Application of Plasma Arc Melting in Aluminium Recycling

Martijn Vos[1], Igor Kostin[2], Aleksandr Krokhin[3], Iliya Strombskoy[4], Aleksey Iliin[5], Ivan Bezrukov[6], Andrey Bezrukov[7] and Sergey Radko[8]
1. Director New Product Commercialization
2. R&D Director
3. Head of Department Casting and New Product Development
4. Group leader - Casting Process Modelling Group
5. Head of Department - Casting Process Modelling Group
RUSAL ETC, Krasnoyarsk, Russia
6. CEO - EPOS Engineering
7. Commercial Director
8. Chief Engineer
EPOS-Engineering, Novosibirsk, Russia
Corresponding author: vos_martijn@yahoo.com
https://doi.org/10.71659/icsoba2025-ch004

Abstract

RUSAL is investigating low temperature plasma arc melting of aluminium as part of its decarbonation strategy. Traditional gas- or oil-fired furnaces increasingly fall short of modern demands for energy efficiency, productivity, and low emissions (particularly carbon monoxide). Plasma arc melting technology delivers intense, rapid heating that dramatically accelerates aluminium melting. Developing such energy-efficient systems requires multidisciplinary collaboration across plasma science, heat engineering, and metallurgy – a convergence that generates substantial economic and technological benefits when executed effectively. Plasma technology is widely used in Russia in heavy industries such as Nuclear and the Ferrous industry. The system design for this project is based on experiences from the Ferromanganese industry.
This paper outlines the R&D project scope and assumptions for utilizing low-temperature plasma arc melting, including furnace modelling, and strategies for maximizing efficiency and productivity.

Keywords: Plasma technology, Aluminium furnace, Remelting of aluminium scrap

1. Introduction

As one of the elements of its decarbonisation strategy, RUSAL is exploring plasma arc melting technology as a high-efficiency, renewable energy source for aluminium scrap remelting. This initiative is driven by RUSAL's continuous growth in remelting aluminium scrap to further reduce the carbon footprint of its aluminium.

Unlike conventional oil or gas burner systems, plasma arc melting operates as an all-electric process. This enables direct integration with the same renewable energy sources powering RUSAL's primary smelting operations, eliminating reliance on fossil fuels. While plasma systems require higher upfront investment, they offer superior energy efficiency and enhanced metal yield compared to traditional fossil fuel-burning furnaces.

Beyond energy waste, combustion-based systems face compounding challenges: they demand cost-intensive fuel infrastructure and emission control systems (often exceeding the furnace cost itself). Critically, the release of untreated exhaust gases conflicts with both global decarbonization targets and tightening environmental regulations.

The current R&D project aims to quantify the operational advantages of plasma technology – specifically, determining when the gains in energy efficiency and material recovery offset the initial capital expenditure.

2. Natural Gas Combustion Systems

Natural gas combustion produces approximately 0.13 tonne of CO_2 per tonne of remelted aluminium. The chemical reaction is shown in Equation (1).

$$CH_4 + 10\,(0.2\,O_2 + 0.8\,N_2) \rightarrow CO_2 + 2\,H_2O + 8\,N_2 \tag{1}$$

Natural gas generates approximately 11 kWh/Nm^3 of thermal energy in the form of heat and radiation depending on the type of burner system. The process not only generates carbon dioxide, water vapour and nitrogen, but due to incomplete combustion, it is also create non-desirable products: CO (carbon monoxide), C (soot) and H_2 (hydrogen).

3. Energy Efficiency and Yield Comparison

A comparison between different combustion burner systems and plasma arc melting is shown in Table 1. Data source for the gas combustion burner systems is Mechaterm [1]. The oil burner data is based on actual oil consumption. The plasma arc melting is based on analysis, and initial tests. The values obtained with plasma arc melting will be confirmed as part of this R&D project.

Table 1. Benchmarking of combustion burner systems with plasma arc melting.

Process	Oil burner	Cold air burner	Regenerative burner	Oxy-fuel burner	Plasma Arc Melting
Energy to melt aluminium	1900 kWh/t	1050 kWh/t	700 kWh/t	660 kWh/t	< 500 kWh/t
Metal loss (dross)	10–17 %	8–15 %	8–12 %	5–10 %	< 5 %

Beyond high energy efficiency and a high yield, there are no direct CO_2 emissions and near-zero NOx emissions in plasma arc melting (combustion-free process).
The higher temperatures enable faster melting and reduce energy waste. Technology is scalable for integration into existing cast house infrastructure. Furthermore, enhanced process control improves the alloy quality of the melt.

4. Low Temperature Plasma Arc Melting

Plasma arc melting is employed in the ferrous industry, utilizing extremely high temperatures (10 000–20 000 °C). However, these temperatures are inefficient for aluminium melting, which requires lower-temperature plasma systems. Some configurations operate under inert atmospheres (e.g., Ar/N_2) to prevent oxidation. Figure 1 illustrates common industrial plasma torch designs.

Equation of heat transfer on the furnace walls (convection + radiation)

$$q_{wall} = h_{ext}(T_{wall} - T_{\infty}) + \epsilon\sigma(T_{wall}^4 - T_{\infty}^4) \quad (8)$$

where:
h_{ext} heat transfer coefficient,
ε degree of blackness.

Some of the modelling output is shown here in Table 3:

Table 3. Heat source comparison modelling results.

	Plasma Arc Heater	Oil Burner
Time to temperature 850 °C	7.5 hours	11 hours
Melting rate	1.5 t/h	1.0 t/h
Energy consumption	409 kWh/t	1900 kWh/t (150 kg of oil)
Thermal efficiency of the heater	80 %	21 %

All modelling parameters will be validated through measurements during the melting experiments.

The experimentation will show whether plasma arc heating is a promising route by itself, or whether a combination with standard electrical heating, e.g. induction heating should be pursued.

7. Conclusions

Plasma-arc melting model demonstrates significant potential as a sustainable, electrically powered solution for aluminium scrap recycling. Key advantages to be validated through ongoing R&D include:

- Energy Efficiency: Exceeds advanced oxi-fuel burners (< 500 kWh/t Al)
- Sustainability: Zero direct CO_2 emissions and near-zero NOx
- High System Efficiency: Plasma torch COP (95–97 %) and furnace efficiency (> 90 %) outperform fossil-fuel systems
- Yield Optimization: Minimal dross formation
- Operational Simplicity: No water cooling required; robust, low-maintenance design
- Precision Control: Smooth power modulation and superior temperature uniformity
- Cost Effectiveness: Low OPEX with high operational readiness

8. References

1. Lee Allen, Mechaterm, “*TMS Supplier Technology Forum 2025”*
2. Akash Pakanati et al., Development of Numerical Model of Plasma Burner for Primary Aluminium Casthouses, *Light Metals, TMS 2025*
3. Kevin Widlic, Hydro Moves Forward with Plasma Technology Project, *Light Metal Age*, February 2025, 34-35