PyroGenesis Aluminum Industry Process Improvement:

Perspective on Macroeconomic & Geopolitical Factors Affecting the Aluminum Industry

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Executive Summary

With both global demand and price for aluminum increasing substantially, technologies that can help the industry maximize output while reducing carbon emissions are key.

Among its offerings, PyroGenesis offers a growing range of industrial technology solutions for the aluminum industry. In fact, the aluminum sector has long been one of PyroGenesis' success stories, continuing to not just bear fruit, but to explode with opportunity in several different directions.

The company's primary expertise in this area is in the recovery of valuable metal and chemicals from the aluminum element known as dross. Dross is a residual waste of the aluminum smelting process.

The aluminum industry had previously developed methods to mechanically separate the still-valuable aluminum from the dross for re-use. The majority of those methods, however, were sometimes dangerous and volatile, with less than optimum efficiency, while leaving a hazardous salt cake that needs to be stored or landfilled – a situation that is become increasingly difficult as landfill bans multiply.

PyroGenesis has modernized and significantly enhanced the dross process, introducing a salt-free method to recover much more – up to 98% – of the valuable aluminum left in dross, a 20% higher rate than the most commonly used process (the rotary salt furnace), and with a 50% lower operating cost, a lower carbon footprint and energy consumption, and a higher return on investment.

As a result, **PyroGenesis' DROSRITE™** systems are in-demand, with the company having won some of the largest dross recovery projects internationally, making the company one of the largest and certainly the fastest growing dross recovery solutions in the world, with 14 large Drosrite™ systems completed (11) or ordered/requested (3).

PyroGenesis contends that while the material and financial advantages alone of Drosrite™ will prove to make this technology increasingly more popular as the industry solution of choice, there exist several macroeconomic and geopolitical factors that will impact that popularity even further.

These factors, highly interrelated, include: increasing worldwide demand for aluminum; the pressing global movement to reduce greenhouse gas and carbon emissions; rising energy prices; supply chain disruptions; volatility caused by international events such as the conflict in Ukraine; and increased aluminum prices.

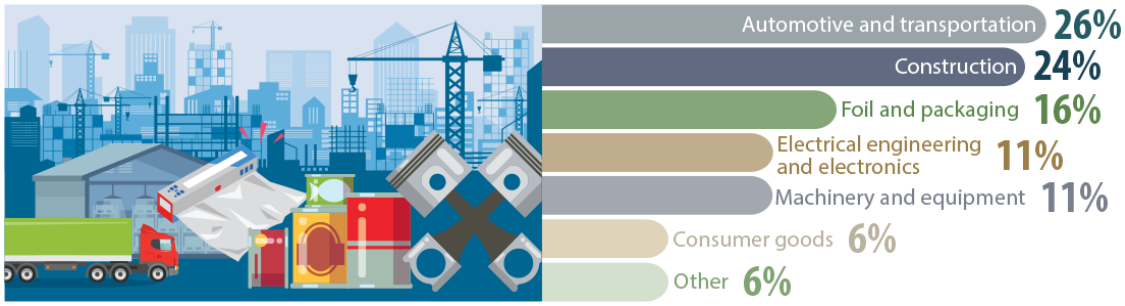
The Impact and Crucial Importance of Aluminum

An energy-hungry industry faces a reckoning, as the growing popularity of its metal collides with demands for a higher quality product and lower environmental impact.

As the second most-used metal in the world by mass (after steel), and the most widely used non-ferrous (metals containing no iron) metal, aluminum is integral to both vital and non-vital industries worldwide.

With incredible usefulness, due to its very low electrical resistance, high strength-to-weight ratio, and durability, aluminum has found widespread applications across construction, electronics, transport, power transmission, food packaging, automotive parts, batteries, and aerospace.

Aluminum Global Uses, 2020 [31]



In short, the world relies on aluminum. Fortunately, aluminum is very common, making up about 8% by mass of the Earth's crust; only silicon and oxygen are more abundant.[1]

Unfortunately, aluminum does not exist in a pure state in nature, so is never found in isolation like, for instance, gold and silver, but rather as a compound in one of 270 different minerals, from which it has to be extracted and refined.

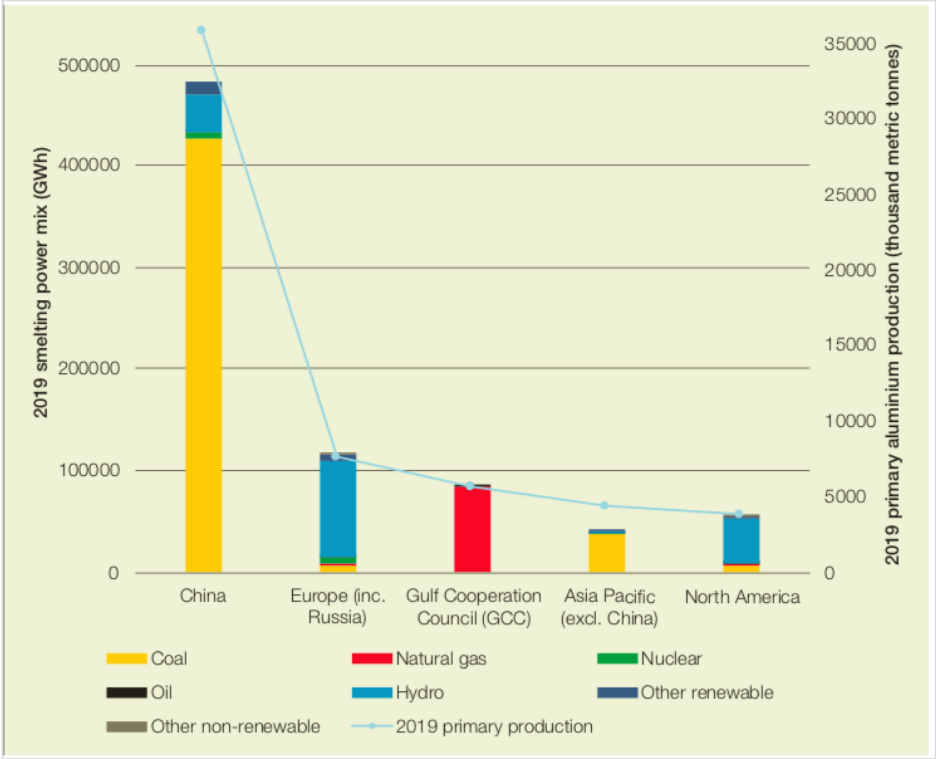
The most common extraction method is through two processes: the first – the Bayer Process – refines bauxite, a naturally occurring ore composed primarily of one or more aluminum base minerals such as aluminum oxide, to produce the substance known as alumina. The second, the Hall–Héroult process, uses electrolysis to release pure aluminum from that alumina.

Combined, this *primary aluminum production* results in the highest quality aluminum, but does so through one of the most energy-intensive and greenhouse gas producing processes in all industry.

Production of 1 kg of aluminum requires between 13.5 to 17 kWh of electricity. While the best smelters, like at Alcoa, the world's largest producer, use about 13 kWh (46.8 megajoules) of electrical energy to produce one kilogram of aluminum, the worldwide average is approximately 15 kWh/kg (54 MJ/kg) or 15,000 kWh per tonne. [2]

In such an energy-intensive industry, the availability of lower-cost renewable power will be key to reaching the desired "net zero by 2050" goal that also limits global warming to +1.5°C–2°C, a scenario set out by the International Panel on Climate Change (IPCC) and affirmed by many in the aluminum sector. Regional dissimilarities in power source will make the transition to renewables difficult for some companies, and also more expensive. [30]

Global power mix and primary aluminum production (2019) [3]



Currently, primary aluminum production accounts for 1.1 billion tonnes of CO2 emissions per year, or 2% of global human-caused GHG emissions – an impact similar to global aviation or shipping. [3]

Aluminum, however, is highly reusable. In fact, 95-98% of aluminum can be recycled, and 75% of all aluminum ever produced is still in use thanks to its excellent recycling characteristics and metal durability. [4]

Furthermore, this recycling of aluminum scrap, or *secondary aluminum production*, requires just 5% of the energy of primary aluminum production – saving 90-95% of the energy needed to make aluminum from bauxite ore, and at drastically lower GHG emissions totals. [5]

But while primary aluminum is sought after for use in critical applications in science and manufacturing, secondary aluminum produced from recycled scrap traditionally contains higher levels of impurities, with quality and consistency issues restricting its use to items like beverage cans and automotive castings. [6]

Consequently, any quantity of higher quality aluminum saved during primary aluminum production (such as provided by PyroGenesis' Drosrite™ dross recovery system**)** is considered a tremendous in-stream benefit, providing noteworthy savings in time, cost, and degradation relative to the secondary production process – while also increasing the output of higher value primary aluminum whose availability will be under mounting pressure for decades to come.

Rising Aluminum Demand

Technologies that can help existing facilities maximize their output of high-quality aluminum will be coveted as worldwide demand accelerates.

Overall aluminum demand is expected to increase by up to 80% by 2050, to 180 million tonnes, including both recycled and primary metal (with the global demand for primary aluminum expected to increase separately by 50% during that period), due to rapid population and economic growth over the coming decades.

These forecasts, from the International Aluminum Institute, the body representing the global primary aluminum industry, suggest that the main growth drivers will be increasing demand in strategic applications where aluminum's unique properties make it the material of choice, including mobility, building and construction, packaging, and light-weight, fuel-efficient vehicles, among others. [7]

As global demand for aluminum increases over the next 30 years, it had been anticipated the need would be met primarily by China and Southeast Asia, the largest aluminum-producing regions.

However, that expectation is in doubt.

China has long been not only the largest producer of aluminum – in 2021 accounting for 57% of the world's primary aluminum production – but also its largest consumer, as the country remains a massive net exporter of semi-manufactured products. But as China's economy grows, its need for aluminum is so great that in 2020 the country became a net *importer* of unwrought aluminum and alloys, importing ever more primary metal to feed both its massive internal needs, plus the needs of products locally manufactured for export. [8]

Meanwhile, in Russia, the world's second largest aluminum producer, the situation is uncertain. At Rusal, the world's biggest aluminum producer outside China that plays a vital role in global supplies by accounting for 6% of global output, production at the Nikolaev alumina refinery in Ukraine has been halted, due to obvious logistical challenges on the Black Sea as a result of the war. The loss of this alumina supply is a key risk in Russia and beyond, as it represents an eventual suspension of primary smelting capacity in Russia, impacting around 900,000 tonnes a year. [9]

The U.S., the #2 consumer of aluminum, does not have the ability to offset China's supply shortcomings. Over the past few decades, the price of electricity kept rising to the point where primary aluminum production in the U.S. is no longer economically viable. The United States has gone from having 23 operational aluminum smelters in 1993 to just six today, with most running far short of maximum capacity.

The decline has been fast. At year-end 2020, three companies—Alcoa, Century Aluminum, and Magnitude 7 Metals—operated six primary aluminum smelters, compared to 2010 when five companies operated nine primary smelters in the USA.

Those remaining American smelters, who operated at about 49% capacity in 2020, down from 60% in 2019, are at risk. Century Aluminum, the largest producer of primary aluminum in the United States, operates the last U.S. smelter capable of producing high purity aluminum necessary for defence and military applications, from the company's Hawesville, Ky. smelter – a facility that, over the past ten years, has twice issued 60 days notices of permanent closure, before pulling its business back from the brink while laying off more than 300 people in the meantime. [10]

But that smelter is coal-fired, a more expensive and at-risk approach as both electricity costs and decarbonisation efforts continue their escalation, potentially forcing the hand of its corporate owners. Indeed, many major American aluminum companies like Alcoa have long considered the North American market a unified whole. As such, when they go searching for cheaper operating locales, they're more apt to find it in Canada, even building their own hydroelectric dams or helping lobby for increasing power capacity.

In the face of such momentum, even protectionist attempts have soured. In September 2020, after the Trump administration announced a 10% import tariff on Canadian aluminum, the threat of retaliatory counter-measures by the Canadian government forced the US to pause tariff implementation until after the American federal election, subsequently dropping the idea completely. [11]

As a result, with the geographical locations of most remaining smelting facilities in North America being in low-cost geographies, about 70% of electricity consumed in smelting facilities comes from existing hydroelectric sources. [12]

As that continued shift impacts industry competitiveness more and more across the world, and with construction timelines for new dams stretching into decades, the dawn of the remaining North American coal-fired smelters is in sight – while hydroelectric powered smelters alone may struggle to support rising primary aluminum demand.

More recently, at En+ Group in Russia, the world's largest supplier of hydropower-produced aluminum with 20% of the market, 2018 trade sanctions have increased and product sales are threatened. The company's owner came under personal sanctions in the UK and U.S., then jeopardized the company's status with Russian officials after breaking ranks with official government line by calling for the end to the war. [13]

With rising global demand for aluminum, plus on-going volatility at the supplier level, technologies and processes such as PyroGenesis' Drosrite™ dross recovery systems that can help existing facilities maximize their output of aluminum will be coveted, both short and long term.

Decarbonisation

Many hurdles lie ahead as the industry lags behind its timeline for achieving a net zero emissions goal by 2050, while maintaining product quality and increasing production.

Running parallel – somewhat paradoxically in the face of energy shortages – to the rising demand for aluminum, is a growing consensus about the need for the aluminum industry to decarbonise.

The electro-intensive global aluminum industry needs to slash its emissions 80% by 2050 to keep in line with the International Energy Agency's "Beyond 2 Degree Scenario" (B2DS) and the Paris Agreement, as well as much of the industry's self-imposed deadlines – a difficult proposition given the expectations of increased demand for the metal. [14]

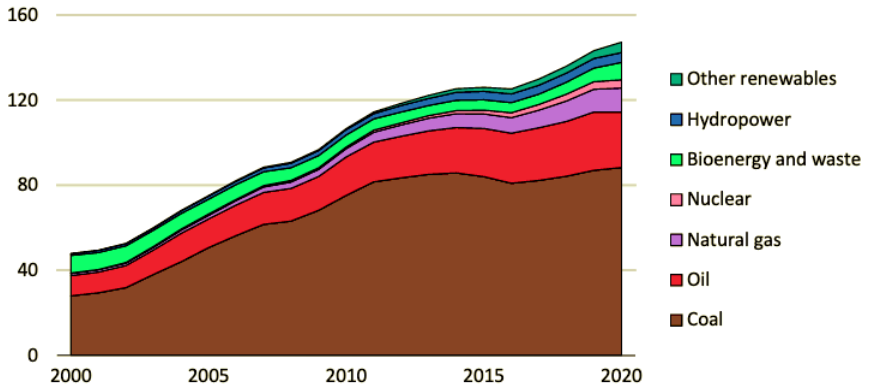
Examples of aluminum players' public climate ambitions [30]

Aluminium player	Ambition*
Alcoa[14]	Reduce GHG emission intensity (Scope 1 and 2) by 30% by 2025 and by 50% by 2030 from a 2015 baseline
EN+ Group/RUSAL[15]	Limit warming to 1.5°C via science-based emissions reduction (sign up to SBTi)
GFG Alliance/Alvance[16]	Achieve carbon neutrality by 2030
Norsk Hydro[17]	Reduce GHG emissions by 30% by 2030
Rio Tinto[18]	Reduce carbon intensity[19] by 30% and absolute emissions by 15% by 2030 and reach net-zero emissions by 2050

Outside of North America, the biggest challenge facing the aluminum sector in meeting this goal is the overwhelming reliance on fossil fuel-based electricity. Using China, the world's largest aluminum producer by far (with 57% of world output) as an example, over 80% of their aluminum capacity uses coal-fired power.[15] An industry having to amend their practice becomes further contested when one considers how entire countries struggle under the impact of the same goal.

China relies on massive amounts of coal to keep people warm, but some provinces struggle to keep the lights on amid Beijing's determination to cut emissions, reduce power prices, and cut coal production. Despite China making significant investments in alternative energy sources such as solar and hydropower, coal remains the dominant source, accounting for 68.5 per cent of the nation's power supply in 2020. [16]

Total primary energy demand by fuel in China [35]



IEA, 2021.

This divergence of emission goals and on-the-ground power source reality led to the current situation, when starting in Fall 2021 China found itself in the grips of a national power crisis.

Partly as a result of conflict between market-oriented coal prices and government-controlled electricity rates, the country's power generators decided they couldn't justify power production with record coal costs cutting into profit margins, so started slowing power generation, leading to widespread rationing and outages.

Compounding the situation, the central government's non-negotiable carbon reduction targets had forced many provincial governments to impose widespread power cuts. Sixteen of mainland China's 31 provincial-level jurisdictions were found to be rationing electricity as they raced to meet Beijing's annual emissions reduction targets. [17]

Against this backdrop, aluminum production in China suffered a 2.3 million tonne drop since the onset of the power crunch.

Analysts have stated that China's pledge to start phasing down coal use from 2026 spells potentially more trouble for the country's primary aluminum sector; with Beijing planning to peak carbon emissions by 2030, it suggests more cutbacks are coming.

As a result, a further global supply crunch is likely, and as more smelters seek to expand despite already inadequate energy sources (non-renewable and renewable), the energy system will put further strain and price pressure on industry.

Technologies like PyroGenesis' Drosrite™ dross recovery system that can help increase existing aluminum supply, while also contributing to decarbonisation efforts, look set to see widespread adoption.

Surging Energy Prices

As countries undertake difficult and costly transitions from carbon-based energy, industry must find ways to adapt while driving greater ROI as they compete for finite power.

While aluminum made with hydro-electricity has one-fifth of the carbon footprint of aluminum made with coal-fired electricity, it also has a lower production cost. As a result, the momentum behind hydroelectricity as the preferred generation technique continues. [18]

For instance, Aluminerie Alouette in Sept Îles Quebec, the largest primary aluminum plant in North America and one of the lowest operating-cost primary aluminum plants in the world, receives its power from the Churchill Falls Hydro Electric project in nearby Labrador.

On an even grander scale, the output of the Kárahnjúkar Hydroelectric Plant in Iceland is devoted entirely to the Fjardaál aluminum smelter. [19]

But these initiatives notwithstanding, the on-going energy shortages are taking a toll on global aluminum output.

Indeed, even renewable energy is under pressure, in a variety of ways. Partly driven by decarbonisation efforts, Chinese industrial planners constructed several large hydroelectric dams to help the industry pivot away from coal, but energy regulations combined with an unusual drought exacerbated energy shortages and forced the country to divert energy away from industrial sectors, like aluminum smelters, and back to regular consumers, impacting output. [20]

Similar power woes have spread to Europe, with the European continent gripped by one of the worst energy crunches in history, as a complicated series of market, political, and geographic factors have united into a perfect storm.

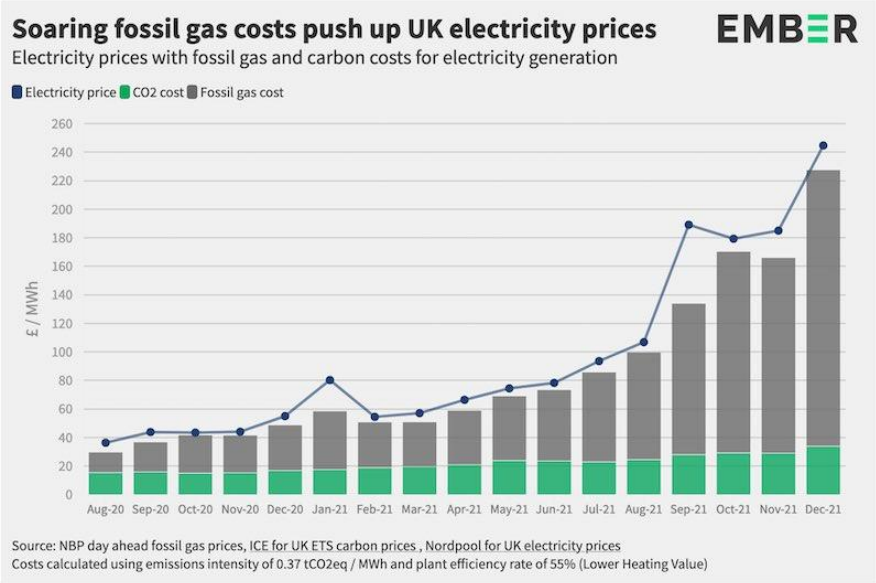
As the European Union gradually cuts down on its long-time dependency on fossil fuels – renewables became the regions main source of electricity for the first time in 2020. [21]

But the shift has not been fast enough, or widespread enough, to contain the fallout from the power crunch as renewable energy was put to the test under unpredictable weather conditions in 2021.

For instance, 2021 saw an unusual period of light wind – what UK energy giant SSE described as “one of the least windy [periods] across most of the UK and Ireland and one of the driest in SSE’s Hydro catchment areas in the last seventy years”. As a result, the company’s renewable assets produced 32% less power than expected between April 1 and Sept. 22. Subsequently, colder-than-expected winter temperatures led to a higher-than-usual power demand, adding to the problem. [22]

While waiting on additional renewables and green alternatives like wind and solar to be rolled out and integrated into the grids, many countries resort to natural gas as a transitional resource.

Prices of natural gas have subsequently skyrocketed, helped along by a surge in demand for energy as countries come out of the restrictions imposed by the pandemic.



Moreover, natural gas is used heavily for residential heating and cooking in Europe, making the price surge even more noticeable for consumers.

Citizens in countries like Spain, Italy, France, and Poland have seen all-time-high energy bills. Gas more than tripled last year, and energy companies, analysts, and traders suggest high prices are set to persist.

Bank of America Corp. estimates European households will pay an average of 54% more for energy this year than in 2020, with the biggest increases in the U.K. and Italy, where average yearly bills are set to jump by the equivalent of more than US$1,000. [23]

All of this has affected smelting activity. Global aluminum production rates started falling at the end of 2021 as power constraints spread from China to Europe.

Analysts at Citi estimate around 800,000 tonnes of smelter capacity has been curtailed in the region, with up to 1.2 million tonnes at risk from soaring power prices. As of January 2022, four smelting operations have announced curtailments totalling over half a million tonnes of annual production capacity, with others flexing output to mitigate power-load price spikes. [24]

“Exorbitant energy prices” were cited by US producer Alcoa as the reason for a two-year curtailment of its 228,000-tonne per year San Ciprian smelter in Spain. The plant will be put out of action, returning in January 2024 with renewable power contracts.

And there are others: [25]

- The KAP smelter in Montenegro, which began powering down its 120,000 tonnes of annual capacity in the middle of December 2021, as the plant’s owner Uniprom was facing a jump in its power bill from 45 euros ($50.89) to 120 euros per megawatt-hour at the start of 2022.

- Romanian producer ALRO is reducing output from five to two potlines at its Slatina smelter, operating at around one-third capacity until further notice.

- Norway’s Hydro doubled down on the amount of capacity it is idling at its Slovalco smelter in Slovakia, reducing production to 60% of the plant’s annual capacity of 175,000 tonnes per year, citing “very high energy prices (which) show no sign of improvement in the short term”. [25]

Europe’s lengthening list of smelter casualties is a warning sign that high energy prices pose a long-term, fundamental challenge for the aluminum industry globally.

As a result, the more an active plant can maximize the amount of viable metal during its initial primary processing, including through effective rescuing of metal from dross using a system like PyroGenesis’ Drosrite™ dross recovery system, the greater the return on investment from the smelting process as a whole.

Rising Aluminum Prices

The industry faces challenges as it hopes to capitalize on soaring demand and price; with new primary production capacity uncertain, maximizing current output is vital.

With energy supply under pressure, and demand for aluminum increasing, aluminum prices spiked to their highest levels ever, surpassing prices seen only once in 30 years.

In October 2021, the price soared to a 13-year high of US$3,000 a tonne, the highest mark since 2008. Before reaching that milestone, aluminum was generally priced in the range of US$1,500 to US$2,000 a tonne. [26]

With Chinese output cuts, a rapid increase in the price of alumina (from which aluminum is made), diminishing exchange stockpiles, and fast-growing demand, volatility was so high that aluminum prices increased 50 per cent for the year, including 15 per cent in only three weeks as speculation grew. [27]

Aluminum Monthly Price – US Dollars per Metric Ton [36]

As the war in the Ukraine drove supply chain issues and additional sanctions on Russia, prices spiked further – up to $3,487 a tonne – on worries about supply reductions from aluminum powerhouse Rusal. [28]

All this is happening during a time when corporations – particularly from the automotive, electronics, and packaging industries, including Apple and Toyota – have already begun demanding "green" or lower carbon aluminum for their products, with a carbon footprint of less than 4 tons of CO2 per ton of aluminum.

Producers, notably the operators of hydroelectric-powered smelters in Norway and Canada who can promote their environmental credentials, are seeing an opportunity, with some aiming to charge premium prices for their “green” product. [29]

Traditionally, high prices and new market opportunities would incentivize more production, but much depends on maintaining a sufficient energy supply – currently imperilled – to support power-hungry aluminum smelters.

With a massive global decarbonisation effort underway, and as the number of new hydroelectric dams that can be built is limited (by high cost, lengthy construction timelines, and protracted government review and approval processes), the key financial opportunity is currently weighted toward maximizing the metal from existing output rates.

With aluminum prices already at all-time highs, demand growing, and new production constrained by a plethora of macroeconomic and geopolitical conditions, every bit of aluminum counts.

PyroGenesis’ Drosrite™, offering the ability to recover high quality aluminum from primary smelting dross at the highest rate in the industry, at a lower operating cost and while contributing to decarbonisation, is one of the few readily available technologies offering immediate benefit.

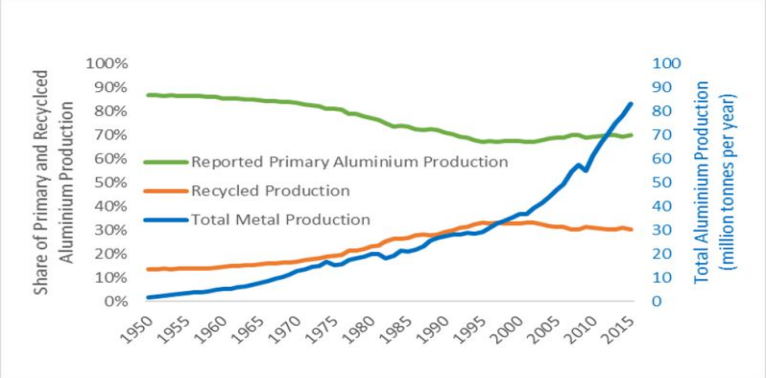
Conclusion

Volatility and structural challenges – both short and long-term – will continue to impact the aluminum industry's energy, production, and cost, highlighting the need for process technology solutions to supplement growth plans.

To meet targeted Net Zero emissions reductions by 2050 during a period when aluminum demand is expected to grow by up to 80%, the aluminum industry must increase drastically the output of secondary aluminum, expand the use of renewable power, and reduce carbon-fuelled production. But large hurdles remain.

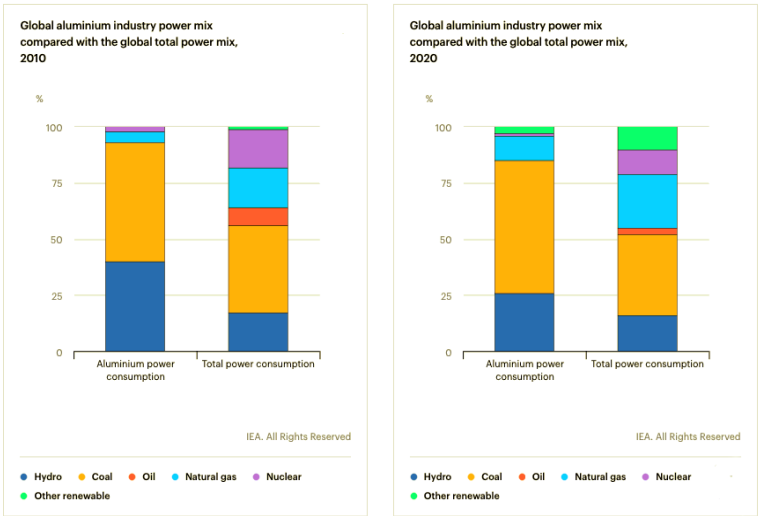
First, the global share of secondary aluminum production has remained relatively constant since 2000, at 31-33% of total aluminum output, with 34% in 2019 representing the highest share during this period.[32]

Global Share of Primary and Recycled Metal Production [34]



Second, while hydropower is currently used for 25% of global aluminum production – even while hydropower accounts for only 15% of the world's power mix – this share has fallen since 2010, when 40% of aluminum production was fuelled by hydropower. [33]

Global Industry Power Mix 2010 VS. 2020 [32]



This decrease is largely due to the fact that over the last decade, aluminum production has increased by over 50% in total, largely driven by expanding aluminum production in China (where coal supplies 90% of production) and the Gulf states (where natural gas and coal are used extensively). [33]

Finally, as the pandemic and the war in Ukraine caused logistics and supply chain volatility, it also fully exposed the vulnerability of aluminum producers to power availability and energy price uncertainty.

Which leaves the over-riding question: how can the industry meet its looming carbon reduction targets?

According to the International Energy Agency (IEA), the answer lies in "[for secondary production growth] improved end-of-life scrap collection and sorting, to enable greater production from scrap", as well as "further development of new technologies to reduce emissions from primary production."[32]

PyroGenesis believes that, with its continuous technological breakthroughs, on-going joint ventures with major aluminum industry producers, and more widespread commercialization of its industry-leading (and patented) clean-energy process improvement and metal recovery technologies, the company will play a major role in helping the industry meet its emissions and production optimization goals over the next few decades.

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