Journal of Mines, Metals and Fuels, *72(6): 523-531; 2024. DOI: 10.18311/jmmf/2024/45481*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.com/index.php/jmmf*

Executive Brief

(This column is particularly dedicated to the people in the industry who look for the signs of change in their industry. This column will help the executives to decide the new routes to take to remain ahead of the competition)

Jayanta Bhattacharya
Hony. Chief Editor

Green Aluminum Production: The Sustained Strides and Regulation Helping the Leaders to take Bold Steps

The Recent News

A 29 June 2024 post by miragenews.com says Rio Tinto will install carbon free aluminum smelting cells at its Arvida smelter in Québec, Canada, using the first technology license issued by the ELYSIS joint venture. This investment will support the ongoing development of the breakthrough ELYSIS™ technology and allow Rio Tinto to build expertise in its installation and operation. Rio Tinto will design, engineer, and build a demonstration plant equipped with ten pots operating at 100 kiloamperes (kA). The plant will be owned by a new joint venture in which Rio Tinto and the Government of Québec, through Investment Québec, will invest $179 million (CAN$235 million) and $106 million (CAN$140 million) respectively as equity partners, for a total investment of US$285 million (CAN$375 million)[1].

Described as the greatest breakthrough in the aluminum industry since the late 1800s, this Alcoa-invented technology has the potential to completely revolutionize the global aluminum industry. Aluminum has always been the leading choice for sustainable product development due to its light-weight, strength and infinite recyclability. ELYSIS™ technology takes the miracle metal's sustainable advantage to a new level. The ELYSIS process emits pure oxygen as a byproduct and eliminates all of the greenhouse gas emissions associated with traditional smelting. This innovation involves replacing the carbon anodes used in traditional aluminum smelting with inert, proprietary materials. Alcoa invented the zero-carbon emissions technology that served as the basis for the creation of the ELYSIS technology enterprise with Rio Tinto, first announced in 2018. ELYSIS intends to license for sale its technology for either retrofits of existing smelters or the construction of new ones. Established in 2018, ELYSIS is a technology partnership between Alcoa and Rio Tinto to

advance technology first developed at the Alcoa Technical Center (ATC) outside of Pittsburgh (https://www.morningstar.com/news/business-wire/20240627543998/alcoa-announces-agreement-on-industrial-scale-demonstration-of-elysis-carbon-free-smelting-technology)[3].

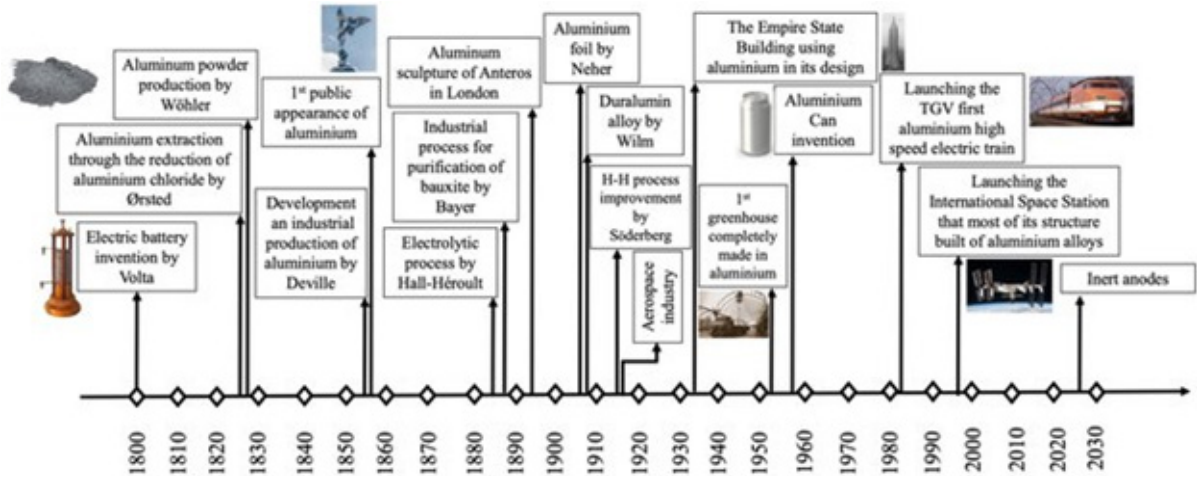

Figure 1. The timeline of aluminium discovery, technological development and applications during the last 200 years. (https://www.researchgate.net/publication/358848920_Aluminium_production_process_from_Hall-Heroult_to_modern_smelters/figures?lo=1)

Figure 2. The technology schematic (https://batteryindustry.tech/elysis-selects-alma-smelter-for-commercial-size-450-ka-inert-anode-prototype-cells/)[4].

Little that We Know of the Technology

Investment by the Government of Quebec

The 450 kA cells at Alma were supported by a $20 million CAD investment from the Government of Quebec to help bring forward the start of work at the site and to further strengthen the capability of manufacturing businesses in the region to supply specialized equipment required for the ELYSIS technology.

The Technology at a Glance

The ELYSIS technology addresses the global trend towards producing low carbon footprint products, from mobile phones to cars, planes and building materials. The new process will reduce operating costs of aluminium smelters while increasing production capacity. It could be used in both new and existing aluminium smelters. In Canada alone, the ELYSIS technology has the potential to reduce GHG emissions by 7 million tons, the equivalent of removing 1.8 million cars from the roads. it consumes approximately 13 000 kW h electricity and 0.4 t of high-quality carbon material for one tonne of primary aluminium via conventional electrolysis process. Considering the 6732 Mt of world primary aluminium production in 2020, if the technology of inert anodes replaces the conventional route, it would reduce 117.5 Mt of carbon dioxide emissions, saving 26.1 Mt of high-quality carbon resources and, meanwhile, generating 58.5 Mt of oxygen per year. Furthermore, when clean energy such as wind or hydropower is used, aluminium electrolysis based on inert anodes would no longer cause significant energy consumption and greenhouse gas emissions, making it a complete carbon-free aluminium electrolysis technology. Thus, inert anode aluminium electrolysis is a disruptive technology that would revolutionise the conventional aluminium electrolysis industry, and plays an active role in achieving the goal of carbon neutrality.

ELYSIS will also sell next-generation anode and cathode materials, which will last more than 30 times longer than traditional components. ELYSIS continues to work closely with the Rio Tinto technology design team in France and Alcoa's Technical Center, where the zero-carbon smelting technology was invented. The Rio Tinto technology team in France is creating commercial scale designs for the ELYSIS technology. Alcoa's Technical Center supports ELYSIS in the manufacture of proprietary materials for the new anodes and cathodes that are essential to the ELYSIS process[2] (https://batteryindustry.tech/elysis-selects-alma-smelter-for-commercial-size-450-ka-inert-anode-prototype-cells/).

Inert Anode Technology

In the modern industry, the production of aluminum is based on the Hall–Héroult process, i.e., the cryolite-alumina molten salt electrolysis. The principle is to reduce the Al^{3+} ions dissolved in the Na3AlF6 cryolite molten salt to aluminium through electrolysis at 950 °C using a consumable carbon anode. Due to the huge consumption and huge emissions of CO_2, CO, and HF gases, the current aluminum electrolysis industry has a large adverse impact on the environment. The concept of inert anodes was proposed in order to reduce the greenhouse gas emissions of the aluminium electrolysis process. The structure and principles of aluminium electrolysis cells using different anodes are shown in (Figure 3, and the related electrolysis reactions can be expressed as follows[3].

The Chemistry

Al_2O_3 (sol) represents the dissolved Al_2O_3 in the cryolite molten salt, made of Al^{3+} and O^{2-} ions, and E is the decomposition voltage of electrolysis. When an inert anode is used, the electrolytic voltage of the inert anode is 1 V higher than that of a carbon anode, and with a shorter cathode–anode distance. Compared to the current pre-baked carbon anodes, the utilisation of inert anodes exhibits several advantages, in terms of no CO_2 emission, no anode consumption, cost-effectiveness and oxygen production capability. The basic chemistry[3-5] is:

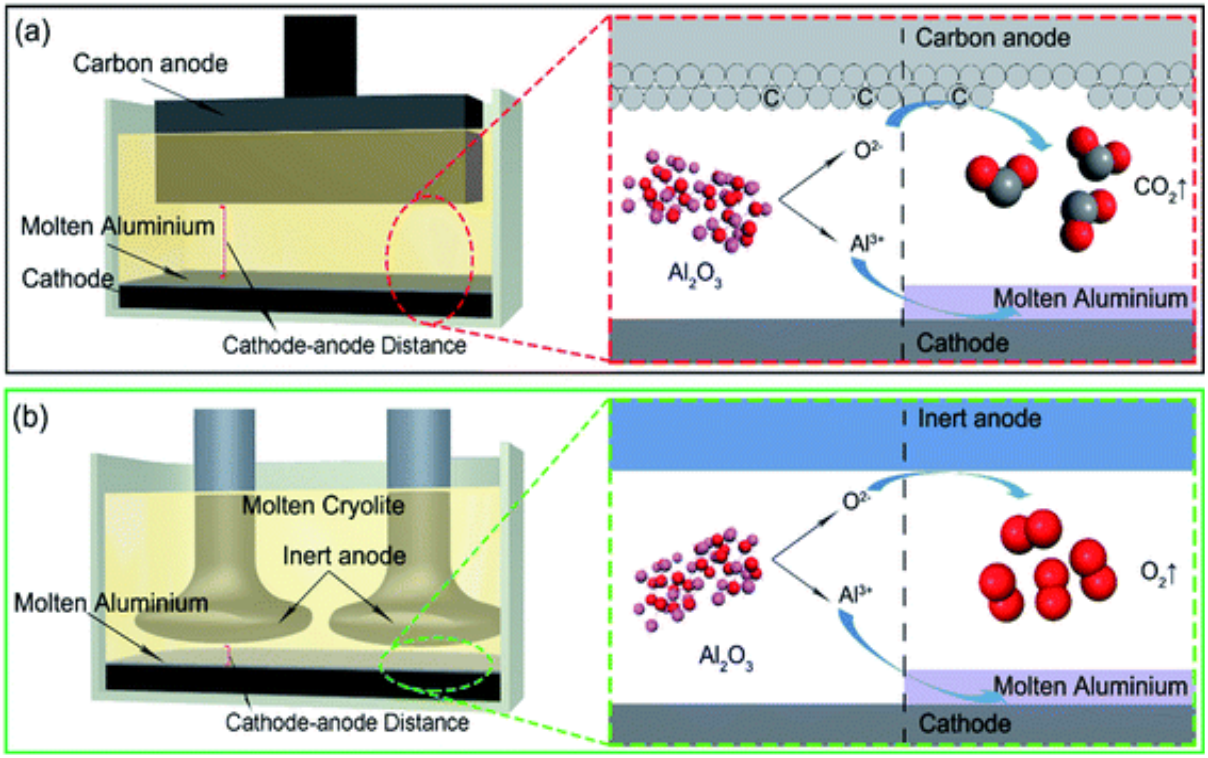

Figure 3. The structure and principles of aluminum electrolysis cells using different anodes.

Carbon Anode:

$$2Al_2O_3(sol) + 3C(s) \Rightarrow 4Al(l) + 3CO_2(g),\ E = 1.18\ V \quad (1)$$

Inert anode:

$$2Al_2O_3(sol) \Rightarrow 4Al(l) + 3O_2(g),\ E = 2.20\ V \quad (2)$$

Inert Anode Materials

More than a few dozen materials are currently under study, which could be classified into metallic anode materials, oxide ceramic anode materials and cermet anode materials as shown in Figure. Among these, the main advantage of metals is good electrical conductivity, while that of ceramics is their excellent corrosion resistance. For cermets, the advantages of both metals and ceramics are combined, showing a long service life in the electrolysis process. Herein, let us see the research progress of these three kinds of materials.

Advantages and Challenges of the Inert Anode Technology

There are three principal potential advantages in favor of developing cell technology with inert anodes[6]:

1. Cost reduction. All costs associated with the consumable carbon anode will then be eliminated, including the capital saving and raw materials costs by eliminating the need for the carbon anode fabrication, baking and rodding plant. These cost savings may be significant. In addition, it has been indicated that there might be 25-30 % lower capital costs for a new cell line with inert anode cell technology.
2. Environmental friendliness. A usual reason for wanting inert anode cells relates to saving fossil carbon consumption by producing oxygen instead of carbon dioxide. Inert anodes would eliminate all greenhouse gas generation

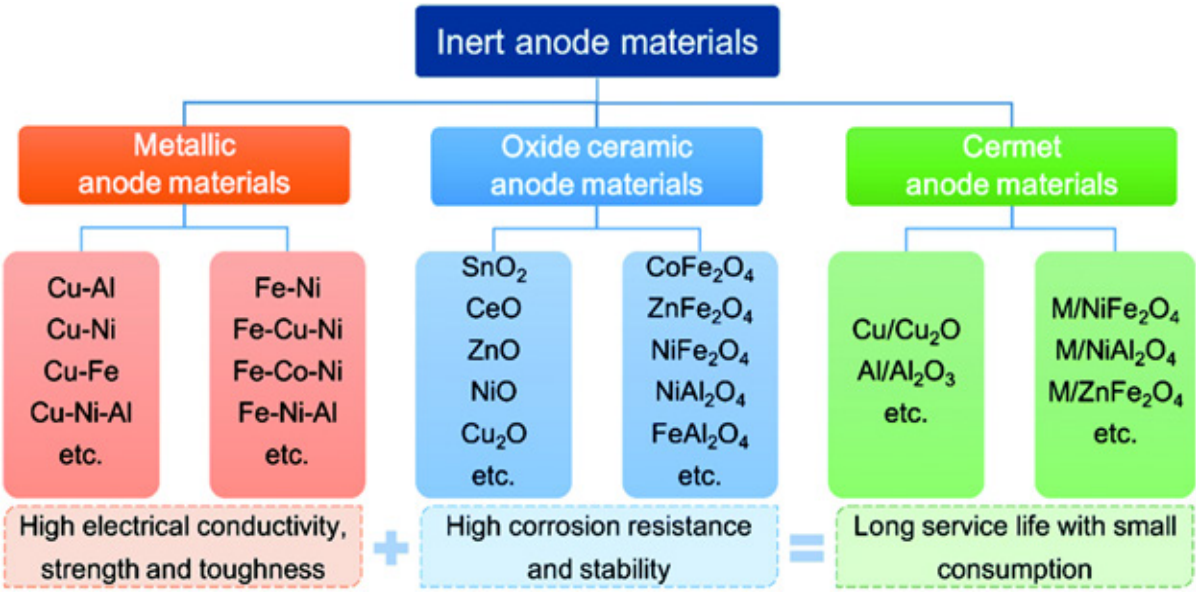

Figure 4. The classification of existing inert anodes including metallic, ceramic and cermet materials.

and emissions from the electrolysis cells. Smelters would no longer generate carbon dioxide, carbon monoxide, sulphurous gases and perfluorocarbon gases (CF4 and C2F6), because carbon would no longer be used as the anode material. Furthermore, there will be no PAH gas emissions from the cells. In addition, the fluoride and dust emissions during anode change will be nearly eliminated. Carbon residues (butts) will also be eliminated. It should also be noted that all emissions associated with the present carbon anode baking furnaces would be eliminated[7].

3. Improved occupational health issues. Inert anodes would reduce the heavy work practices associated with the present prebaked carbon anode change. This is presently the operational procedure on prebake cells that causes the most severe heat stress for the operators, as well as causing the largest thermal disturbance of the cells. The frequency of anode changes will be drastically reduced with inert anodes. Working conditions in the cell rooms would also be improved by avoiding all anode effects.

There are two main challenges in the development of inert anode materials:

1. The wear rate of the anodes. The anode material should have low solubility and reactivity in the electrolyte and also show good chemical resistance to the anodically produced oxygen. There will be extreme requirements for keeping the wear rates of these anodes low. It should be noted that short-term electrolysis tests of a few hours' duration may give a rather poor basis for reliable estimates of wear rates given in millimetres per year. In addition, the anode material should be physically stable at the operating temperature, mechanically robust and resistant to thermal shock. The latter may require that the anodes must be preheated before they are inserted into the electrolyte[8].
2. The impurity metal content in the aluminium. The need for making pure aluminium will become more stringent in coming years. The corrosion products formed by the dissolution of the anode oxide materials into the electrolyte report predominantly to the aluminium contaminating the metal produced. Hence, the anode corrosion should be low enough to give impurity contents meeting specifications for smelter grade aluminium.

The Collaboration

The technology partnership between Alcoa and Rio Tinto was to advance technology first developed at the Alcoa Technical Center (ATC) outside of Pittsburgh. Rio Tinto's demonstration project will occur at Arvida in Quebec, Canada,

and includes 10 ELYSIS smelting pots operating at 100 kiloamperes (kA), a size similar to those operating at smaller-scale commercial smelters.

Alcoa has the right to purchase up to 40 percent of the metal produced from the demonstration at Arvida, allowing for Alcoa customers to benefit from ELYSIS's carbon-free electrolytic process early in the technology development cycle. The target for first production is by 2027. This is also for Alcoa to derive benefits of carbon tax stipulations[9].

"Since inventing the aluminum smelting process in 1886, which is still in use today, Alcoa has continued to create transformational technologies to improve our industry," said William F. (Bill) Oplinger, President and Chief Executive Officer of Alcoa Corporation. "We are proud to progress the technology initially developed at our technical center to its next phase within the ELYSIS partnership. Aluminum plays a critical role in the world's energy transition and decarbonization efforts; with the ELYSIS technology, the smelting of this important metal can also be done without direct carbon emissions".

To support the industrial demonstration, Alcoa will manufacture the proprietary ELYSIS anodes and cathodes at ATC, which will include installing and operating new equipment. Alcoa anticipates benefitting from the learnings of this phase of the demonstration and expects to apply them to future phases in ELYSIS's development. Metal produced through the ELYSIS process will further improve upon Alcoa's lower carbon products already on the market, such as the Sustana™ product line.

Rio Tinto will design, engineer, and build a demonstration plant equipped with ten pots operating at 100 kiloamperes (kA). This facility will use the same technology that has been successfully demonstrated at the ELYSIS Industrial Research and Development Center in Saguenay—Lac-St-Jean. This pilot operation will be a critical step in Rio Tinto's learning journey towards full scale industrialization of the ELYSIS™ technology.

The plant will have the capacity to produce up to 2,500 tonnes of commercial quality aluminium per year without direct greenhouse gas emissions, with first production targeted by 2027. It will be located adjacent to the existing Arvida smelter, allowing the use of the current alumina supply and casting facilities[7-9].

Rio Tinto Aluminium Chief Executive Jérôme Pécresse said**:** "This investment will further strengthen Rio Tinto's industry-leading position in low-carbon, responsible aluminium in North America with our

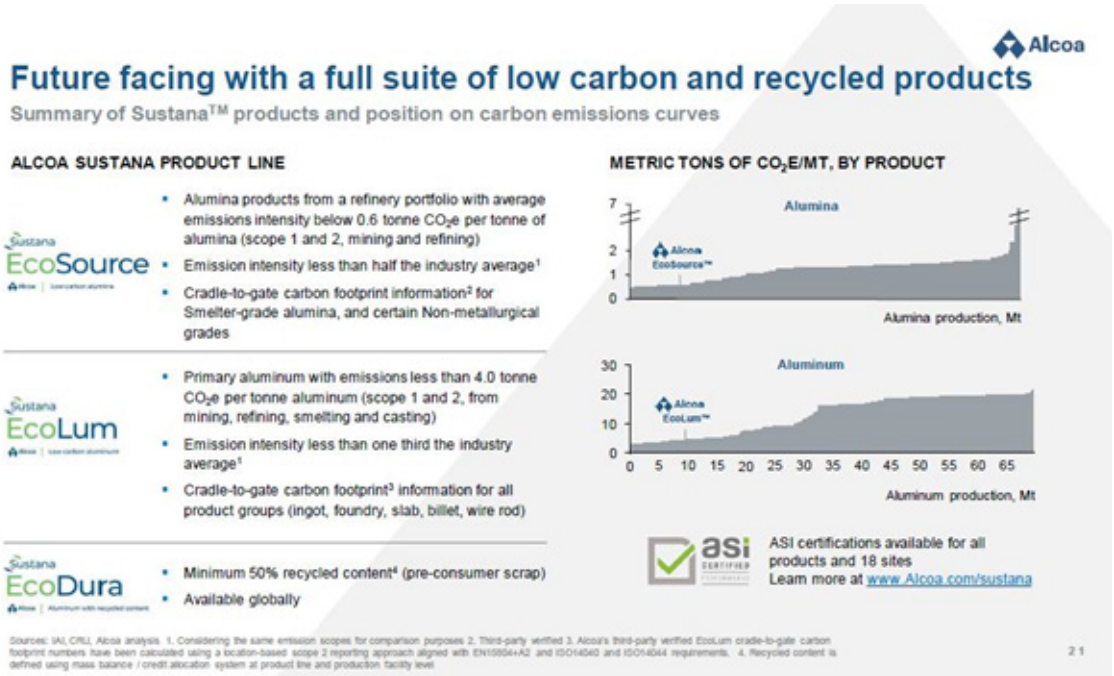

Figure 5. Sustana product lines.

hydro-powered smelters and our recycling capacity. Becoming the first to deploy the ELYSISTM carbon-free smelting technology is the next step in our strategy to decarbonize and grow our Canadian aluminium operations. In addition to delivering even lower-carbon primary aluminium for our customers, this investment will allow Rio Tinto to build its expertise on installing and operating this new technology, while the ELYSIS joint venture continues its research and development work to scale it up to its full potential." Québec Minister of Economy, Innovation and Energy; Minister for Regional Economic Development; and Minister for the Metropolis and the Montreal Region, Pierre Fitzgibbon, said: "ELYSIS™ is a truly disruptive technology for the industry, and it's thanks to Quebec expertise that we are the first in the world to produce GHG-free aluminium. This is a technological innovation with unprecedented benefits for our aluminium sector, which remains an undisputed world leader".

The Growing Market

From the green aluminum research reports, one can confirm that the low-carbon or green aluminum market is indeed taking off. According to Bloomberg analysts, the growing demand for green aluminum and the recent investment in green technology is driving the possible creation of an entirely separate premium trading market for green aluminum alone. The pressure on aluminum manufacturers to meet climate protection goals and move toward net-zero carbon (or carbon neutral) is so significant that it is causing commodity trading markets to respond. Producers of green aluminum and sustainable metals know that an increase in demand drives a premium price. "….that's why many producers have begun rebranding their low-carbon products to demonstrate the value their green aluminum offers. Rio Tinto has launched its RenewAl product, while Alcoa has released an entire product line called Sustana, which features its Ecolum low-carbon product"**.**

Launching Green aluminum brands is gaining momentum, as it increases brand awareness and leadership perception and seems needed to get a potential Green Upcharge. Additional Green/Low-Carbon Aluminum brands out in the market include: Reduxa by Norsk Hydro, Allow by Rusal, CelestiAl by EGA, NaturAl by Century, and Restora by Vedanta. Super Green Aluminum brands (metal with high recycled content; mainly post-consumer) include Norsk Hydro's Circal, among others.While neither manufacturer will state exactly how much of a premium its environmentally friendly aluminum is commanding, executives from both companies say that their low-carbon products are subject to supply and demand like any other good. Green aluminum is necessary, and buyers will undoubtedly pay extra for its increased value. In fact, wire rod currently commands the highest premiums due to its use in power wiring linked to the green energy transition around the world[10].

The Demand sides

The demand for green primary aluminum is only in its infancy. Manufacturers are continuing to set environmental responsibility goals targeting their supply chain. In industries that rely heavily on aluminum supply, aluminum products branded as green or low-carbon will become more and more appealing[10]. But for that to actually happen, the uncertainty and price of conventional fuels have to increase. While the world looks for market uncertainties like supply and price, it is still not sure when and how it will really happen. In the meanwhile, the conventional suppliers are taking advantage of sunk cost, low asset value, market leverage and the low middle class and poor demanding cheap aluminum. High uncertainties will however, favor green aluminum.

Industries like consumer electronics, auto manufacturing, roof window manufacturing, and consumer packaged goods are looking for ways to keep their products low-carbon so they can meet government regulations as well as the standards set by their consumers and investors. Global industries like these that rely on aluminum are putting pressure on the producers to shift towards a more sustainable production process.

The automotive industry began its "Drive Sustainability" campaign that would see major automotive makers join to commit to more green production processes. The sourcing of green aluminum has been a key strategy in meeting these objectives. Recently, Hydro partnered with Mercedes-Benz to supply low-carbon aluminium to reduce the carbon footprint of their vehicle fleet; Rio Tinto and Ford Motor Company signed a MoU to jointly develop more sustainable and secure supply chains for battery and low-carbon materials to be used in Ford vehicles; Alcoa had previously supplied sustainable aluminum to RONAL GROUP for the wheels on Audi vehicles.

Apple is in a similar position. Looking to reduce the carbon footprint of its supply chain, the company recently laid out a $10 million investment in a partnership between Alcoa and Rio Tinto to establish an aluminum production facility in Quebec, Canada. Called Elysis, the production facility is set to use a low-carbon technology to produce the aluminum alloy Apple needs for its iPhones. The green technology used at the joint production facility is expected to cut carbon emissions drastically.

Specially-marked low carbon beverage can have been launched in Canada using aluminium from Rio Tinto and leveraging ELYSIS technology. In Japan, 100% recycled aluminum cans have been produced by UACJ with collaboration of Toyo Seikan; these cans are reported to have a carbon footprint 60% lower than traditional 350 ml cans. On the building and construction side, VELUX , a roof window manufacturer, has partnered with Norsk Hydro to manufacture green aluminum products and halve its carbon emissions by 2030[10].

Other Developments

In an another development, still not sufficiently reported, Norsk Hydro ASA, Norway has made the world's first batch of aluminum using green hydrogen in a step toward decarbonizing the production of the metal[9]. The Norwegian producer replaced natural gas with green hydrogen during a test at its extrusion plant in Navarra, Spain, it said in a statement on Thursday. Hydro's renewable hydrogen company, Hydro Havrand, conducted the trial in partnership with Fives North America Combustion, an engineering firm with expertise in hydrogen burner technology. For more than a century, Hydro has been searching for new uses for the vast amounts of hydroelectric power that Norway generates each year. The company first found success making artificial fertilizers via a pioneering electrochemical process, and later focused its attention on aluminum, which is one of the world's most energy-intensive industrial commodities to make. Now, it's betting that hydrogen could prove even more lucrative. "Green hydrogen can remove hard to abate emissions from fossil fuels in processes where electricity is not an alternative, both in the aluminum industry and in other heavy industries," Per Christian Eriksen, head of Hydro Havrand, said. "This test is part of developing commercial fuel switch solutions and to demonstrate that hydrogen can be used in aluminum production".

References

1. Rio Tinto to deploy ELYSIS tech for carbon-free aluminium smelting. Available from: https://www.miragenews.com/rio-tinto-to-deploy-elysis-tech-for-carbon-free-1265976/
2. The world's first carbon-free smelting technology. Available from: https://www.alcoa.com/products/elysis#:~:text=The%20world's%20first%20carbon%2Dfree%20smelting%20technology&text=The%20ELYSIS%20process%20emits%20pure,smelting%20with%20inert%2C%20proprietary%20materials.
3. Alcoa announces agreement on industrial-scale demonstration of ELYSIS™ carbon-free smelting technology. Available from: https://www.morningstar.com/news/business-wire/20240627543998/alcoa-announces-agreement-on-industrial-scale-demonstration-of-elysis-carbon-free-smelting-technology
4. ELYSIS selects alma smelter for commercial size 450 kA inert anode prototype cells. Available from: https://batteryindustry.tech/elysis-selects-alma-smelter-for-commercial-size-450-ka-inert-anode-prototype-cells/
5. Recent progress of inert anodes for carbon-free aluminium electrolysis: A review and outlook. Available from: https://pubs.rsc.org/en/content/articlelanding/2021/ta/d1ta07198j

6. Inert anode. Available from: https://www.sciencedirect.com/topics/engineering/inert-anode
7. carbon aluminum solutions. Available from: https://www.alcoa.com/products/sustana
8. United States, Securities and Exchange Commission, Washington, D.C. 20549, SCHEDULE 14A, (Rule 14a-101). Information Required in Proxy Statement, Alcoa. Available from: https://www.sec.gov/Archives/edgar/data/1675149/000095010324002738/dp207311_def14a.htm
9. Norway firm produces world's first aluminum using green hydrogen. Available from: https://financialpost.com/pmn/business-pmn/norway-firm-produces-worlds-first-aluminum-using-green-hydrogen
10. Available from: https://www.harboraluminum.com/en/green-aluminum

Disclaimer: This report does not claim to have verified the data and the results put forth by the references used in the text. Readers' caution and discretion are encouraged.