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1 EXECUTIVE SUMMARY

The goal of the RETROFEED project is to successfully lead resource and energy intensive industries towards adopting more sustainable business practices, through optimization of their resource and energy consumptions. Six companies from five different industrial sectors have decided to participate as demonstrators and provide their technical know-how:

- TORRECID S.A. in the ceramic frits sector
- SECIL Companhia Geral de Cal e Cimento, S.A. in the cement sector
- ASAS Aluminyum Sanayi Ve Ticaret Anonim Sirketi in the aluminum sector, with support of Sistem Teknik
- FERRIERE NORD S.p.A. supported by HTT Engineering, spol. s.r.o. and TENARIS SILCOTUB S.A. in the steel sector
- FERTIBERIA S.A. in the agrochemicals sector

Core processes within the involved industrial sectors will be modified and advanced control and monitoring systems implemented to ensure adequate integration of the retrofitted equipment without changes in productivity. To facilitate adoption of new practices and aid in decision-making, a decision support system will be developed within each industry to respond to different key performance indicators which will be properly identified. Ultimately, the goal of RETROFEED is to provide industries with the necessary tools and strategies to incorporate variable, preferably biobased feedstock, leveraging on circular economy opportunities.

Although industrial sectors may seem disparate, some up to a greater extent, some commonalities have been established between their business as usual practices and their expectations from RETROFEED. This report aims to identify how transferrable RETROFEED solutions are between the involved industrial sectors, and whether any industrial symbiosis relationships could arise between partner industries.

2 ABBREVIATIONS

Abbreviation	Meaning
API	American Petroleum Institute
ASAS	ASAS Aluminyum Sanayi Ve Ticaret Anonim Sirketi
CO	Carbon monoxide
DSS	Decision Support System
EAF	Electric Arc Furnace
FENO	FERRIERE NORD S.p.A.
FTIB	FERTIBERIA S.A.
HTT	HTT Engineering, spol. s.r.o.
IT	Information Technology
NPK	Nitrogen-Phosphorus-Potassium
REII	Resource and Energy Intensive Industry
SDGs	Sustainable Development Goals
SECIL	SECIL Companhia Geral de Cal e Cimento, S.A.
SILCOTUB	TENARIS SILCOTUB S.A.
STEK	Sistem Teknik
TCID	TORRECID S.A.
TOC	Total Organic Carbon
VOC	Volatile Organic Compound

3 INTRODUCTION AND OBJECTIVES

The 2030 Agenda for Sustainable Development was conceived as a call for action to promote development of key focus areas critical to achieving world-wide evolvement towards sustainable practices at economic, political, social and environmental levels [1]. Seventeen Sustainable Development Goals (SDGs) were outlined and adopted by the United Nations constituting members, committed to coordinate national and international efforts to mitigate poverty, end inequalities, pursue climate action, prevent environmental degradation and secure both peace and justice [2]. Efficiency enhancement of industrial practices through unrivalled innovation is one of RETROFEED pillars, where core processes in characteristic resource and energy intensive industries (REIIs) will be retrofitted to accommodate alternative feedstock, either biobased or resulting from circular economy practices, and reduce the energy and emissions tolls on the production processes. State-of-the-art monitoring and programming tools will be developed for successful and forthwith adoption of new practices, and will comprise part of a vast information network feeding decision-support systems (DSS) that will guarantee sustained optimization of plant performance. In this way, RETROFEED addresses many of the SDGs pursuits, particularly those within goals number 9, 12 and 13: “Industry, Innovation and Infrastructure”, “Responsible Consumption and Production” and “Climate Action”. Energy and resource efficiencies will be boosted by 19% and 22%, respectively, whereas a reduction of 135 annual kton of greenhouse gases emissions is expected once solutions are implemented.

Transitioning between industrial practices is a complicated endeavor that involves identifying opportunities for change, implementing process modifications, adapting production to the new conditions, and training personnel. The RETROFEED project is aimed at providing strategies for bridging the gap between purposeful innovation and successful implementation, with the ultimate goal of achieving the energy, material and emissions objectives delineated before. To demonstrate the power of the retrofitting solutions, six production facilities in different sectors have decided to participate and cooperate through sharing their expertise in their respective areas:

- **TORRECID S.A.** (TCID) in the **ceramic frits** sector
- **SECIL Companhia Geral de Cal e Cimento, S.A.** (SECIL) in the **cement** sector
- **ASAS Aluminyum Sanayi Ve Ticaret Anonim Sirketi** (ASAS) in the **aluminum** sector
- **FERRIERE NORD S.p.A.** (FENO) and **TENARIS SILCOTUB S.A.** (SILCOTUB) in the **steel** sector
- **FERTIBERIA S.A.** (FTIB) in the **agrochemicals** sector

These facilities share that either their processes rely heavily on fossil fuels to meet the energy demand of the production process and/or their feedstock is limited to a few options due to infrastructure and consequent process adaptation constraints. Activities within RETROFEED are

aimed at overcoming these obstacles through interdisciplinary collaboration of multiple stakeholders in the applied research, IT systems development and process engineering fields.

Following a thorough characterization of the main processes in each industry, synergies and complementarities between RETROFEED activities have been identified. This exercise was mainly concerned with studying how replicable changes in one sector are across other involved sectors, and whether participating industries could benefit from by-products or wastes being produced by their project partners.

4 INDUSTRIAL SECTORS REVIEW

RETROFEED is targeted at optimizing energy and material uses in REIIs. Although pathways to achieve these goals are varied among the different participating industries, achieving more efficient energy and materials management practices whilst reducing cost and controlling emissions are common to all. The strategy for integration of these new practices consists on application of advanced control and digitalization tools that will regulate and replicate performance, respectively. The data generated by these systems will provide higher accuracy and flexibility to the decision support systems to be developed, to assess different operative scenarios.

4.1 TORRECID – Ceramic frits industry

TORRECID is a Globalized Multinational Business Group dedicated to providing products and services to the ceramic and glass sectors in 28 countries around the world. The headquarters are located in Alcora (Spain) (Figure 1), where main investigations and developments are centralized.

Figure 1. Headquarters of TORRECID Group

TORRECID Group offers a wide selection of frits and glazes for ceramics and glass (Figure 2). Frits are a homogeneous melted mixture of inorganic materials that are used in enameling iron and steel and in glazing porcelain and pottery. Glazes are vitrifying suspensions containing frits and other raw materials, like colour stains, salts and additives, among others, that when going through a milling process and applied in small particles on ceramic support, allow different finishes depending on the formulation and raw materials used.

Figure 2. Frits and glazes

TORRECID facilities in Alcora produce 8,000 tons of ceramic frits annually. Frits are prepared by fusing raw materials in a furnace at high temperature. The molten material is then water quenched causing the melt to solidify rapidly and shatter into friable particles or frits. Frits are dried and post-treated resulting in a high variety of products.

4.1.1 Targets & expected outcomes of the retrofitting

The objective of the RETROFEED project at TORRECID's demo-site is **to retrofit a ceramic smelter through the development of automated monitoring and control solutions to adapt the furnace towards reducing waste and emissions, as well as material and energy consumptions in the overall process**. These objectives are expected to be accomplished by adequately controlling materials inflow to and outflow from the furnace, adjusting combustion and quenching water flows to frit composition and production rate and exploiting heat recovery from flue gases.

4.2 SECIL – Cement industry

SECIL was founded in 1930 and is today one of Portugal's leading cement producers. With an annual output of 4 million tons of cement, it meets more than 35% of the country's demand for this product. Although cement production is its core business, SECIL lies at the heart of a group of around 40 companies operating in complementary areas such as concrete, pre-fabricated concrete products, hydraulic lime, plasters, claddings, among others, as well as quarrying.

SECIL Group has a strong international presence, with 8 plants in 7 different countries in 4 continents. The total installed capacity is approximately 9.6 million tons, with 3 facilities in Portugal (Figure 3), 2 in Brazil and 1 in Tunisia, Lebanon and Angola, respectively.

SECIL has contributed with its products to emblematic works in Portugal such as the Dams of the "Douro Internacional" National Park, Arrábida, "25 de Abril" and "Vasco da Gama" bridges, the "Gare do Oriente" station, "Bairro dos Olivais" and Alvalade neighborhoods, the port of Setúbal, the Alqueva dam, numerous bridges and viaducts of the National Highway Network, buildings like the Ritz, the headquarters of the newspaper "Diário de Noticias", and the football stadiums in Braga, Luz and Setúbal.

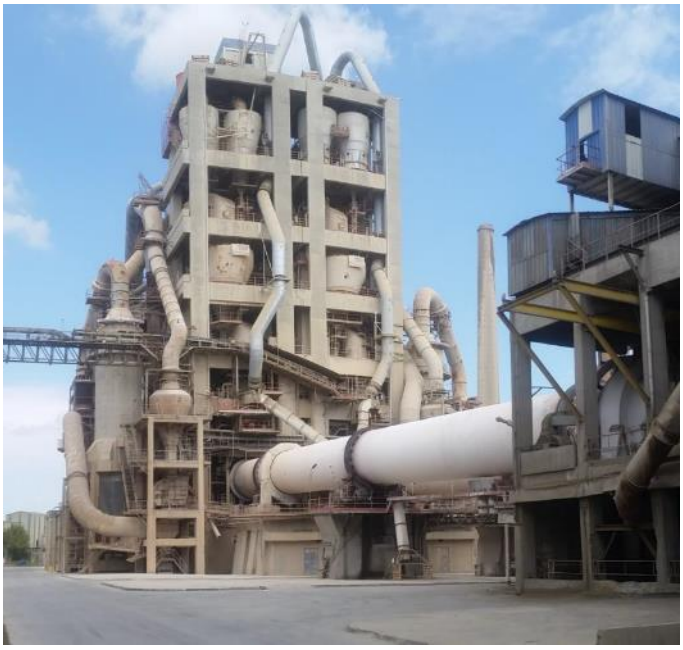

Figure 3. Kiln and cyclone pre-heaters view at SECIL plant in Maceira Liz

4.2.1 Targets & expected outcomes of the retrofitting

At SECIL plant in Maceira-Liz, the main goal is **to reduce greenhouse gases emissions associated to clinker production**. Abatement of pre-combustion emissions will be targeted by **replacing fossil fuels with wastes and biobased sources**. **A new burner will be designed** to adapt its functioning to the new fuels. **Novel sensors** aimed at checking quality of alternative fuels and final product will be installed and **flame visualization tools** developed to ensure adequate combustion conditions and that the produced clinker and alternative fuels conform to the standards.

4.3 ASAS – Aluminum industry

Since its establishment in 1990 in Gebze, Turkey, ASAS has become one of the leading aluminum products manufacturers in Europe, carrying out exports to more than 80 countries all over the world [3]. In 2015, the total revenue from international operations was estimated at 83 million USD and the company's annual turnover approached 400 million, with this value increasing by roughly 26% every year [4][5]. ASAS counts with five distinct production facilities: aluminum extrusion, aluminum flat rolled products, aluminum composite panel, PVC profile and roller shutter. These premises take up 300.000 m^2 of built land and their yearly production starts at 25,000 tons for some products, amounting to 120,000 tons for others.

RETROFEED activities will take place at the Aluminum Extrusion Production Facility (Figure 4), where profiles are manufactured at an annual production rate of 75,000 tons. In the same complex, surface treatment of the profiles takes place, with anodic oxidation totaling 40,000 t/year and glossing and painting 25,000 t/year. Profiles can be converted into tailored end products demanded by clients in the mechanical treatment facility.

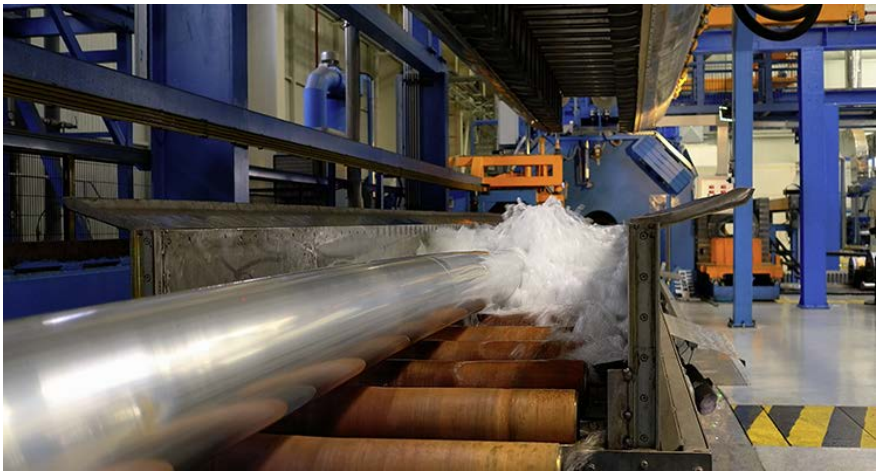

Figure 4. Aluminum extrusion facilities at ASAS

4.3.1 Targets & expected outcomes of the retrofitting

ASAS' goal is t**o reduce the energy consumption of the aluminum production process by increasing the amount of scrap the process can admit, thus reducing the proportion of aluminum ingots fed to the smelter**. An **O_2 injector will be coupled to the furnace** to regulate combustion conditions and emissions generation once changes in feedstock occur. To expand the availability of scrap that can be used, a **delacquering system** to remove surface contamination will be developed and implemented, alongside sensors to monitor both oxygen levels inside the furnace and total organic carbon (TOC). Removal of contamination from the surface of aluminum scrap leads to the generation of volatile organic compounds (VOCs), carbon monoxide (CO), hydrocarbons. The delacquering unit will contemplate these effects and through adjustment of the combustion process and selection of the best route for the combustion gases, regulate emissions.

4.4 FERRIERE NORD & TENARIS SILCOTUB – Steel industry

FERRIERE NORD

FERRIERE NORD S.p.A., founded in the sixties, is nowadays the leading company of the Pittini Group, an international firm that operates in the field of steel mainly for building purposes. This leadership is consolidated in the field of highly safe and highly ductile steel for reinforced concrete, bearing the HD®Pittini trademark.

FERRIERE NORD S.p.A., with two manufacturing facilities in Osoppo and Potenza, can rely on two electric steel mills, two rolling mills for the production of steel bars and coils for reinforced concrete, one rolling plant for wire rod and several plants for the production of meshes and lattice girders (Figure 5). FERRIERE NORD S.p.A. steel production in the Osoppo site reaches 1.5 million tons per year using a single Electric Arc Furnace (EAF) charged with scrap.

Figure 5. (a) Burner view inside EAF (b) Scrap charging into EAF (c) Wire rod rolling mill

TENARIS SILCOTUB

Through its mills in Zalau and Calarasi, TENARIS is the leading Romanian producer of small diameter seamless steel pipes used in Oil & Gas, mechanical, automotive, chemical, petrochemical and power generation sectors.

The mills are part of a fully integrated production process, starting with steel production from scrap at the steel shop in Calarasi, which has a production capacity of 600,000 tons a year. Transformation of raw material into seamless pipes is performed at the TENARIS SILCOTUB facility in Zalau, which has an annual capacity of 225,000 tons and counts with a component center dedicated to executing added value operations to the tubes, to obtain components to be employed in the automotive and earth moving machineries sectors, as well as a new laboratory which performs metallurgical and mechanical tests. There is also a coupling shop which does API and Premium connection threads, responding to the requirements of Oil & Gas companies.

Figure 6. Electric arc furnace at TENARIS SILCOTUB

4.4.1 Targets & expected outcomes of the retrofitting

An EAF (Figure 6) requires both electrical and chemical energy to achieve suitable melting conditions for steel scrap. While the former is employed in electrode polarization and generation of the electric arc, the latter is mainly supplied to the system through burners which employ primarily fossil fuels. The main goal of FERRIERE NORD and TENARIS SILCOTUB is **to reduce their reliance on fossil fuels to achieve the required thermal and material conditions inside their EAF furnaces.** FERRIERE NORD intends to accomplish this through the design of **a new burner** where natural gas

will be replaced with biochar and plastics as fuels, and modification of an injector to accommodate biochar feeding to the EAF in place of anthracite. On the other hand, TENARIS SILCOTUB plans to develop **an injection lance** that can blow rubber and plastics to the melt to supply additional chemical energy, as well as sludges and EAF dust to replace raw materials.

4.5 FERTIBERIA – Agrochemicals industry

FERTIBERIA Group is a Spanish fertilizer producer, and one of the leading international providers of ammonia and its derivates. FERTIBERIA and its subsidiaries' fertilizer production capacities amount to 75% of the total production in Spain and 100% in Portugal. In addition to fertilizers, the company produces and sells chemicals for gardening enthusiasts and industrial applications, with a total annual revenue estimated at €858 million, with direct application fertilizers representing 65% of the total.

Fourteen factories distributed across Spain, Portugal and France comprise the production network of roughly 8 million annual tons of fertilizer products. The FERTIBERIA CLASSIC area, specialized in producing solid fertilizers for direct soil application, is the firm's most iconic and well-recognized branch. Practically all facilities have the capacity to fabricate these kinds of products, which are categorized into simple and complex based on their composition. Simple fertilizers include urea and compounds exclusively composed either of nitrogen (N) or phosphorous (P), whereas their complex counterparts contain different proportions of N, P and potassium (K), as well as other additives. The Huelva plant in Spain (Figure 7) is one of the main manufacturers of complex NPK (nitrogen-phosphorous-potassium) products, with an annual production of 250,000 tons.

Figure 7. Aerial view of FERTIBERIA plant at Huelva.

4.5.1 Targets & expected outcomes of the retrofitting

RETROFEED is aimed at modifying process conditions at the NPK production facility at Huelva, **to expand its feedstock processing capabilities thus allowing to replace several raw material imports with biobased wastes and by-products from other industrial sectors**. **Advanced**

process monitoring and control tools will be deployed for successful integration of these changes to full-scale production without affecting productivity and compromising the company's environmental policy, strictly focused on controlling emissions and waste generation. In fact, FERTIBERIA plant at Huelva is a zero-waste facility: there are virtually no material losses, since products falling out of specification are recycled and reused, and water uses and emissions are regulated under stringent operating limits. RETROFEED modifications are expected to reduce the process' energy toll and raw materials consumption, associated costs and increase industrial symbiosis and waste valorization opportunities between industries.

5 IDENTIFICATION OF SYNERGIES ARISING FROM THE RETROFITTING

Successful implementation of RETROFEED solutions is contingent upon features common to all industries, pertaining to the following areas:

- Alternative raw materials quality
- Sufficient energy generation to replace traditional supply sources
- Final product quality assessment

In cases where fuels are intended to be replaced, quality assurance of raw materials substitutes is critical to attain satisfactory results without compromising performance. Therefore, industries such as TENARIS SILCOTUB and FERRIERE NORD could greatly benefit from the online quality verification tools to be installed at SECIL, aimed at estimating the lower heating value of the alternative fuels. Installing such measuring devices could potentially broaden the plants' autonomies in terms of feedstock processing and selection, without having to recur to third parties for fuel conditioning. Sustained and reliable provision of fuel could allow to expand the scope of RETROFEED solutions in these industries, to be replicated in several production units without risk of failure. The clinker characterization tools to be developed at SECIL may also become valuable for TORRECID for quality assessment of the vitrified products, which could be performed in an analogous way to clinker, since crystal structures and covalent bonds are intended to be identified.

At the same time, the flame visualization tool and the multi-fuel burner to be developed at SECIL could potentially be adapted and replicated in ASAS and TORRECID, to expand their fuel flexibility and combustion diagnosis strategies. Developments on the burner to be designed at FENO could also be leveraged upon to serve as a model for these industries to incorporate alternative feedstock in their burners. It goes without saying, that solutions are directly transferrable from one steel industry to the other.

TENARIS SILCOTUB also plans to push further its circular economy capabilities through valorizing EAF dust as raw material. At SECIL, flue dust is also a considerable by-product of the rotary kilns and is currently valorized in a production facility within the firm. These possibilities shed light on the opportunity for metal processing facilities like ASAS and even TORRECID, to find value in the metal-rich dusts resulting from the smelting processes. However, extrapolation of these initiatives is by no means straightforward since adequate delineation of purification strategies and tradeoff analysis are required to render valorizing dusts as a viable alternative.

Although EAFs operate at virtually 100% scrap, the delacquering system to be developed at ASAS alongside the TOC analyzer may become valuable resources for the steel shops, if it is determined that a higher degree of scrap cleaning could positively affect the yield and the emissions generated from the burning of surface contamination.

All the involved processes rely on chemical energy to achieve the required thermal conditions in the process equipment. FERTIBERIA intends to implement a heat generating reaction that can supply about three times the energy currently being supplied to their process. Although not directly transferrable to other sectors, this innovation sheds light on the technical feasibility and broad versatility of chemical reactions which can be easily tailored to meet process demands.

6 IDENTIFICATION OF INDUSTRIAL SYMBIOSIS OPPORTUNITIES

Industrial symbiosis is the act of valorizing waste or by-products from certain industries to turn into usable raw materials for others [6]. The process lies at the heart of circular economy principles, preserving resource availability, enhancing utilization efficiency and reducing associated production expenses. Although valorizing by-products may seem logical from a technical standpoint, there are geographical boundaries which should be accounted for when assessing the viability of the proposed interactions. Within RETROFEED, unless raw materials are imported from distant locations from the plants' headquarters and/or transportation expenses and associated emissions justify the implied costs, it is unlikely that industries will incur in savings by utilizing by-products or wastes produced by their project partners. Still, market prices and trends as well as geographical considerations should be carefully assessed, to detect potential synergies between members of the consortium. Nonetheless, the guidelines presented herein could be adopted by industries belonging to the same industrial sectors as RETROFEED partners, which may be strategically located to fully take advantage of these opportunities.

It must be emphasized that virtually all industries participating in RETROFEED either possess on-site facilities for treating their waste or are associated to other third parties who focus on making a profit out of it. Yet, some alternatives could still be explored:

- Industrial grade lime is a raw material common to many industries participating in RETROFEED. The wastewater at TORRECID is rich in this product, and its recovery highly plausible since it is a matter of choosing adequate water treatment/brine management technologies for this purpose.
- Applications for the EAF dust may be explored further, especially if combined with wastewaters generated from steel polishing. This way, some heavy metals could potentially be lixiviated leaving a stream rich in valuable compounds for plant growth such as zinc, iron, and manganese.
- The slag produced in ASAS may have potential to be incorporated as a raw material at TORRECID, where aluminum oxide is used as feedstock for frit production. This compound is also present in the slags of FERRIERE NORD and TENARIS SILCOTUB (though in lower quantity, still considerable), as well as other metal oxides which may also be adapted for use in the ceramic frits process. With adequate treatment, these oxides could also be turned into salts FERTIBERIA employs in fertilizer formulations, such as aluminum sulfate. Proper assessment of this possibility should be carried out to determine the technical and economic viability of the implicated separation and purification methods.
- The slag at ASAS could also find use in the steel plants, where aluminum oxides aid in slag formation in the EAFs, and aluminum is employed in steel killing (removing excess oxygen from the molten metal). The use of waste frit produced at TORRECID in the steel industry could also be assessed since this material is rich in various refractories containing silicon, magnesium, aluminum, among others.

It is evident there is great potential for the industrial sectors involved in RETROFEED to interact with one another. For proper evaluation of these alternatives, a thorough understanding of the feedstock conditions that must be met for each specific case is necessary, and the analysis complemented with market and price trends. Ultimately, the exploration of these options is contingent upon leveraging tradeoffs in costs associated to capital, emissions and energy savings accomplished through replacing raw materials while incurring into additional expenses for required pre-treatment operations.

7 CONCLUSION

After thoroughly analyzing activities to be carried out as part of RETROFEED, a synergies and complementarities analysis was performed, and the actual significance of RETROFEED solutions realized. RETROFEED marks a breakthrough in the ways of meeting the demands of REIIs, bolstering plant efficiencies through innovative, tailored actions whose repercussions extend far beyond the plant where they are intended to be implemented. These findings open a wide horizon of possibilities to drive change and adopt increasingly sustainable practices. Moreover, it is expected that by the end of this project, industries will have been presented with a new perspective to detect profitable opportunities from what they once regarded as waste, becoming fully aware of the benefits of a circular economy.

Overall, thanks to the close collaboration of all involved parties, RETROFEED will provide by the end of the project, a methodology to strategically overcome the challenges of Industry 4.0, ensuring flawless adoption of new practices and sustained performance over time.

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