

AA24 - Decarbonizing Alumina Calcination by Fuel Conversion

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Abstract

Aluminium producers have launched low carbon emission initiatives to reduce their carbon footprint of aluminium production. The production of alumina in alumina refining plants also gets into the spotlight of the decarbonization discussion. As part of the alumina refinery, alumina calcination contributes significantly to CO₂ emission, which itself is accounting for approximately 30% of these carbon dioxide emissions. Emission reduction in the calcination process will directly reduce the carbon footprint of an alumina refinery.

Over the last decades Outotec built more than 60 alumina calcination plants worldwide, which covers a significant share of global smelter grade alumina production capacity. The development and implementation of fuel conversion is responding to the industry request to reduce mainly SO₂ and CO₂-emission. The industry can reach the decarbonization goals using mainly three levers: 1. Improving energy efficiency by deploying best available technologies, 2. Switching from high carbon intensive fuels to low carbon dioxide emitting fuels, and finally 3. by capturing CO₂ emissions. In the past heavy fuel oil was mainly used as fuel and is still being used as energy carrier in many refineries. Fuel conversion from heavy fuel oil to natural gas is already significantly reducing carbon emissions simply because the carbon content in the fuel is lower in natural gas, as compared to heavy fuel oil. Switching to natural gas will inherently lower emission. Further reduction will be possible using alternative fuels including hydrogen and/or bio-based fuels.

On the long run, hydrogen fuel seems to be a feasible green energy carrier. However, the availability of renewable energy to produce green hydrogen is a challenge. Fuel conversion from heavy fuel oil or coal gas to more climate-friendly natural gas is therefore considered as bridging technology.

Keywords: Alumina calcination, Sustainability, Fuel efficiency, Emission reduction.

1. Introduction

As the world focuses on environmental conservation and reducing carbon emissions, sustainability is a topic of growing importance in the alumina industry. Incorporating sustainability in alumina production involves a comprehensive approach that encompasses energy efficiency, emissions reduction, water conservation, responsible mining, waste management, recycling, and stakeholder engagement [1-3].

Alumina refining is an energy-intensive process. From a technology point of view, reducing energy consumption and associated greenhouse gas emissions is of particular interest. The use of renewable energy sources, such as solar, wind, or hydroelectric power, in alumina production can significantly reduce the carbon footprint. There are many ongoing initiatives and companies are already investing in renewable energy projects to power their operations and reduce their reliance on fossil fuels. One recent example is the joint development of the world's largest solar process steam plant for Ma'aden's Alumina Refinery [5].

The fuel consumption in alumina refining is depending on the technology used, the availability of fuels, and the emission standards. Figure 1 shows the energy consumption in metallurgical alumina production worldwide and by region, based on data from International Aluminium Institute [4]. It includes the consumed energy within the plant perimeter by bauxite refining processes (including calcination) and by those auxiliary operations on site which are directly connected with the total production process. Plants producing metallurgical alumina from nepheline ores or other non-bauxitic sources (e.g. fly ash), which globally contribute less than 1% of production, are not considered in the data.

Latest available data from 2021 on worldwide alumina refineries indicates a fuel energy consumption of 1.2 million of terajoules (TJ), with primarily use coal (with a share of 51.5 %), followed by natural Gas (31,4 %), and fuel oil (7.9 %). Coal is the dominant fuel in China with a share of 72% of the fuel used. Outside China Natural Gas is meanwhile the predominant fuel type contributing to 58% of the fuel used in alumina refineries.

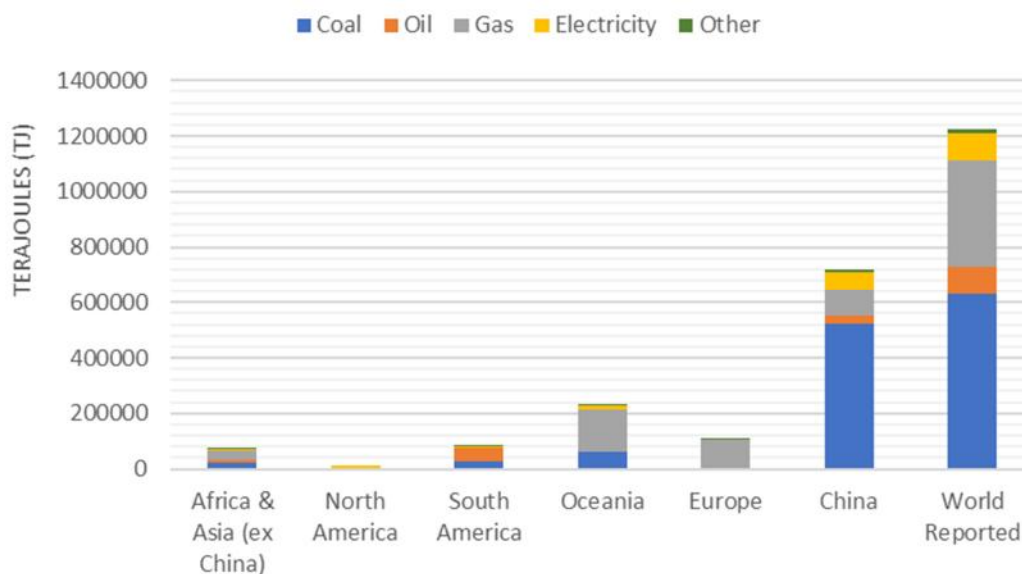


Figure 1. Metallurgical Alumina Refining Fuel Consumption worldwide and regional breakdown (based on data from International Aluminium Institute [4]).

There is no data available on the used fuel types for the calcination area only, however it can be assumed that the fuel type in the refinery power plant and in the calciner is in most cases the same. Coal is not directly used in alumina calciners and is a special case, as calciners can only be fuelled with coal gas for obvious reasons.

The development and implementation of fuel conversion is responding to the industry request to reduce CO₂-emissions. The industry can reach the decarbonization goals using mainly three levers:

1. Improving energy efficiency by deploying best available technologies,
2. Switching from high carbon intensive fuels to low carbon dioxide emitting fuels, and finally
3. By capturing CO₂ emissions by and implementing carbon capture and storage (CCS) technologies to capture and store CO₂ emissions

Carbon dioxide emission varies depending on the specific type of fuel. The carbon emission factor represents the amount of carbon dioxide (CO₂) emitted per unit of energy produced when a fuel is burned. In the following the focus will be on the first two points of the decarbonization levers listed above.

2. Alumina Calcination

Alumina is the feedstock for primary aluminium metal production, and alumina calcination is one of the primary energy consumers in this production chain. Alumina calcination process requires depending on the applied technology approximately 2.8 to 4.5 GJ of energy per tonne of alumina produced, which can exceed 30 % of the total energy for the alumina production process alone.

The latest generation of Outotec alumina calciners (GEN 5) is in the meantime in operation over years. It is enhancing the sustainability of the entire calcination process with a higher fuel efficiency as compared to previous generations [11, 12]. The compact design reduces the required construction material and is therefore more sustainable from a construction and manufacturing perspective (see Figure 1).

Energy efficiency is one of the main drivers for technology development, initially for cost reasons and meanwhile to reduce the carbon footprint of production. The highly endothermic and high-temperature process of alumina calcination requires large amounts of energy, which generates CO₂ emissions when using fossil fuels. Research into alternative fuels is ongoing, with producers looking into supplementing or substituting fossil fuels by, for example, solar or hydrogen-based concepts [6, 7]. Electric calcination is currently in the early stages of development, with low technology readiness. It is capital intensive and needs large-scale, low-cost, renewable electricity to be considered viable.

Heavy fuel oil has been the fuel type used in the past and is still being used as energy carrier in many refineries. Fuel conversion from heavy fuel oil to natural gas will be already significantly reducing carbon emissions simply because the carbon content in the fuel is lower in natural gas, as compared to heavy fuel oil. Switching to natural gas will inherently lower emission. Further reduction will be possible using alternative fuels including bio-based fuels, and/or hydrogen.

An established indicator for CO₂ emissions is the Carbon emission factor, which is described and discussed in the following chapter.

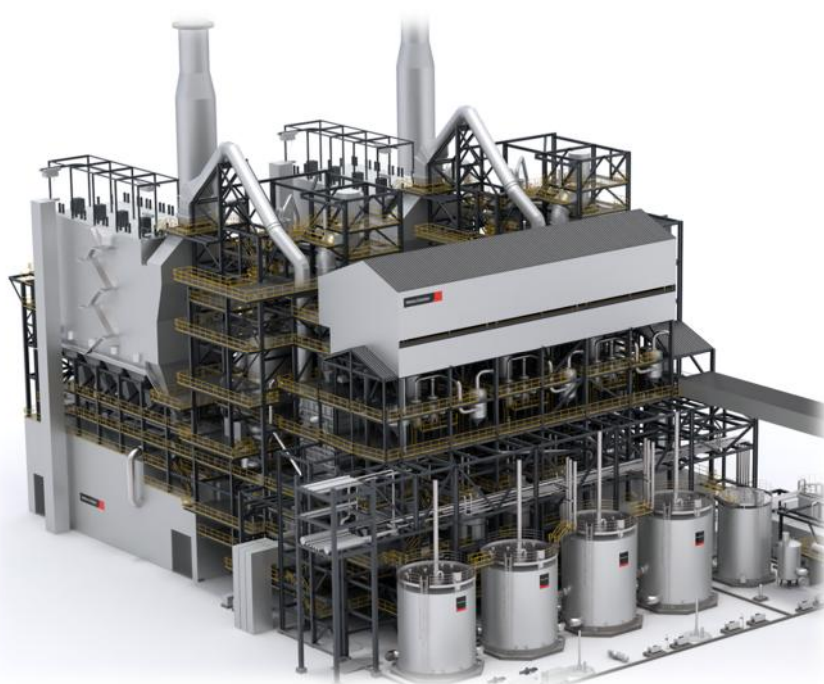


Figure 2. Compact design of an Outotec Alumina Calcination and Hydrate Filtration Plant

3. Carbon Emission Factors

Carbon emission factors for fuel oil can vary depending on the specific type of fuel oil and its composition. The carbon emission factor represents the amount of carbon dioxide (CO₂) emitted per unit of energy produced when a fuel is burned.

Figure 3 shows specific carbon emission (indicated in t CO₂ per TJ) for fuels used in an alumina refinery, (Natural gas, fuel oil, lignite as basis for coal gas, LPG, and Diesel) or potentially usable, like hydrogen. Data is based on information from German Umweltbundesamt [9, 10]. These values are reflecting only the emission within the furnace, and are not including upstream fuel related emissions. For example, hydrogen-based emissions in a calciner will be close to zero, as there is not carbon content in the hydrogen fuel. Looking at the entire life cycle of hydrogen, the carbon emission associated with hydrogen production by renewable sources (green hydrogen) or by steam reforming is vital. Within this article background emission are not considered though.

Coal respectively lignite can be used in a calciner only when converted to coal gas. The emission shown in the diagram is referring to combustion of coal/lignite, however the emission in a calciner will be varying as an upstream gasification step is required to generate coal gas.

The indicated values are approximate and can vary depending on factors such as the specific composition and quality of the fuel.

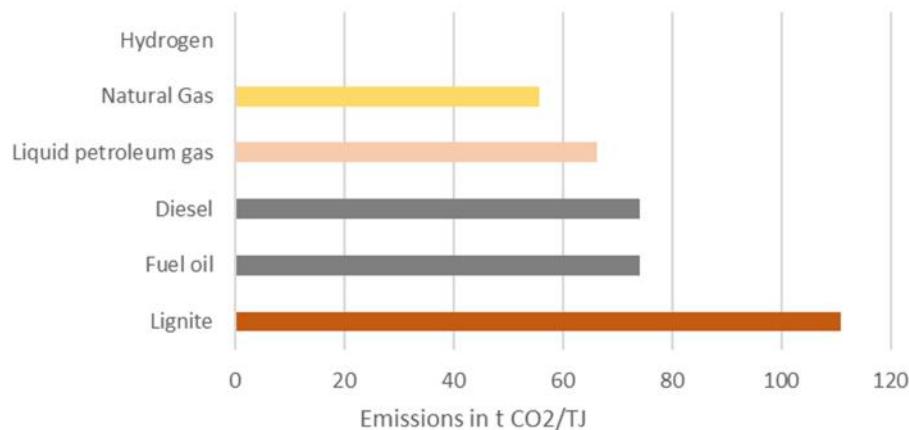


Figure 3. Specific carbon emission of various fuels

4. Driver, Limitation and Technical Constraints for Fuel Switching

Fuel switching refers to the process of shifting from one type of fuel to another, often with the goal of reducing environmental impacts or improving energy efficiency.

There are several common factors that contribute to the decision to switch fuels, including environmental concerns, technological advancements, energy security, cost competitiveness, and/or public opinion and social responsibility.

On the other hand, switching from one fuel source to another often necessitates significant changes to infrastructure. For example, transitioning from fuel oil to natural gas requires the local availability of this fuel gas at site, either by pipeline connection or by supply of Liquefied Petroleum Gas (LPG) via a port. The upfront costs and logistical challenges associated with infrastructure upgrades can be substantial.

4.1 Driver

There are several common factors that contribute to the decision to switch fuels, including environmental concerns, technological advancements, energy security, cost competitiveness, and/or public opinion and social responsibility.

One of the main drivers for fuel switching is the need to reduce greenhouse gas emissions and mitigate the impact of climate change. Switching from fossil fuels, such as coal or oil, to cleaner energy sources like natural gas, or renewables will reduce carbon dioxide and other pollutant emissions.

Technological benefits of gaseous fuels over liquid fuels are another important driver for switching fuel. Handling natural gas is much easier as handling fuel oil, as it does not require fuel atomization and is requiring less operational interventions.

Regulatory policies and regulations can play a significant role in driving fuel switching, which is the consequence of emission goals, see above. Mandates, incentives, or penalties aimed at reducing emissions, promoting renewable energy, or phasing out certain fuels are creating a strong impetus for industries to switch to cleaner energy sources.

4.2 Limitation

Switching from one fuel source to another often necessitates significant changes and infrastructure investments. The accessibility of alternative fuels at remote locations will impact the feasibility of fuel switching project. The availability of alternative fuels can be limited, particularly in certain regions. Existing fuels do have a well-established supply chain and infrastructure network. The development and distribution of alternative fuels and their infrastructure need time and investment to reach a comparable level of availability.

Different fuels possess varying energy densities. Fossil fuels like heavy fuel oil (HFO) and diesel have high energy densities, which means they can store a large amount of energy in a relatively small volume. Alternative fuels, such as natural gas or even hydrogen, generally have lower energy densities. The availability of fuel has to be secured, though, and storage and buffer capacities have to be considered in any fuel switching project.

Fuel switching projects are brownfield projects and the technical compatibility must be investigated. The change of fuel has also an impact on the combustion air flow, and the offgas flow of a calciner. All equipment and vessels must be investigated to ensure that a proper plant performance is ensured, and especially that the solids flow in the calcination system is not negatively impacted by fuel switching. Retrofitting or replacing existing equipment to accommodate new fuels will be costly and time-consuming.

4.3 Technical Constraints

Technical constraints are limiting the field of application when implementing a fuel switching project. When retrofitting an alumina calcination plant there are several mechanical constraints that need to be considered. These constraints depend on the specific characteristics of the plant, the retrofitting requirements, and the available space. Common mechanical constraints are space limitations, structural integrity, equipment compatibility, piping and ductwork modifications, electrical systems, Heat transfer considerations, Environmental factors and finally the maintenance access to ensure a proper operation and maintenance of the modified system. Safety aspects are of particular importance and will be addressed in a separate chapter (Chapter 5).

Retrofitting a combustion system involves integrating new equipment or modifying existing systems. Limited space can pose challenges in accommodating new components and ensuring proper layout and accessibility for maintenance. This is strongly linked to ensuring maintenance access, and escape routes. Adequate space, clearances, and safe access to equipment must be maintained to ensure ongoing operational and maintenance needs.

4.3.1 Structural Integrity

The existing structure of the calcination system must be assessed to ensure it can support any additional loads introduced by the retrofit. The structural analysis should consider factors such as increased equipment weight, vibration, and dynamic loads.

4.3.2 Equipment Compatibility

Retrofitting may involve integrating new equipment with the existing infrastructure. Compatibility between the new and existing systems is crucial to ensure proper functionality, such as aligning connection points, matching power ratings, and accommodating differences in size and configuration.

4.3.3 Piping and Ductwork Modifications

Retrofitting requires changes to the plant's piping and ductwork systems. Constraints may arise due to limited space, existing routing, clashes with other components, or the need to maintain adequate flow rates and pressure drops for the modified fuel system.

4.3.4 Electrical Systems

Retrofitting may involve modifications to the electrical systems, such as upgrading transformers, switchgear, or adding new generator units. Constraints in this area include electrical load distribution, available capacity, and maintaining proper grounding and safety measures.

4.3.5 Material Flow Considerations, Velocities, and Alumina Product Quality

State of the art calcination plants rely on efficient heat transfer processes and reliable material transport in the systems in venturi driers, lift ducts, air lift system, cyclones etc. Retrofitting will impact the flow behavior in a calcination system due to varying combustion air requirements and off gas quantities. Therefore, it is important to investigate velocities, heat transfer performance, and potential change in alumina product quality due to higher mechanical impacts.

4.3.6 Environmental Factors

Retrofitting must be compliant with environmental regulations, such as emission control measures or noise reduction. Meeting these requirements can introduce constraints related to space for additional pollution control equipment or noise mitigation measures.

These technical constraints must be investigated within a feasibility study prior to any execution project. There is no general and all fitting approach when retrofitting an alumina calcination plant. Each project will have its own unique set of challenges, and a thorough analysis and design process is necessary to overcome these constraints and ensure a successful retrofit. Safety requirements are changing over the years. Therefore, special attention shall be paid for compliance with current safety standards and elaborated in the following.

5. Safety Aspects

When switching fuels in an alumina calcination plant, safety considerations and compliance measures need to be considered. As a first step fuel compatibility must be ensured and investigated. This means that the existing equipment, including furnace, and fuel handling systems, must be compatible with the new fuel. Any modifications or upgrades to accommodate the specific characteristics of the new fuel, such as its heating value, viscosity, or sulphur content, must be thoroughly investigated in the initial concept phase.

The combustion characteristics of the new fuel, including its ignition characteristics, flame stability, and emissions profile needs to be studied. Combustion controls, burner settings, and air-to-fuel ratios must be adapted to the new fuel to ensure proper combustion, to optimize the combustion process and minimize emissions. In alumina calciners there are typically preheat burners (see Figure 4) and main burners installed, which must be separately evaluated.

The storage and handling requirements of the new fuel must be evaluated in terms of storage capacity, safety protocols, fire protection systems, etc. A hazardous area classification shall be performed according to established industry codes. The starting point is to identify sources of release of flammable gas, which may arise from normal and abnormal operation.



Figure 4. Startup burner using natural gas (Example from ETİ Alüminyum A.S. Multi-purpose GEN5 calciner)

Training and Safety Procedures must be provided to plant personnel regarding the safe handling, storage, and combustion of the new fuel. Standard operating procedures and safety protocols must be updated to address any specific considerations associated with the new fuel, such as storage guidelines, emergency response procedures, and personal protective equipment (PPE) requirements.

A thorough risk assessment must be conducted to identify potential hazards and develop mitigation strategies. Factors like fuel properties, transportation risks, storage risks, and operational risks associated with the new fuel shall be addressed and appropriate risk management measures must be implemented to minimize the likelihood and impact of accidents or incidents. During the fuel switch process and after its completion comprehensive testing and monitoring should be performed and key parameters such as emissions, combustion efficiency, equipment performance, and safety systems must be monitored to ensure that the alumina calcination plant operates safely and effectively with the new fuel.

The emergency response plan must be updated to include specific provisions for fuel-related incidents or accidents. This includes training of personnel on emergency procedures, escape routes, and handling fuel-related emergencies, such as fuel leaks, spills, or fires.

Fuel switching is not finished with the commissioning of the plant. Instead, regularly audits and inspections must be conducted to ensure ongoing compliance with safety regulations and environmental requirements. Operational practices, maintenance procedures, and safety protocols must be regularly reviewed to identify any areas that require improvement or corrective actions.

6. Support by CFD Simulation

Computational Fluid Dynamics (CFD) simulation is an integral part of today's design process. Fuel switching projects can be supported by CFD simulation, which is providing valuable insights into the flow and combustion characteristics of different fuels. The simulation requires accurate input data and validation against experimental results to ensure reliability.

The combustion process is modelled for the current and future used fuel, and if applicable for blending ratios, allowing to analyse parameters such as temperature distribution, reaction rates, velocities in the furnace and species concentrations. This information helps in understanding the combustion efficiency, pollutant emissions, and heat transfer characteristics. An example of a CFD simulation result is shown in Figure 5.

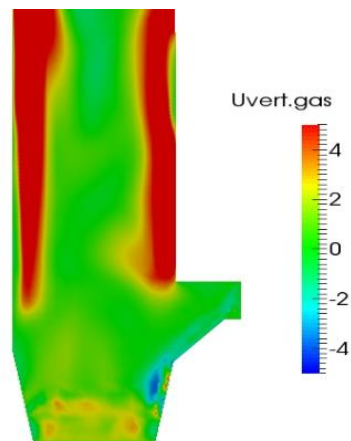


Figure 5. Performance of CFD to get temperature distribution, reaction rates, velocities and species concentrations of a calciner

By simulating fuel combustion in different configurations, CFD helps optimizing the design and operation of combustion systems. Burner design, fuel injection strategies, and combustion chamber geometry can be designed to maximize fuel efficiency, reduce emissions, and improve overall performance. CFD simulations allows also to provide predictions of pollutant emissions resulting from different fuel types and combustion conditions. This information helps in evaluating the environmental impact and compliance with emissions regulations.

7. Impact of Fuel Switching on Emissions

Depending on the fuel type fuel switching can significantly change the offgas properties and the emission profile. The main potentially harmful emissions of alumina calcination plants are Nitrogen Oxides (NOx), Carbon Monoxide (CO), Particulate Matter (PM) and Sulphur Oxides (SOx). Depending on the fuel type other emissions from combustion processes are released to the

atmosphere including dioxins, furans, PAHs (polyaromatic hydrocarbons), VOCs (volatile organic compounds) and heavy metals. Usually NO_x, CO, PM and Sulphur Oxides are subject of regulatory emissions limits. Although the CO₂ emissions are not directly regulated, there are clear ambitions among producers to reduce these as well [13].

Different fuels have different compositions, which results in variations in the offgas composition. For example, switching from a high-sulphur fuel (e.g. Heavy fuel oil HFO) to a low-sulphur fuel will significantly reduce sulphur dioxide (SO₂) emissions, leading to improved air quality. Similarly, changes in the carbon content of the fuel will affect the emissions of carbon dioxide (CO₂) and carbon monoxide (CO). The emission level is depending on the combustion characteristics and chemical composition of the fuel used and must be investigated.

The example of fuel switching from HFO to natural gas and the changes in emissions can be seen from Figure 6. HFO with its high sulphur content was polluting environment in the past. The sulphur content in HFO is significant (up to 5 % by mass) and the combustion reaction results in the formation of sulphur dioxide SO₂. Released to the atmosphere it will eventually lead to the formation of acid rain (via sulfuric acid). Using natural gas instead of HFO will completely avoid -sulphur dioxide (SO₂) emissions as natural gas contains virtually no sulphur.

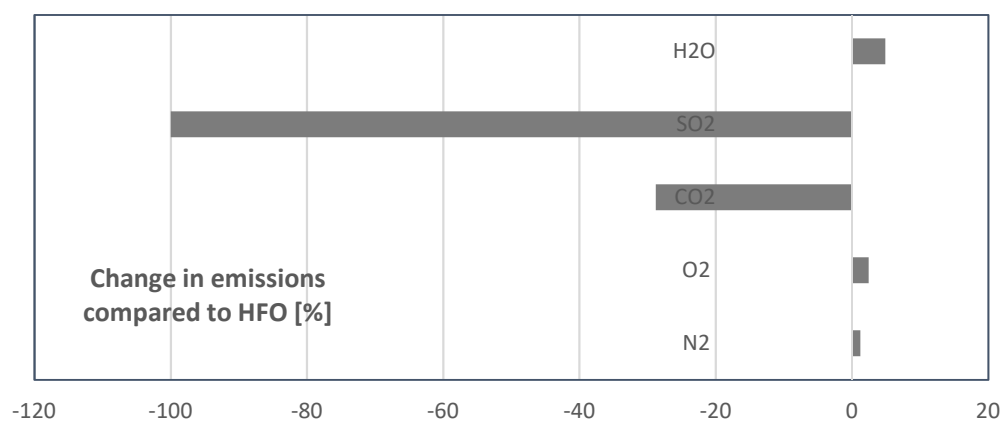


Figure 6: Comparison of emissions from HFO and natural gas; change in emissions in % relative to HFO.

8. Summary and Conclusions

Fuel switching refers to the transition from one fuel type to another aiming at reducing emissions and improving environmental sustainability. The conclusions from fuel switching in the alumina industry depends on several factors such as the type of alternative fuel used, the current efficiency of the process, and the scale of implementation. Generally, the following conclusions can be drawn:

- **Reduced greenhouse gas emissions:** By switching to cleaner energy sources, the alumina industry can lower its carbon footprint and contribute to mitigating climate change.
- **Mechanical constraints:** Retrofitting a combustion system involves integrating new equipment and modifying existing systems. Adequate space, clearances, and safe access to equipment must be maintained to ensure ongoing operational and maintenance needs.
- **Plant Safety:** When switching fuels in an alumina calcination plant, safety considerations and compliance measures need to be addressed. A risk assessment must be conducted to identify potential hazards and develop mitigation strategies. The implementation of updated control systems system (like a safety instrumented system) and ensuring compliance with current standards can be challenging but is unavoidable.

Fuel switching from heavy fuel oil to natural gas is a bridging technology; the next step to significantly reducing carbon emissions is achieved by using carbon free fuel sources.

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