Sustainability: The Aluminium Way

By **P.K. Narasimharaghavan***

Sustainability is a property to which every material and organisation aspires and yet most people would find it difficult to give it a precise definition. Such a definition came from the Brundtland Commission of the United Nations in 1987. Sustainability is meeting the needs of the present without compromising the ability of future generations to meet their own needs. Put more succinctly: "The world is not ours to own but to act as guardians for generations to come." Putting this concept into practice, sustainability can be regarded as:

- **1)** Social progress, which recognises the needs of everyone
- **2)** Effective protection of the environment
- **3)** Prudent use of natural sources
- **4)** Maintenance of high and stable levels of economic growth and employment

In order to monitor the progress towards sustainability it is necessary to develop indicators for economic, environmental and social progress and at regular intervals, perhaps annually, to quantify these indicators. The indicators must be chosen in consultation with all of the stakeholders, employees, customers, shareholders, suppliers, legislators, neighbours etc. These indicators must be consistent year to year, be measurable, relevant to the material being studied and easily understood.

What is sustainability?

Sustainability is based on a simple principle: Everything that we need for our survival and well-being depends, either directly or indirectly, on our natural environment. Sustainability creates and maintains the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations.

Sustainability is important to make sure that we have and will continue to have, water, materials, and resources to protect human health and our environment.

Sustainability has emerged as a result of significant concerns about the unintended social, environmental, and economic consequences of rapid population growth, economic growth and consumption of our natural resources.

The four main types of sustainability are human, social, economic and environmental. These are defined and contrasted below. It is important to specify which type of sustainability one is dealing with as they are all so different and should not be fused together, although there is some overlap. Specialists in each field best deal with these four types of sustainability. For example, social scientists have a lot to say about social sustainability; economists deal with economic sustainability and biophysical specialists deal with environmental sustainability.

A definition of environmental sustainability (ES) has been given by Daly (1973, 1974, 1992, 1996, 1999) and Daly and Cobb (1989):

1. Output rule:
Waste emissions from a project or action being considered should be kept within the assimilative capacity of the local environment, without unacceptable degradation of its future waste absorptive capacity or other important services.

2. Input rule:

- Renewable resources: (e.g., forest, fish) harvest rates of renewable resource inputs must be kept within regenerative capacities of the natural system that generates them.
- Non-renewables: Depletion rates of non -renewable resource inputs should be set below the historical rate at which renewable substitutes were developed by human invention and investment according to the Serafian quasi-sustainability rule (see below). An easily calculable portion of the proceeds from liquidating non-renewables should be allocated to the attainment of sustainable substitutes.

Serafian Quasi-Sustainability Rule of Non-Renewables

The Serafian rule pertains to non-renewable resources, such as fossil fuels and other minerals, but also to renewablesto the extent they are being mined. It states that their owners may enjoy part of the proceeds from their liquidation as income, which they can devote to consumption. The remainder, a user cost, should be reinvested to produce income that would continue after the resource has been exhausted. This method essentially estimates income from sales of an exhaustible resource. It has been used as a normative rule for quasi-sustainability, whereby the user cost should be reinvested, not in any asset that would produce future income, but specifically to produce renewable substitutes for the asset being depleted. The user cost from depletable resources has to be invested specifically in replacements for what is being depleted in order to reach sustainability, and must not be invested in any other venture – no matter how profitable. For non-renewable energy, a future acceptable rate of extraction of the non-renewable resource can be based on the historic rate at which improved efficiency, substitution and re-use became available. These calculations show the folly of relying on technological optimism, rather than on some historic track record.

* The Author is presently working as Associate Vice President (Quality Assurance & technology) in Sesa Sterlite Ltd., Vedanta Aluminium & Power, Jharsuguda, Orissa State, India.

Causes of unsustainability

When the human economic subsystem was small, the regenerative and assimilative capacities of the environment appeared infinite. We are now painfully learning that environmental sources and sinks are finite. Originally, these capacities were very large, but the scale of the human economy has exceeded them. Source and sink capacities have now become limited. As economics deals only with scarcities, in the past source and sink capacities of the environment did not have to be taken into account.

Conventional economists still hope or claim that economic growth can be infinite or at least that we are not yet reaching limits to growth.

Human sustainability

- Human sustainability means maintaining human capital. Human capital is a private good of individuals, rather than between individuals or societies. The health, education, skills, knowledge, leadership and access to services constitute human capital. Investments in education, health, and nutrition of individuals have become accepted as part of economic development
- As human life-span is relatively short and finite (unlike institutions) human sustainability needs continual maintenance by investments throughout one's lifetime.
- Promoting maternal health and nutrition, safe birthing and infant and early childhood care fosters the start of human sustainability. Human sustainability needs 2–3 decades of investment in education and apprenticeship to realise some of the potential that each individual contains. Adult education and skills acquisition, preventive and curative health care may equal or exceed formal education costs
- Human capital is not being maintained. Overpopulation is intensifying and is the main dissipative structure worsening per capita indices. That is far graver than overcapitalising education so that labourers have PhDs.

Social sustainability

- Social sustainability means maintaining social capital. Social capital is investments and services that create the basic framework for society. It lowers the cost of working together and facilitates cooperation: trust lowers transaction costs. Only systematic community participation and strong civil society, including government can achieve this. Cohesion of community for mutual benefit, connectedness between groups of people, reciprocity, tolerance, compassion, patience, forbearance, fellowship, love, commonly accepted standards of honesty, discipline and ethics. Commonly shared rules, laws, and information (libraries, film, and diskettes) promote social sustainability.
- Shared values constitute the part of social capital least subject to rigorous measurement, but essential for social sustainability. Social capital is undercapitalised, hence the high levels of violence and mistrust.
- Social (sometimes called moral) capital requires maintenance and replenishment by shared values and equal rights, and by community, religious and cultural interactions. Without such care it depreciates as surely as does physical capital. The creation and maintenance of social capital, as needed for social sustainability, is not yet adequately recognised. Western-style capitalism can weaken social capital to the extent it promotes competition and individualism over cooperation and community.
- Violence is a massive social cost incurred in some societies because of inadequate investment in social capital. Violence and social breakdown can be the most severe constraint to sustainability.

Economic sustainability

- Economic capital should be maintained. The widely accepted definition of economic sustainability is maintenance of capital, or keeping capital intact. Thus Hicks's definition of income - the amount one can consume during a period and still be as well off at the end of the period - can define economic sustainability, as it devolves on consuming value-added (interest), rather than capital.
- Economic and manufactured capital is substitutable. There is much overcapitalisation of manufactured capital, such as too many fishing boats and sawmills chasing declining fish stocks and forests.
- Historically, economics has rarely been concerned with natural capital (NC) (e.g., intact forests, healthy air). To the traditional economic criteria of allocation and efficiency must now be added a third, that of scale Daly, 1992). The scale criterion would constrain throughput growth–the flow of material and energy (NC) from environmental sources to sinks.
- Economics values things in money terms, and has major problems valuing NC, intangible, intergenerational, and especially common access resources, such as air. Because people and irreversibles are at stake, economic policy needs to use anticipation and the precautionary principle routinely, and should err on the side of caution in the face of uncertainty and risk.

Environmental sustainability (ES)

- Although ES is needed by humans and originated because of social concerns, ES itself seeks to improve human welfare by protecting NC. As contrasted with economic capital, NC consists of water, land, air, minerals and ecosystem services, hence much is converted to manufactured or economic capital. Environment includes the sources of raw materials used for human needs, and ensuring that sink capacities recycling human wastes are not exceeded, in order to prevent harm to humans.
- Humanity must learn to live within the limitations of the biophysical environment. ES means NC must be maintained, both as a provider of inputs (sources), and as a sink for wastes. This means holding the scale of the human economic subsystem (D population _ consumption, at any given level of technology) to within the biophysical limits of the overall ecosystem on which it depends. ES needs sustainable consumption by a stable population.
- On the sink side, this translates into holding waste emissions within the assimilative capacity of the environment without impairing it.
- On the source side, harvest rates of renewables must be kept within regeneration rates.
- Technology can promote or demote ES. Non-renewables cannot be made sustainable, but quasi-ES can be approached for non-renewables by holding their depletion rates equal to the rate at which renewable substitutes are created. There are no substitutes for most environmental services, and there is much irreversibility if they are damaged.

Aluminium and sustainability

While copper, lead and tin have been used for thousands of years, aluminium is a comparatively young metal. Yet, even though its commercial use dates back only about 150 years, more aluminium is produced today than any other non-ferrous metal.

Aluminium is one of the most important and widely used metals in transport (cars, trucks, buses, trains and aircraft), construction (roofing, wall cladding, windows and doors), packaging (cans, aerosols, foil and cartons) and electrical sectors. In all sectors, it is valued for being light, strong, durable, flexible, impermeable, thermally and electrically conductive and non-corrosive.

Bauxite, the natural ore used to make aluminium, is one of the most abundant minerals in the earth's crust. Mined bauxite is refined into alumina, which is then smelted into aluminium. Approximately five tons of bauxite is required to refine two tons of alumina, which in turn are smelted to make one ton of aluminium metal.

In many of its applications, aluminium provides environmental benefits. Its lightweight helps improve the fuel economy of cars and planes and reduces emissions. And, when those vehicles are eventually scrapped, 95% of the aluminium can be recycled.

Because aluminium can be infinitely recyclable, 75% of all aluminium ever produced is still in use, with no loss in quality. Recycling aluminium uses only 5% of the energy – and produces only 5% of the greenhouse gas emissions – as primary production. Beverage cans are among the most recycled aluminium products in the world, and can be back on the shelf just six weeks after their first use.

Aluminium can, with justification, be described as the "green" metal. Over the past decade there has been a growing awareness of the toll that our industrialised society takes of the world's natural resources. Aluminium is a considerable ally in the fight against waste, energy consumption and environmental damage.

Aluminium industry can point to a consistent record of improvements with respect to its impact on society, and its products are utilised in every walk of life, with tangible advantages over competing materials, and ultimately simple and efficient recycling.

The new concept of life-cycle analysis of materials and products is fully accepted by the aluminium industry, which is only too happy to see standardised international methods applied to aluminium in its various applications on a 'cradle to cradle' basis, and for this unique material to stand up to public scrutiny of its sustainability credentials.

Aluminium in use

Automotive applications

The average car now contains over 90 - 130 kgs of aluminium, (about 7 - 10% of the weight), and this level is increasing. This aluminium may be in castings, forgings, or wrought form for the body & structure. The driving force behind this is "light Weighting" the substitution of steel by Aluminium to reduce vehicle weight and thus increase fuel efficiency. Although primary aluminium uses more energy to produce than steel, the fuel saving over the life of the vehicle is around six times the energy invested in producing that aluminium. For 100kg saved on the weight of a car, 0.35 litres of fuel per 100 km is saved. Further savings accrue when the aluminium in the vehicle is recycled into the next generation of cars.

Similar arguments apply to the increasing use of aluminium in commercial vehicles. A lighter vehicle structure permits more goods to be carried per load, resulting in less journeys.

From an environmental point of view, the Aluminium Industry estimates that, over its whole lifecycle, 1 kg of aluminium introduced in a truck saves more than 20 kg of CO_2.

Again this is a positive environmental impact from the energy invested in the aluminium production.

Packaging

Across the world, around 10 – 12% of all aluminium is used in packaging. This takes many forms, from the ubiquitous beverage can, to other food cans, aerosols, trays, tubes, foils and laminates. These are attractive to both packagers and consumers, and contribute to our economy by, not only weight reduction arguments as above, but by the barrier properties of aluminium, which extends shelf-life of products and thus reduces wastage. Additionally, this packaging is recyclable, indeed the beverage can is probably the most recycled consumer item, and can be recycled, remanufactured, refilled and back on the shop shelf within six weeks.

Building & Construction

This sector is also a major consumer of aluminium. It is extensively used in windows, curtain walls, roofing and cladding, solar shading, solar panels etc., as well as in some structural applications. Factors that make aluminium a preferred choice for so many applications are high strength-to-weight, forming methods which aid design flexibility, long, low-maintenance service life, attractive, durable finishes, and ultimately the certainty that at the end of the building's useful life the aluminium will be recycled to begin another useful life.

As with automotive use, aluminium incorporated into building design is likely to save much more energy throughout the life of the building than was consumed in its initial manufacture.

This is because aluminium building systems help in maximising solar gain during winter months, and also in minimising it during summer months. The net result is a significant increase in efficiency of fuel consumption for both heating and air conditioning.

Despite these benefits, there are still a number of sustainability issues specific to the aluminium industry that need to be addressed with particular attention.

These include:

- Mining
- Smelting and Power Sources
- Recycling
- Energy and greenhouse gases;
- Waste management;
- Biodiversity and land management;
- Resource efficiency and recycling; and
- Indigenous rights and local communities.

Mining

Aluminium oxide, or alumina as it is known, is the raw material from which aluminium metal is produced. Aluminium oxide is produced from bauxite, an ore mainly found in the tropical and sub-tropical regions of Latin America, South America, Africa and Australia, Brazil, India. The world's known deposits of bauxite are sufficient to support the current production rate of aluminium for another 300 years. Much more is available but beyond this time frame there is little incentive to search for more.

The aluminium industry worldwide takes great care in its mining operations to reinstate land after the bauxite has been dug out. Open cast methods are usually used to mine bauxite, and great care is taken to restore and re-vegetate mine sites following the mineral extraction. The residue of the process which separates aluminium oxide from the bauxite, known as 'red mud' is ultimately cleaned and back-filled to the mine as part of this process. Globally, the area rehabilitated each year now equals the area being mined.

Smelting and power sources

The manufacture of aluminium requires substantial amounts of electricity. The primary energy expenditure amounts typically to 14.2 kilowatt hour per kilogram of aluminium. Some of the Smelters in Scotland and Ireland are powered by hydroelectric power which is cheap and environment friendly. Work is continuously going on to improve the efficiency of the production process resulting in environmental improvements, lower emission levels and reduced energy consumption. The aluminium industry has invested heavily to increase energy efficiency in production and in improvements to the internal and external environments. Very significant reductions have been made in emission levels of fluorides, Sulphur dioxide and dust. The fluorides collected in the furnace gases during "dry scrubbing" are fully recovered. Spent 'pot-linings' are now recycled and no longer destined for land-fill. The favourable primary energy source when using hydro-electric power, added to the possibility of exporting the energy in the form of aluminium metal, has prompted many producers of primary aluminium to transfer their production to countries where high hydro-electric energy production contrasts with a low number of consumers, such as in Norway or Venezuela. Around 50% of the electricity used to produce primary aluminium worldwide comes from environmentally-friendly hydro-electric power and other renewable, non-polluting sources. A further 3.5% comes from nuclear power, again substantially free from CO_2 emissions.

Recycling

Aluminium is easily and economically recycled. There is an energy saving of 95% in the production of secondary aluminium compared with the production of the same weight of primary metal. Thus it can be seen that the energy invested in primary production is not lost, but remains to encourage repeated recycling of the metal into new products. In total, it is calculated that 75% of all aluminium produced since industrial output began in the late 19th century is still in use today.

The recycling rate for new scrap arising during fabrication is 100%. For some applications, such as lithographic sheet, the recycling rate for old scrap (that scrap recovered after use) is also 100%. In transport applications, the recycling rate exceeds 95%, remembering that vehicles will be in service for many years before they are recycled. In building applications, the recycling rate is 92-98% and the current recycling rate for aluminium packaging is 35 - 40% in the average.

If best technology is used, the quality of this recycled aluminium is equal to the primary metal. The annual production of primary metal in the world is approximately 51 million tons, with more than double that tonnage recycled.

Energy and greenhouse gases

Existing primary aluminium production processes are energy intensive by nature. The main source of energy consumption during production is the electricity used for the electrolysis process. Also, during the refining of alumina from bauxite ore, a significant amount of energy is required to produce the solution of bauxite in caustic soda, for the calcination process and for the recovery of caustic soda after use. As energy costs are a major part of overall production costs, improved energy efficiency is essential for the aluminium industry, both from an economic and environmental point of view. Improved energy efficiency will also reduce indirect emissions from production of the electricity used in the electrolysis process.

Primary aluminium production results in associated direct greenhouse gas emissions from the use of fossil fuels in the alumina calcination process, as well as indirect emissions from production of electricity used in the electrolysis process. Direct greenhouse gas emissions also arise from process-related conditions in the electrolysis, such as consumption of anodes (CO_2) and PFC emissions (Per Fluoro Carbon) from anode effects. Reduction of greenhouse gas emissions from energy use and from the electrolysis processes is thus important to reduce the overall carbon footprint of primary aluminium.

Waste management

Between two and four tons of bauxite are required to produce one ton of alumina. Once the alumina is extracted from the bauxite, the remaining bauxite residue is stored in landfills. Disposal of the bauxite residue is a challenging aspect of alumina production due to relatively large volumes, occupation of land areas, and the alkalinity of the residue and the run-off water. The way of storing of bauxite residue and handling of run-off water is critical.

Aluminium smelters also generate significant quantities of solid waste. One of the main sources of waste production during the smelting process is from the relining of pots, which takes place every five-to-eight years. The carbon portion of the spent pot lining (SPL) is considered a hazardous waste because of its fluoride, cyanide, PAH and reactive metal content. The refractory materials are not considered hazardous. It is thus important both to minimise the generation of SPL by extending life times of the pots, as well as to ensure proper handling of SPL waste through treatment and use by other industries, such as the cement industry.

Biodiversity and land management

The vast majority of the world's bauxite comes from surface mines in tropical areas, where bauxite occurs in horizontal layers, normally beneath a few metres of overburden. Because bauxite is located close to the surface and with relatively shallow thickness, bauxite mining involves disturbance of relatively large land areas, which can include natural and critical habitats. As a result, mining sites may overlap with, or be adjacent to, protected areas and/or areas of conservation value (particularly in tropical areas), and may result in significant deforestation. Effective mitigation of biodiversity impacts from bauxite mining will involve avoiding negative impacts (including avoidance of invasive species) to protected areas and areas with natural and critical habitats, as well as rehabilitation of mined areas.

For logistical reasons, most alumina refineries are located close to a bauxite mine, or at the nearest harbour from which the alumina can be shipped out. Thus, there may be similar biodiversity challenges at refinery sites, landfills for bauxite residue deposits or bauxite slurry pipelines.

Resource efficiency and recycling

Minimising losses of aluminium wherever they might occur in the value chain is a high priority for the aluminium industry. The concept of resource efficiency is a guiding principle, and actions to minimise losses can include optimisation of material use in the first place, tailoring the material use to specific applications, design for environment and recycling, or recycling of scrap.

In most cases, recycling of aluminium is economically and environmentally beneficial. Aluminium can be recycled an infinite number of times with no loss of quality. As a result, there is a very large and growing global aluminium material pool, and a well-developed global refining and recycling capacity, which itself creates a strong demand for scrap.

While minimisation of process scrap in the production and fabrication stages is the first step towards improving environmental performance (energy consumption and emissions per ton of product), the minimisation of post-industrial and post-consumer scrap and waste is also a priority. Collection and recycling of process as well as post-industrial and post-consumer scrap is also important to minimise waste and bring scrap back to useful products. This is relevant for all process steps, from primary aluminium production, through to production of end-user products and end-of-life management. Post-consumer aluminium scrap is generally recycled very successfully, with significant energy and emissions reductions compared to primary metal production. In addition, recycling of post-consumer products helps to significantly minimise resource use and reduce waste going to landfill.

Overall aluminium recycling rates are impressive and growing: The International Aluminium Institute (IAI) reports end-of-life recycling rates for aluminium used in building and transportation at 90%. In the world, consumer packaging recycling/recovery rates are at about 40 - 45%, with some packaging forms such as beverage cans as high as 70%, while other forms are below 50%. Robust data on material collection and recycling are not available in many countries, however.

In order to optimise and improve collection and recycling of post-consumer aluminium scrap, products need to be designed in a way that enables and supports efficient collection and recycling. This is especially challenging for complex products that utilise combined materials (such as composites used in buildings and transportation or multi-material laminated packaging), as these products need to be dismantled into separate material streams before re-melting.

The majority of aluminium is used in products with very long use phases, for example transportation products that have a typical lifetime of 20 years or buildings with lifetimes of approximately 50 years. The IAI reports that 75% of aluminium ever produced is still in circulation. Even with growing volumes of aluminium recycling and increasing end-of-life recycling rates, the strong overall global demand for aluminium means that the production of primary aluminium is required to support this growth.

Recycling of post-consumer scrap and waste requires a number of conditions, including the availability of systems to collect and sort used materials, and the adequate design of products that enable classification and recycling, among others. Collection infrastructure is not available everywhere in the world or for all types of products. Millions of people depend on collecting recyclable materials from streets, dumps, abandoned sites and even landfills. It will be a challenge to maintain the vital role they perform while supporting them with improvements to the health and safety conditions of their work.

Through the use of only 5% of the original energy input, this metal can be made available not just once but repeatedly from these material resources for future generations. The growing global markets for aluminium products are supplied by both primary (around 65%) and recycled (around 35%) metal sources. The increasing demand for aluminium and the long lifetime of many products, limiting their availability for short term recovery but maximising their in-use benefits, mean that the overall mass of primary metal consumed will continue to be around double that of recycled metal, for the foreseeable future.

Indigenous rights/local communities

Mining and mining-related activities (exploration, development, resource extraction, processing, transportation and waste disposal) often take place on, or near, indigenous lands. Mining or large-scale industrial development requires access to land and water that is often the basis of livelihoods for local communities.

Major industrial developments can have significant adverse impacts on indigenous groups and/or vulnerable groups and individuals, affecting their rights to self-determination, infringing on their lands, territories and resources, and threatening their ability to maintain their culture, including their cultural heritage and recognition of their distinct identities. The possibility of resettlement holds the potential for human rights infringements. It is important to ensure that indigenous groups be given sufficient opportunity and resources to be able to offer their free, prior and informed consent (FPIC) in decisions that may affect them, particularly in relation to projects that may impact their lands, territories and natural resources.

At the same time, mining and industrial activities can have positive benefits for local communities, creating both direct and indirect employment and wage-earning opportunities, and can also generate government revenue and net foreign exchange earnings.

Closure or major restructuring of a mine or large industrial facility can have major impacts on the livelihood of affected employees, suppliers and local communities.

In areas of political instability and conflicts, the manner in which security of assets and employees is maintained can also pose risks to the rights of local people.

Sustainability

In addition, recent technological advances and voluntary environmental efforts mean that aluminium made is more sustainable today than ever before. Energy required to produce new aluminium is down more than a quarter since 1995 and the industry's carbon footprint is down nearly 40%. As the aluminium industry relies more and more on recycled aluminium to meet demand, the metal is increasingly the sustainable material of choice. Strong, lightweight and infinitely recyclable, aluminium is a vital material that keeps the modern world moving.

The aluminium industry, through the work of the Aluminum Association, is an early pioneer in developing comprehensive, peer-reviewed research on the environmental impact of material production and use. The aluminium industry supports the life cycle assessment approach to research which tracks the impact of a product in all stages of its life from raw material extraction, to production and use, to disposal or recycling.

The threat to aluminium

Due to its versatility, finding a single alternative to aluminium is difficult. It turns out that more than 40 years after the film The Graduate, Mr. McGuire was right: The future is still in plastics. Many plastics have some of the characteristics of aluminium, but none have all of them. They also don't have the same level of embodied energy or messy manufacturing process intrinsic to aluminium.

Carbon fibre is a wonderful, albeit expensive alternative to many different aluminium applications. The transportation industry is starting to see the practical uses of carbon fibre. Half of every new Boeing 787 Dreamliner is made of composite plastic and carbon fibre materials, resulting in a 30% reduction in the use of aluminium compared to the Boeing 777. Carbon fibre also keeps more moisture in the cabin at high altitudes (good for long flights). ■

References

Daly, H E, ed (1973) Toward a Steady State Economy, Freeman, San Francisco, CA.

Daly, H E (1974) The Economics of the Steady State, Am. Econ.Rev. March, 15–21.

Daly, H E (1992) Allocation, Distribution and Scale: Towards an Economics which is Efficient, Just and sustainable, Ecol. Econ., 6(3), 185–193.

Daly, H E (1996) Beyond Growth: the Economics of Sustainable Development, Beacon Press, Boston, MA.

Daly, H E (1999) Ecological Economics and the Ecology of Economics, E Elgar Publications, Cheltenham.

Daly, H E and Cobb, J B (1989) For the Common Good, Beacon Press, Boston, MA.