7. Natural graphite

Natural graphite is a form of carbon where atoms are arranged in layers that have weak bonds between each other. The particular layered structure of graphite makes it one of the most stable and unreactive materials. Graphite also retains its strength and physical properties at temperatures in excess of 2200 ºC. The weak bond between layers causes graphite to be soft and slippery, resulting in a high natural lubricity. This layered structure can be modified by techniques such as intercalation where atoms of another element are incorporated between the layers to achieve certain properties such as superconductivity, or impregnation, where graphite is infused with other materials to achieve similar results as intercalation.[1]

Natural graphite is mined in three qualities: vein, flake and microcrystalline (often referred to as amorphous graphite), with different uses.[2] Mines can be either open pit or underground.[3] Current supply of natural graphite is dominated by Chinese producers. Synthetic graphite is concentrated in countries/regions such as USA, Europe and Japan. Because of higher production cost and process knowledge, the graphite market is still dominated by natural graphite.

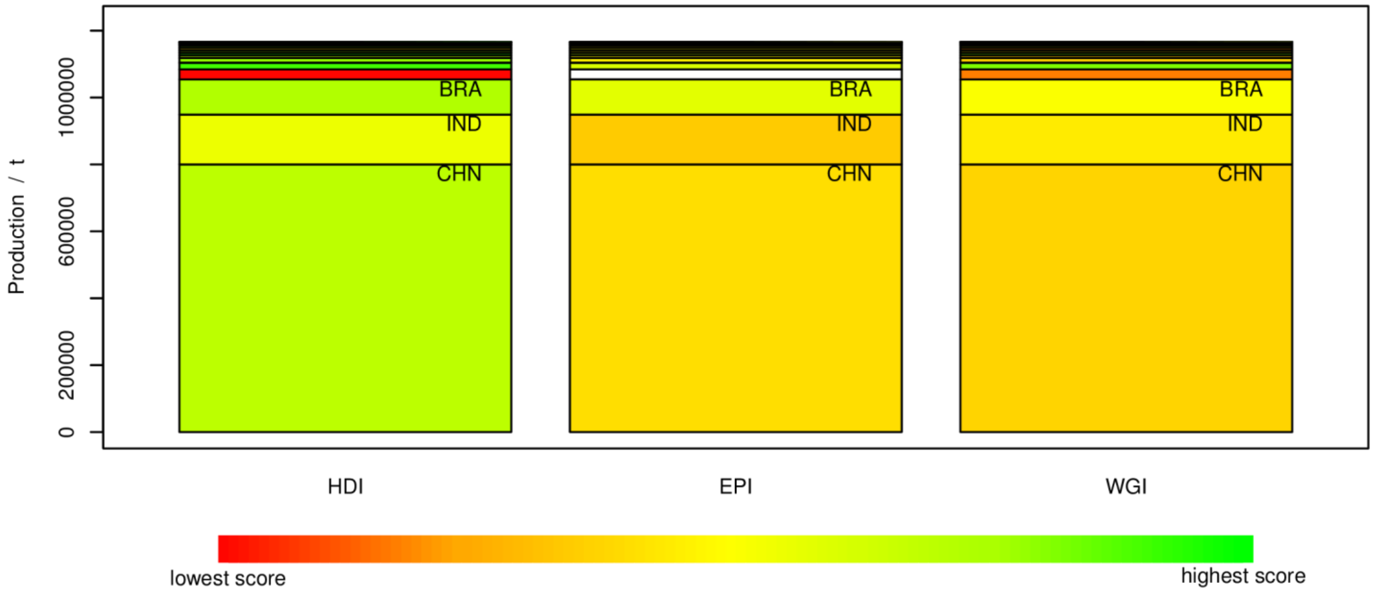

Figure 1: Distribution of natural graphite production[4] and corresponding scores of the producing countries in the Human Development Index (HDI)[5], Environmental Performance Index (EPI)[6], and World Governance Indicators (WGI)[7]. Both the EPI and WGI are used to assess supply risks with the EU methodology for determining critical raw materials.[8] CHN = China; IND = India; BRA = Brazil.

After a short decreasing period down to a price of natural graphite of 0.69 US$/kg in 2009, the price of natural graphite increased up to a value of 1.18 US$/kg in 2011.[9] These prices do represent the monetary values of the quality flake. Amorphous was five times cheaper (on average) than flake natural graphite during 2008 to 2011.

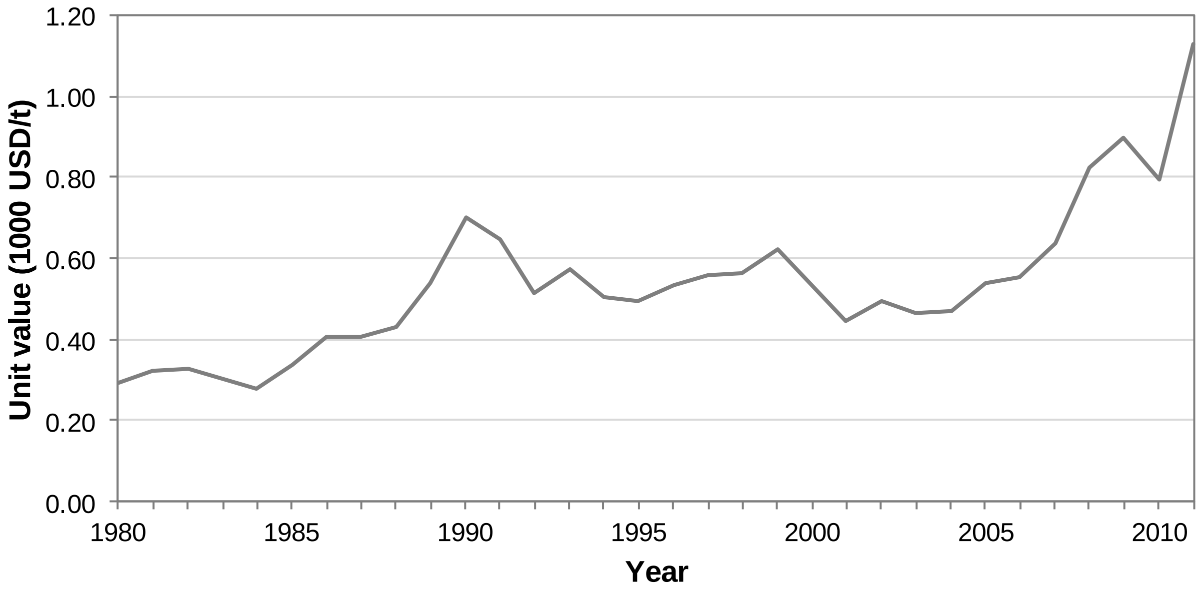

Figure 2: Natural graphite price development during 1980 – 2011. The unit value is defined as the value of 1 ton (t) of natural graphite in current dollars (estimated).[10]

Uses and Substitutability

Steel Industry

The steel industry represents a 24% share of natural graphite consumption. In this industry, graphite (both natural and synthetic) is used for its high temperature stability, thermal shock resistance, chemical inertness and ability to withstand corrosion. Natural graphite is used as a refractory liner for furnaces, ladles and crucibles in the continuous casting of steel and as an agent to increase the carbon content of steel.[11] Natural graphite can be substituted in the steel industry (increasing the carbon content of steel) by use of manufactured graphite powder, scrap from discarded machine shapes, and calcined petroleum coke.[3,9].

Foundries

Foundries (factories that produce metal castings) account for a further 24% of the share of natural graphite use. Graphite is used in blocks that form the lining of the blast furnace due to its high temperature stability (refractory). Graphite is ideal because it is highly unreactive and resistant to acids, alkalis and other chemical substances.[11] In principle, natural graphite can be substituted for manufactured graphite powder and calcined petroleum coke.[3,9]

Crucible production

Graphite is the main component in the manufacture of crucibles, and 15% of natural graphite is consumed in this industry alone. Natural graphite is the preferred material due to its corrosion resistance, thermal shock resistance and oxidation resistance capacity. Graphite can be substituted by silicon carbide[1], however, it does have better properties than alternatives.

Electrical applications

A share of 12% of the consumption of natural graphite is attributed to electrical applications. Most important are the manufacture of carbon brushes in electric motors, where graphite is preferred due to its high stability.[1] In many cases natural graphite can be substituted by synthetic graphite.[3]

Refractories

The refractory industry consumes 8% of natural graphite. Due to graphite's high temperature stability, thermal shock resistance and chemical inertness, graphite is ideal for use as a component in bricks that line furnaces such as oxygen furnace, electric arc furnace and blast furnaces.[1] Silicon carbide can be used as a substitute for graphite in refractory applications.[12] Moreover, zirconia and SiAlON are potential alternatives. Synthetic graphite does not compete with natural graphite in refractories.[13]

Lubricants

Graphite possesses exceptional lubricating properties, which make it highly suitable for use in lubricants. This application accounts for 5% of total natural graphite use, in the form of graphite powder. Its applications include the use in heavy machinery to reduce friction between parts where high temperatures prevail, such as in sliding bearings, piston rings, guide bearings and steam joint rings, sliding and sealing rings for mechanical seals, vacuum pumps, compressor and pumps.[1]. Natural graphite can be substituted by synthetic graphite or by molybdenum disulfide (but the latter is prone to oxidation).[3,12]

Pencils

Pencils, although traditionally known as "lead" pencils, contain nontoxic microcrystalline ("amorphous") natural graphite mixed with clay. Graphite is suitable for this application because the weakly held layers of carbon atoms slide easily over each other and allow for a black streak to be left on paper.[14] Substitutes for pencils include the use of pens and ink as well as coloured pigments or charcoal.

Batteries

Batteries account for 4% of natural graphite consumption. Here graphite (both natural and synthetic) is used for anodes due to its electrical conductivity.[1,3] An alternative to graphite anodes for lithium-ion batteries has been developed (with improved properties); the production technology is currently at the pilot stage.[15]

Summary

In principle, it is possible to substitute natural graphite by either its synthetic alternative (e.g. in batteries or for increasing the carbon content of steel), by replacing the product as in the case of pencils, by other compounds as in high temperature applications (e.g. refractories). In the latter case, it is difficult to fully substitute graphite while retaining the same level of performance.

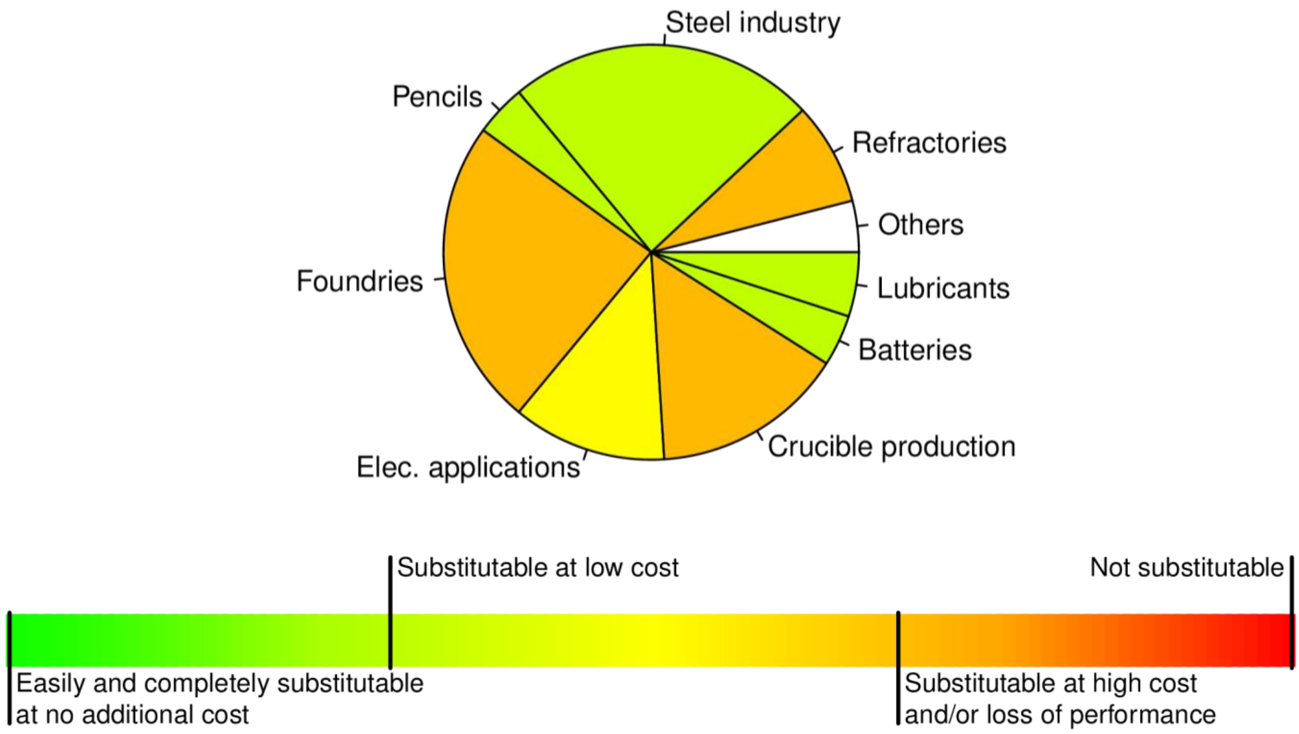

Figure 3: Distribution of end-uses and corresponding substitutability assessment for graphite. The manner and scaling of the assessment is compatible with the work of the Ad-hoc Working Group on Defining Critical Raw Materials (2010).

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Substitution of Critical Raw Materials

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