
Sodium 11 22.990	Magnesium 12 24.305				
Potassium 19 39.098	Calcium 20 40.078				
Rubidium 37 85.468	Sr 38 87.62	Scandium 21 44.956	Ti 22 47.867		
Cesium 55 132.91	Ba 56 137.33	Y 39 88.906	Zr 40 91.224		
Fr 87 [223]	Ra 88 [226]	* 57-71	Hf 72 178.49		
		89-102	103	104	
			La	Pf	

* Lanthanide series

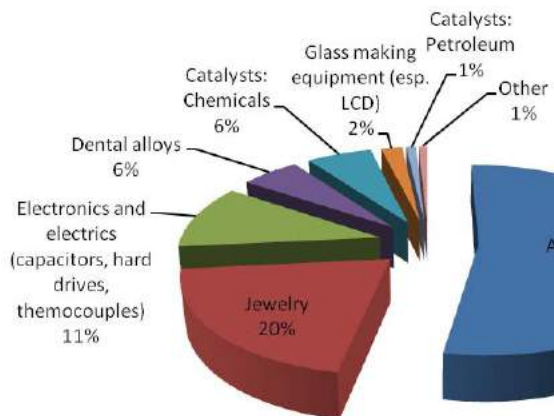
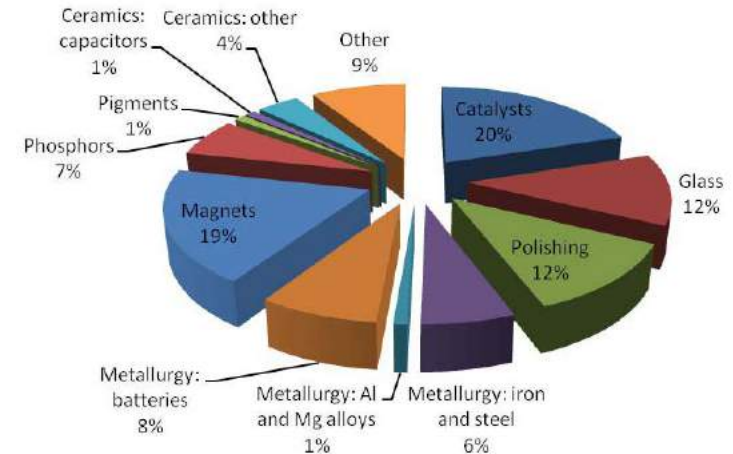
Lanthanum 57 138.91	Cerium 58 140.12	Praseodymium 59 140.91	Niodymium 60 144.24	Promethium 61 [145]	Samarium 62 150.36	Europium 63 151.96	Gadolinium 64 157.25	Terbium 65 158.93	Dysprosium 66 162.50	Holmium 67 164.93	Erbium 68 167.26	Thulium 69 168.93	Ytterbium 70 173.05
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb

Iron 26 55.845	Cobalt 27 58.933	Nickel 28 58.693
Ru 44 101.07	Rh 45 102.91	Pd 46 106.42
Os 76 190.23	Ir 77 192.22	Pt 78 195.08

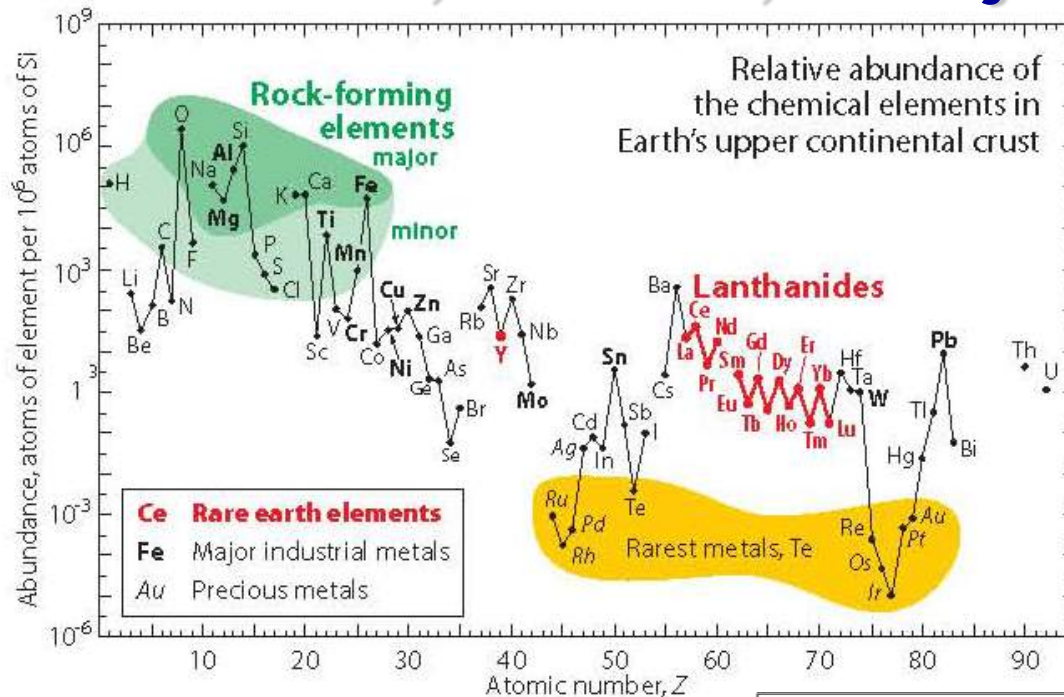


Global Precious Metals Reserves

Economic Importance



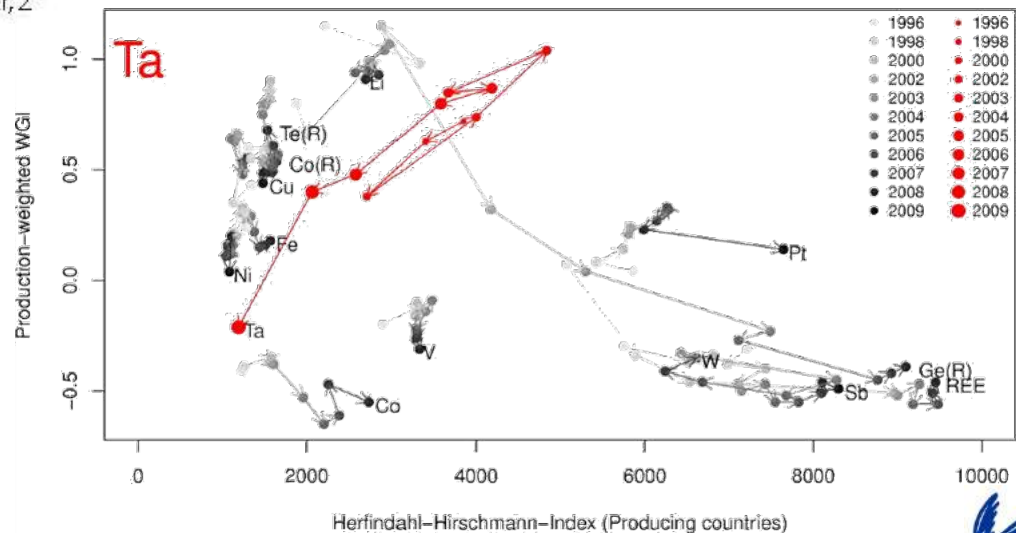
Precious, Rare Earth, and Major Industrial Metals



WGI Worldwide Governance Indicator
vs
Hersfindahl-Hirschman Index

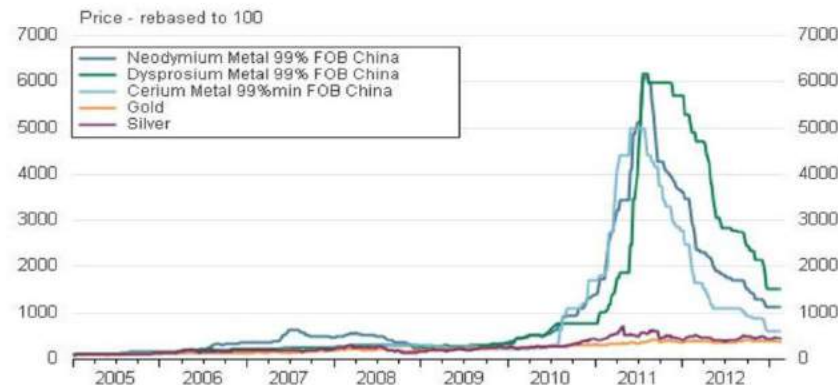
$\sum (\text{market share})^2$ of 50 largest firms

Above 2500 means highly concentrated



EU Critical Materials for Energy

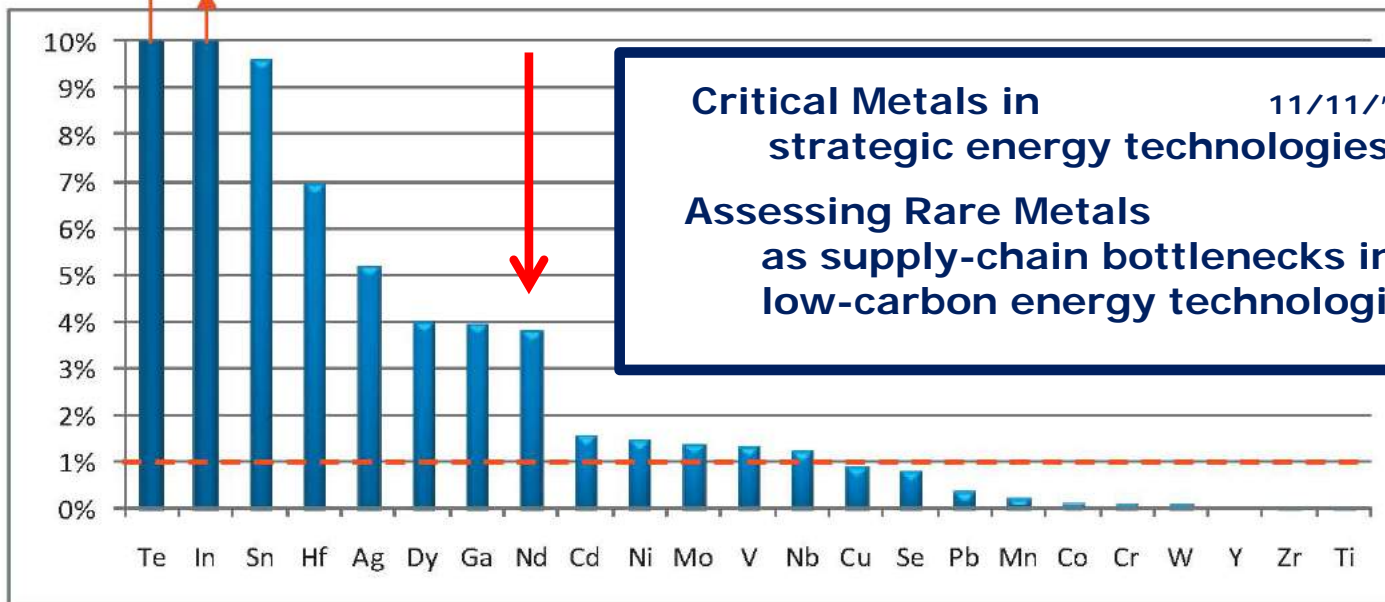
Rare earth prices vs. gold and silver



Te: 50%

In: 19%

EU Metal Need in 2030 as % of 2010 World Supply



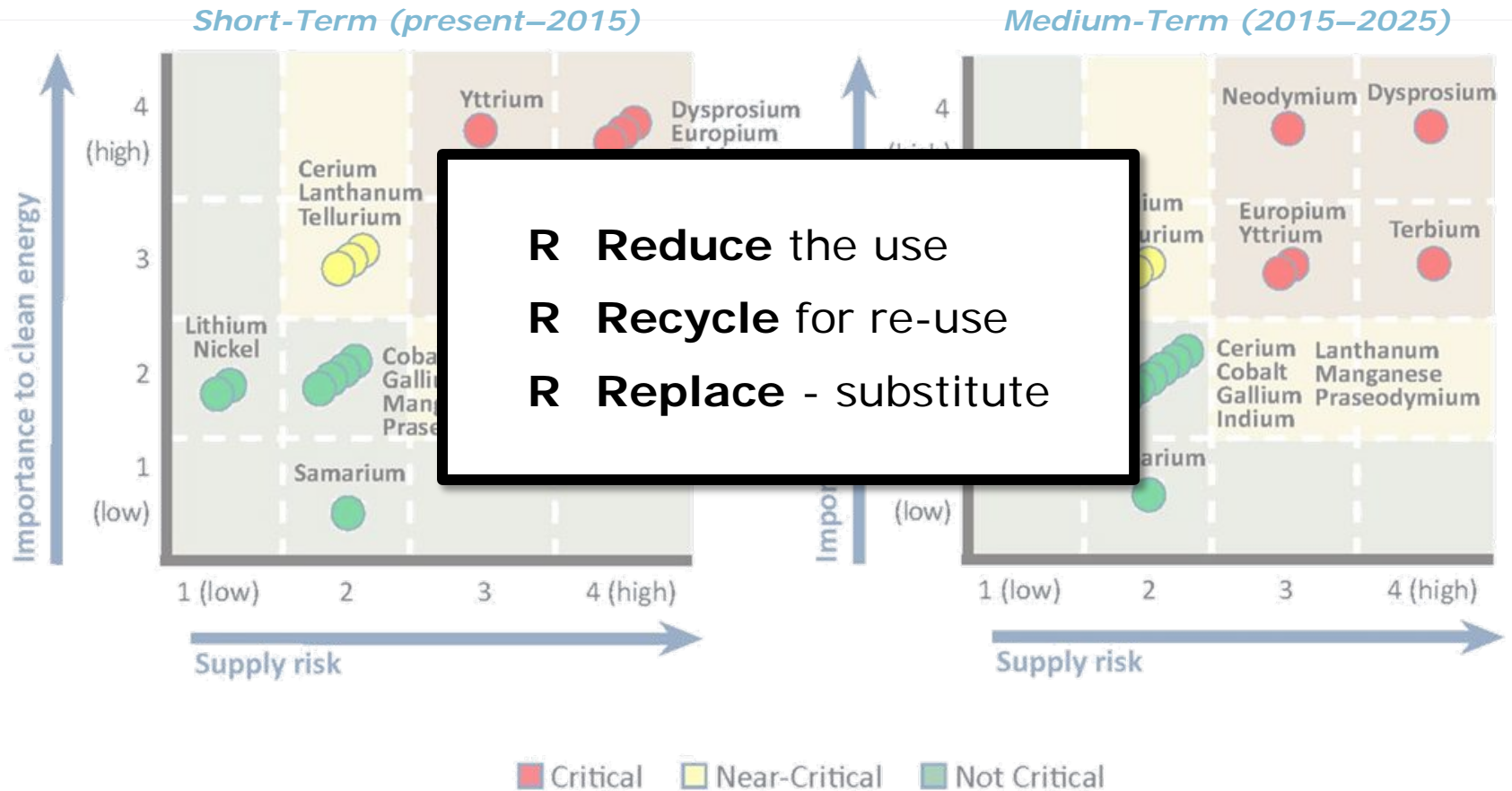
**14
critical
metals**

**Critical Metals in
strategic energy technologies**

11/11/'11

**Assessing Rare Metals
as supply-chain bottlenecks in
low-carbon energy technologies**

US DOE 2011 Critical Materials List (16)



All Energy Related – PV coatings, magnets, batteries, phosphors