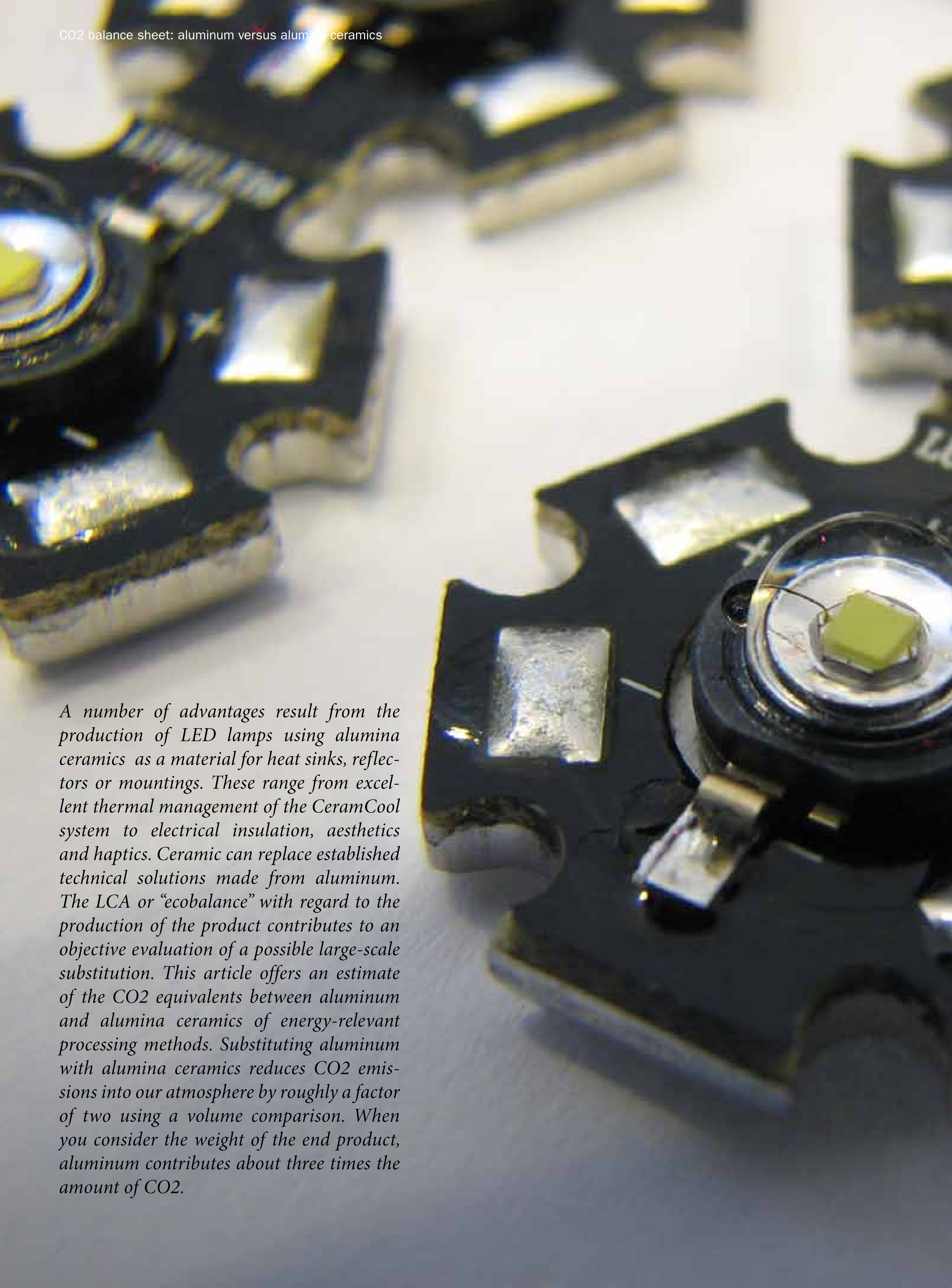
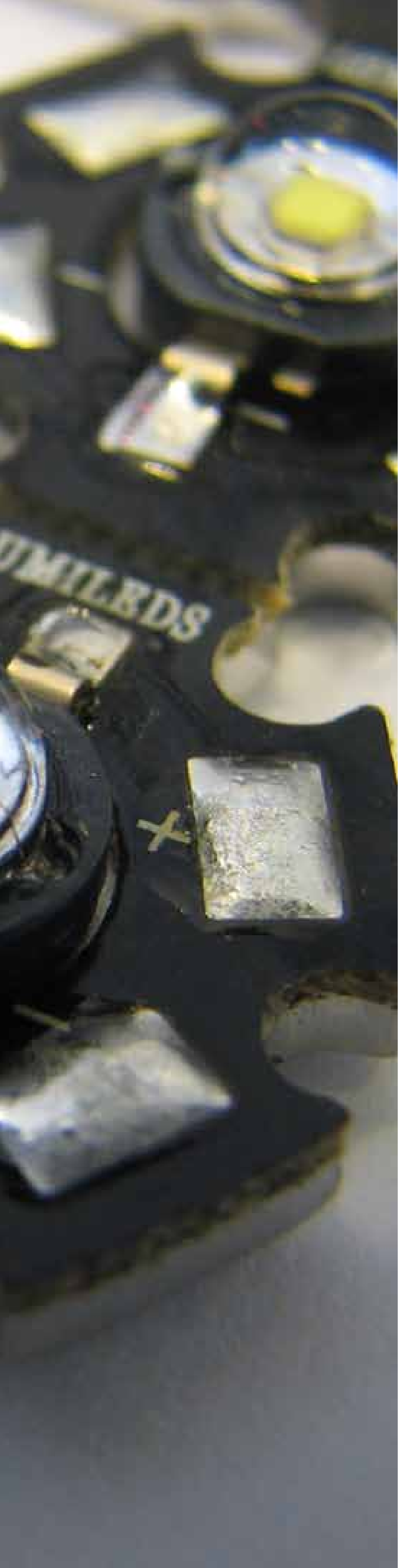


A number of advantages result from the production of LED lamps using alumina ceramics as a material for heat sinks, reflectors or mountings. These range from excellent thermal management of the CeramCool system to electrical insulation, aesthetics and haptics. Ceramic can replace established technical solutions made from aluminum. The LCA or "ecobalance" with regard to the production of the product contributes to an objective evaluation of a possible large-scale substitution. This article offers an estimate of the CO_2 equivalents between aluminum and alumina ceramics of energy-relevant processing methods. Substituting aluminum with alumina ceramics reduces CO_2 emissions into our atmosphere by roughly a factor of two using a volume comparison. When you consider the weight of the end product, aluminum contributes about three times the amount of CO_2.



CO_2 balance sheet: aluminum versus alumina ceramics

An excursion into manufacturing processes with a focus on CO_2 generation

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Bauxite is a rock mainly comprising minerals that are various hydrous aluminum oxides (e.g. boehmite, gibbsite, diaspore) and typical impurities mainly of iron, silicon and titanium. In particular, the typical dark reddish brown color is a consequence of a significant iron content. This raw material is strip-mined and serves as the basis for the production of aluminum metals and alumina ceramics. Using the Bayer process, a common method invented by Karl Josef Bayer in 1888, bauxite is mixed with a sodium hydroxide solution, finely ground and heated with steam. The aluminum hydroxide dissolves, the impurities precipitate and are separated from the solution with filters (red mud). As the solution cools down, the purified aluminum hydroxide finally precipitates.

The purification of the hydroxide requires around 0.5 kWh of electricity per kg of ceramic alumina powder, which develops through calcination. This is achieved by heating aluminum hydroxide to 1200˚C, which removes the water, converts the hydroxide into oxide and results in Al_2O_3. The calcination kilns are fired with natural gas, using roughly 0.5m³ per kg of Al_2O_3. The manufacturing process for metallic aluminum and alumina ceramics is identical up to this point. Using stoichiometry, 530 g of aluminum is obtained from 1000g of Al_2O_3. For the CO_2 balance sheet this means that the energy consumption from the Bayer process is about twice as high for 1 kg of aluminum than for 1 kg of alumina ceramics. This fact is considered in the tabular overview in the calculation by a factor of two.

The processes go different ways after calcination. By far, the most amount of energy is required for fused-salt electrolysis, during which metallic aluminum is obtained from the alumina powder. The melting temperature of Al_2O_3 is very high (apprx. 2200˚C). It is thus necessary to mix the alumina powder with cryolite (Na_3AlF_6), which reduces the melting temperature down to approximately 950˚C. At fused-salt electrolysis the aluminum metal is deposited at the cathode in the electrolytic cell. The anode consists of carbon blocks that decompose to CO_2 during the reaction. This process consumes 15 kWh of electrical energy and additionally directly releases 1.2 kg of CO_2 per kilogram of aluminum. Another important factor to consider in the ecobalance is the formation of harmful gases such as carbon monoxide and hydrogen fluoride. Aluminum takes shape when it is cast; the metal is melted at temperatures of around 700˚C, which consumes comparatively little energy.

After calcination the ceramic powder is ground, dried and, depending on the production process, combined with 2-12% organic binding agents. Die casting is the preferred method for forming powder

Figure 1. Bauxite raw material: The basis for the production of aluminum and ceramic. Source: Geological collection, University of Tübingen, thanks to Dr. Udo Neumann

bodies in mass applications with complex geometries. Dry pressing is suitable for the large-scale production of less complex components. Electricity consumption of 0.4 kWh/kg was assumed together with grinding and drying in evaluating the production process. Sintering requires the most amount of energy in the production of ceramic components, consuming 1 m^3/kg of natural gas. Moreover, approx. 0.4 kg of CO_2 is released for each kilogram of ceramic sintered as the organic binding agents are burned.

This concludes the process evaluation and energy estimates regarding the production of aluminum and alumina ceramic components. A tabular summary of all CO_2 relevant process steps provides a good overview here. Figures from the Bayrisches Landesamt für Umwelt, Infozentrum UmweltWirtschaft [Bavarian State Office for Environment, InfoCenter Environmental Economics] were used in calculating the CO_2 equivalents of various energy sources. According to these figures, the production of 1 kg of metallic aluminum creates roughly 13.5 kg of CO_2 as opposed to 4.8 kg for 1 kg ceramic alumina. When you consider the weight of the end product, aluminum contributes about three times the amount of CO_2.

The density of aluminum is 2.7 g / cm^3; Al_2O_3 has a density of 3.9 g/cm^3 (factor 1.44). Replaced by the same volume (Al_2O_3: 4.8 kg CO_2 × 1.44 = 6.9 kg CO_2), the CO_2 balance is still significantly better for alumina ceramics than for aluminum. Using a rough estimate, substituting aluminum with alumina ceramics for a component of the same size reduces CO_2 emissions into our atmosphere by approximately a factor of two.

Whenever considering CO_2 we should ask the question at which point a comparison no longer makes sense. Right here, with the heat sink as the end product? One step

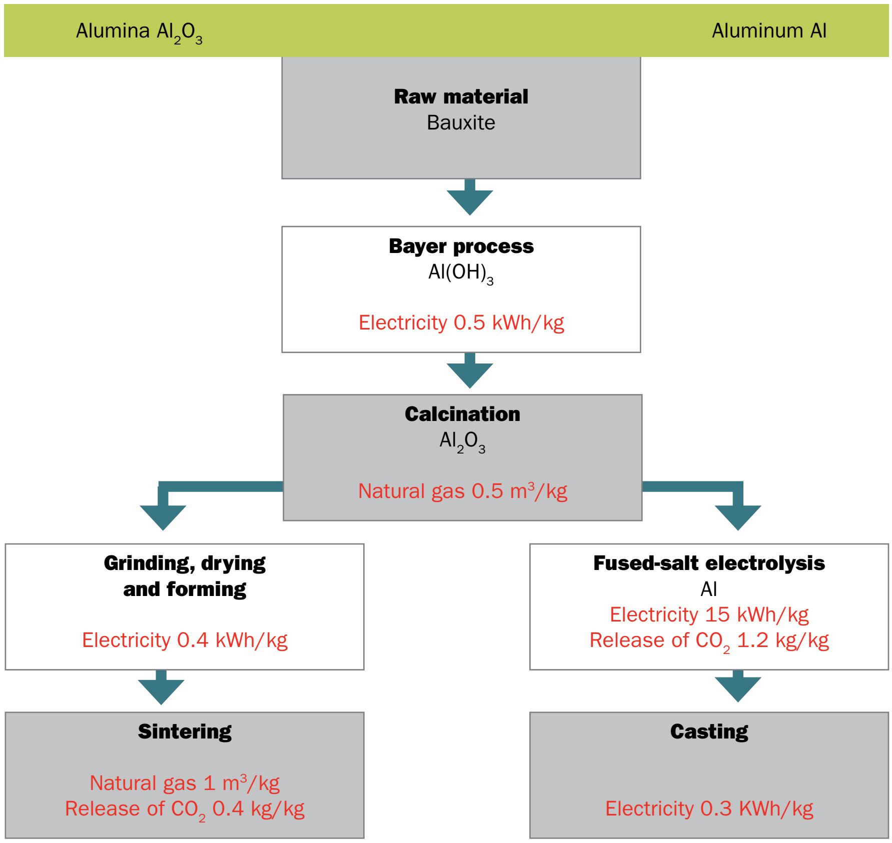

Figure 2. Overview of energy-relevant processing methods. Note: Several energy sources are used in this process. To increase clarity, all numerical values in this article have been simplified and rounded.

Formed ceramic parts undergo heat treatment below the melting temperature; alumina Al_2O_3 e.g. at 1300-1600˚C (air). Sintering uses the most energy of all process steps in the production of ceramic, yet the amount of CO_2 released is only half the amount released in aluminum production.

Energy source	Quantity	Unit	Total quantity CO_2 equivalents*
Electricity	1.00	kWh	0.62 kg
Heating oil	1.00	l	3.12 kg
Natural gas	1.00	m^3	2.46 kg
Liquid gas	1.00	l	1.90 kg
Diesel	1.00	l	3.13 kg
Gasoline	1.00	l	2.92 kg
Wood pellets	1.00	kg	0.07 kg
			*Including upstream process

Table 1. CO_2 equivalents of various energy sources. Source: Bayrisches Landesamt für Umwelt, Infozentrum UmweltWirtschaft, http://www.izu.bayern.de

Figure 3. Substituting an aluminum heat sink with a ceramic CeramCool heat sink with a comparable geometric form reduces CO2 emissions by 50%. Millions of these compo-nents are in use – an important contribution to the environment.

Materials	Density
Aluminum	2.7 g/cm^3
Aluminua ceramics	3.9 g/cm^3
Factor	1.44

Table 2. Comparison of specific weight.

further, after it has been populated with electronic components? Another step further, in its use, e.g. as a LED lamp which saves more energy with ceramic thanks to more efficient cooling for its service life of 15,000 or even 40,000 hours? There are too many imponderables to be able to provide a single simplification. What appears to be more interesting and calculable, however, is the final stage—disposal or recycling. Metallic aluminum in part can be partly reused through recycling; in contrast, a sintered ceramic component cannot be reused in the production of ceramics. Yet ceramic is absolutely chemically stable and entirely neutral for the environment. Disposal is not critical; worn-out ceramic components are used, among other things, as a filling material in road construction. With metallic aluminum, on the other hand, metal ions can be released into the groundwater under unfavorable conditions. Also considering the harmful products from fused-salt electrolysis, there are many convincing ecological arguments in favor of using modern advanced ceramics.

Process step	Energy Source	Consumption	Factor	CO_2 equivalent
Bayer process	(electricity)	0.5 Kwh/kg	2	0.6
Calcination	Natural gas	0.5 m^3/kg	2	2.5
Fused-salt electrolsys	Electricity	15 kWh/kg	1	9.0
Fused-salt electrolysis	Release of CO_2	1.2 kg/kg	1	1.2
Casting	Electricity	0.3 kWh/kg	1	0.2
Total				13.5

Table 3. Aluminum—calculation of CO_2 equivalents (for the significance of the factor see the notes on the Bayer process). When you consider the weight of the end product, aluminum contributes about three times the amount of CO2.

Process step	Energy Source	Consumption	Factor	CO_2 equivalent
Bayer process	(electricity)	0.5 Kwh/kg	1	0.3
Calcination	Natural gas	0.5 m^3/kg	1	1.3
Processing	Electricity	0.4 kWh/kg	1	0.3
Sintering	Natural gas	1 m^3/kg	1	2.5
Sintering	Release of CO_2	0.4 kg/kg	1	0.4
Total				4.8

Table 4. Alumina ceramics—calculation of CO_2 equivalents.

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