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Circular carbon and electrified heat: carbon neutral syngas heated by Paul Wurth Tempra to reduce blast furnace CO_2 emissions

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Decarbonizing existing blast furnaces (BFs) is a central challenge for integrated steel producers pursuing climate neutrality while preserving asset value and production continuity. This paper presents an integrated, retrofit focused pathway combining Paul Wurth EASyRedgas: thermal dry reforming of coke plant by products with the Paul Wurth Tempra electric gas heating system, implemented within a Top Gas Recycling (TGR) configuration with CO_2 removal. The approach converts internal carbonaceous waste streams into a high-quality syngas feed, electrifies the high temperature conditioning of that gas, and enables staged incorporation of hydrogen and CO_2 management to achieve significant Scope 1 CO_2 reductions with limited CAPEX risk and competitive OPEX. The anticipated benefits of retrofitting this technology into existing BF-based integrated plants are substantial. By incorporating this method into the decarbonization roadmap, plants can achieve a marked decrease in carbon emissions, contributing to a more sustainable steel production. The paper will detail the results obtained so far and outline the expected future outcomes, emphasizing the role of this technology in the industry's transition towards greener practices. This paper highlights a crucial step in the decarbonization of steel production, offering a cost-effective solution that aligns with global sustainability goals.

KEYWORDS: BLAST FURNACE; CO_2; CIRCULAR CARBON; SYNGAS.

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FOREWORD

Blast furnace (BF)-based steelmaking remains the dominant route for primary steel production, driven by high productivity, flexible iron ore sourcing, stable hot metal quality, and energy self sufficiency enabled by coal derived by product gases. Modern blast furnaces routinely achieve production levels of 4.5-5.0 MTPA with competitive operating costs, particularly in regions without CO_2 taxation. At the same time, the BF route faces increasing pressure due to its relatively high carbon footprint, which depends on raw material quality and operational efficiency. Reducing CO_2 emissions while preserving the intrinsic advantages of blast furnace ironmaking is therefore a key challenge for integrated steel producers.

RATIONALE FOR THE EASYREDGAS TECHNOLOGY DEVELOPMENT

Coke remains an unavoidable carbon source in the BF process, making the integration between coke making and ironmaking central to any decarbonization strategy. Coke plants generate three major carbon bearing by products: coke oven gas (COG), coal tar and coke fines. COG, rich in H_2 and CH_4, has traditionally been used as a fuel in reheating furnaces and captive power plants, but its availability for metallurgical use is increasing as alternative fuels emerge and renewable electricity replaces internal power generation. Coal tar faces declining market potential due to regulatory constraints, while coke fines—unsuitable for direct BF charging—are increasingly surplus due to declining sinter capacity and emerging alternative agglomeration routes. These trends favor coordinated reuse of coke plant by products within the blast furnace process.

EASYREDGAS CONCEPT

To address this opportunity, SMS developed Paul Wurth EASyRedgas technology [1], which converts COG together with coke plant residues (coal tar and/or coke fines) into a hot reducing gas (See figure 1).

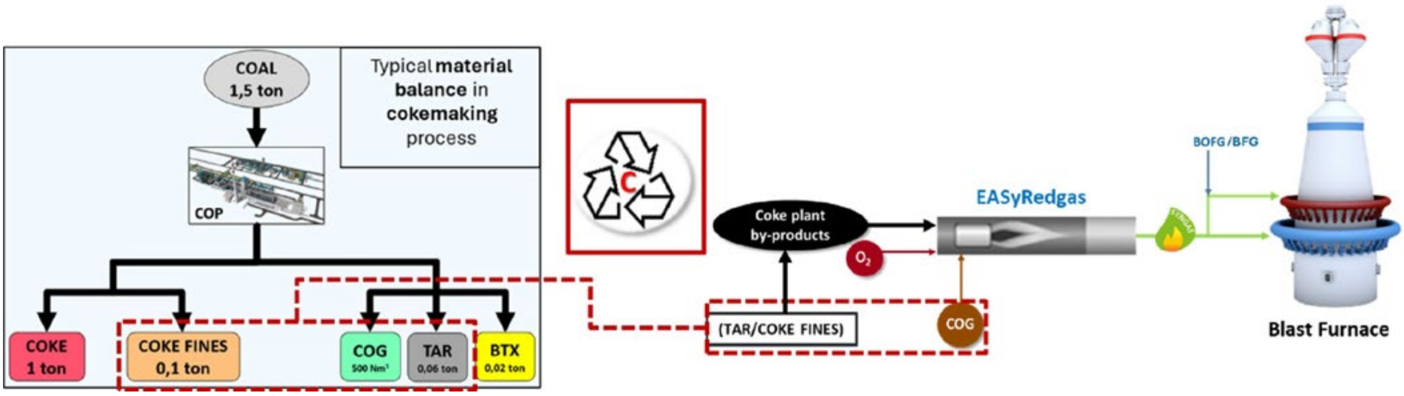


Fig.1 - Concept of the EASyRedgas technology.

The process is based on high-temperature thermal dry reforming, using mainly CO_2 generated by oxy-combustion of recycled by-products to reform hydrocarbons into a syngas rich in CO and H_2. The resulting syngas is suitable for direct injection into the BF shaft or tuyeres, with shaft injection identified as the preferred retrofit option (see figure 2). Thermal Reforming removes heavy hydrocarbons and suppresses soot formation, enabling injection at temperatures comparable to the ones existing lower BF shaft (900-1000 °C) without disturbing the thermal balance of the BF shaft, once the syngas stream is mixed with cold BF gas or BOF gas.

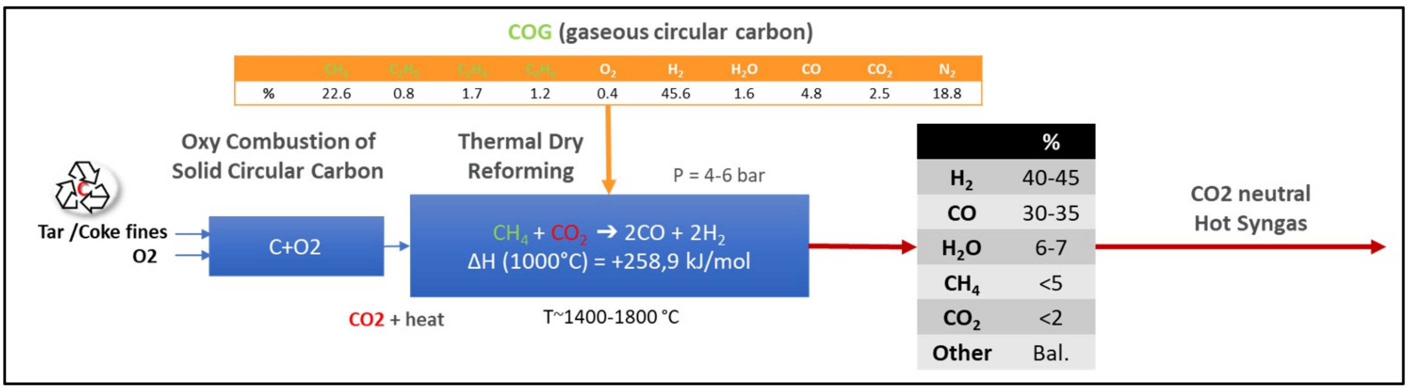


Fig.2 - Process scheme of EASYREDGAS.

EASYREDGAS TECHNOLOGY VALIDATION

Following process modeling and thermodynamic assessment, SMS group designed and operated an industrial pilot plant to validate the technology. Pilot campaigns conducted in 2024 ITALIANA COKE industrial coke oven plant Italy demonstrated stable production of hot syngas with suitable composition and temperature, refractory integrity of the reactor, and no significant soot formation using industrially produced COG and COAL TAR. Thanks to these results, EASyRedgas reached Technology Readiness Level 6 (TRL 6), confirming its suitability for industrial application under realistic operating conditions [1].

EASYREDGAS APPLIED TO BLAST FURNACE DECARBONIZATION

EASyRedgas can play a key role in the decarbonization of the BF based steel production route, due to several distinctive features. It utilizes input streams already available within the plant enabling energy and resource autarky for the adopting steelworks. A further advantage is input material flexibility enabled by material balance neutrality: when coal tar or coke fines are profitably sold on the market EASyRedgas can replace them with external carbon sources in equivalent amounts without affecting the overall CO_2 balance thus keeping its decarbonization potential. The hot syngas produced is suitable for BF shaft injection in terms of temperature and composition ensuring a reduction in coke rate implying and a net CO_2 emission decrease of approximately 7%. Finally, the industrial design features a limited footprint achievable through a vertical arrangement, making it suitable as an add-on retrofit for existing BFs which often have congested layout.

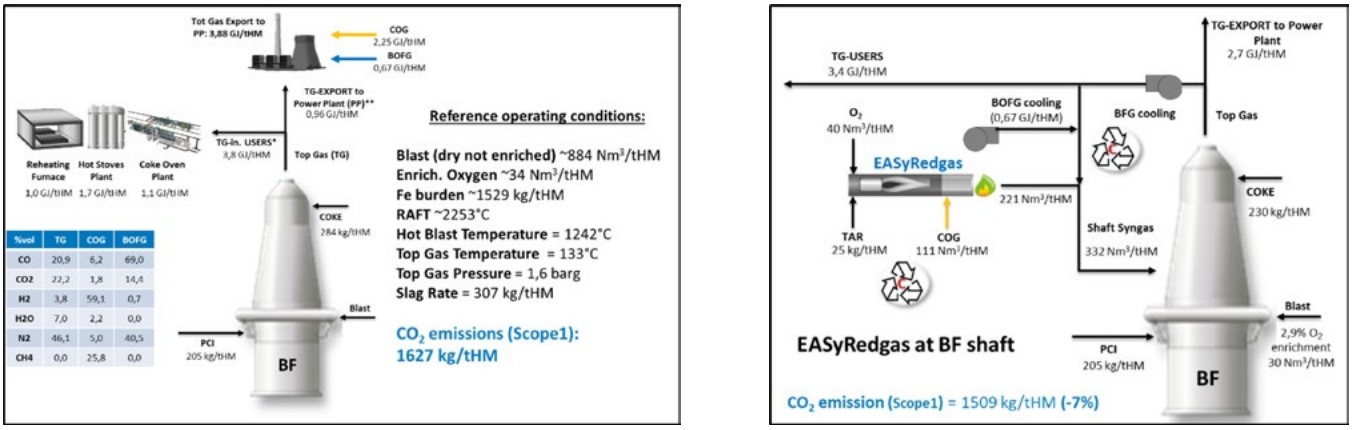


Fig.3 - EASyRedgas as first step for BF decarbonization.

EASYREDGAS WITH PAUL WURTH TEMPRA IN A TOP GAS RECYCLING BF

Figure 3 illustrates the potential CO_2 reduction through BF shaft syngas injection using EASyRedgas as an add on technology. To further advance BF decarbonization, process electrification must take center stage. In response SMS has developed Paul Wurth Tempra, an electric gas heating technology enabling high efficiency, fossil-free heating for the next Blast Furnace decarbonization step where recycled top gas must be heated above 1000°C. Tempra has unique technical features: It is scalable, up to 30 to 40 MW per unit, highly efficient, with 97% energy efficiency proven in a 0.5 MW pilot plant operated for over 1000 hrs in the RINA CSM test center in Castel Romano (Italy) (figure 4); versatile, as it can work with multiple gases (hydrogen, air, steam and various combination of CO, CO_2 H_2, N_2 and H_2O) and supports process stability, thanks to a robust response to process fluctuations.

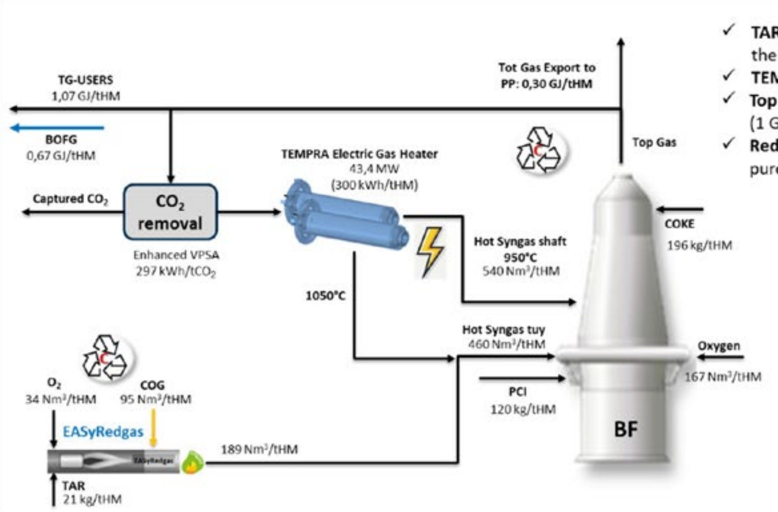
TEMPRA pilot unit -Castel Romano-Italy

TEMPRA PILOT UNIT DATA

Power	0.5 MW
Voltage (ph-ph)	690 V
Design Pressure	10,2 bar (g)
Gas outlet temperature	1080 °C
Shell temperature	101 °C max.

Fig.4 - TEMPRA Pilot Plant in Castel Romano (Italy).

If Tempra and EASyRedgas are combined in a top gas recycling BF configuration where CO_2 in the recirculated top gas is removed in a dedicated unit, the resulting process scheme is shown in figure 5.



- ✓ **TAR** and **COG** are consistent with the COP production needed for the BF specific running conditions.
- ✓ **TEMPRA** allows to avoid the **top gas consumption** in **hot stoves.**
- ✓ **Top Gas USERS:** Coke oven plant (0,7 GJ/tHM), Reheating furnaces (1 GJ/tHM) consistent with production requirements.
- ✓ **Reduced gas export to power plant** compensated by externally purchased power

CO_2 emission (Scope1) = 1139 kg/tHM (-30%)

%vol	TG	COG	BOFG	Syn_Shaft	Syn_Tuy
CO	43,7	6,2	69,0	65,0	52,4
CO2	31,1	1,8	14,4	6,5	4,1
H2	15,7	59,1	0,7	23,4	36,6
H2O	7,0	2,2	0,0	1,5	3,1
N2	2,4	5,0	40,5	3,6	2,9
CH4	0,0	25,8	0,0	0,0	0,8

Fig.5 - Electrically heated -Top Gas Recycling BF: E-TGR BF with EASyRedgas.

The denomination E-TGR stands for Electrically Heated Top Gas Recycling and derives from the adoption of Tempra in the gas heating stage. In this scheme, oxygen is used instead of hot blast, avoiding high nitrogen content in the recirculated gas to improve process efficiency. Tempra enables direct electrification of gas heating, so the BF top gas is no longer consumed in hot stoves. The coke rate is reduced to 196 kg/tHM with PCI of 120 kg/tHM.

With this setup, CO_2 emissions drop by 30%, keeping the delivered energy through internal gases to the internal users at the required amount. This step demonstrates how the combination of circular carbon, advanced electrification, and efficient gas management delivers a major reduction in CO_2 emissions from a BF plant, relying solely on in plant energy sources and electricity.

RE-PURPOSING OF EXISTING BF ASSETS BY MEANS OF TEMPRA TO INCREASE COST EFFICIEN-CY

In a Top Gas Recycling BF configuration with Tempra as recirculated gas heater, the existing hot stoves—used for Blast heating in conventional BFs—becomes redundant in the process loop shown in figure 5. These units can therefore be re-purposed as Thermal Energy Storage (TES) enabling a cost efficient of time-dependent renewable electricity, from captive wind and solar sources. Leveraging its long-standing BF expertise, SMS group has verified that the existing hot stoves, when operated as regenerative heat exchangers, provide sufficient capacity to store 10-12 hours of energy required to meet process gas heating demand in the configuration of figure 5. Coupling

Tempra as the renewable electricity based heat source with repurposed hot stoves as TES, results in a cost efficient gas heating system that exploits day-night electricity price variations.
Figure 6 shows the two operating modes: on the left, during periods of low-cost renewable power, energy is stored in repurposed hot stoves; on the right, when electricity prices rise, the stored heat is used to keep the process running efficiently though a proprietary gas -gas heat exchanger. This approach keeps a CO_2 reduction of approx. 30% while delivering significant OPEX savings lowering electricity cost. Re-tasking hot stoves to TES, makes decarbonization practical and cost-effective for existing BFs, supporting efficient and process continuous electrification through renewable power.

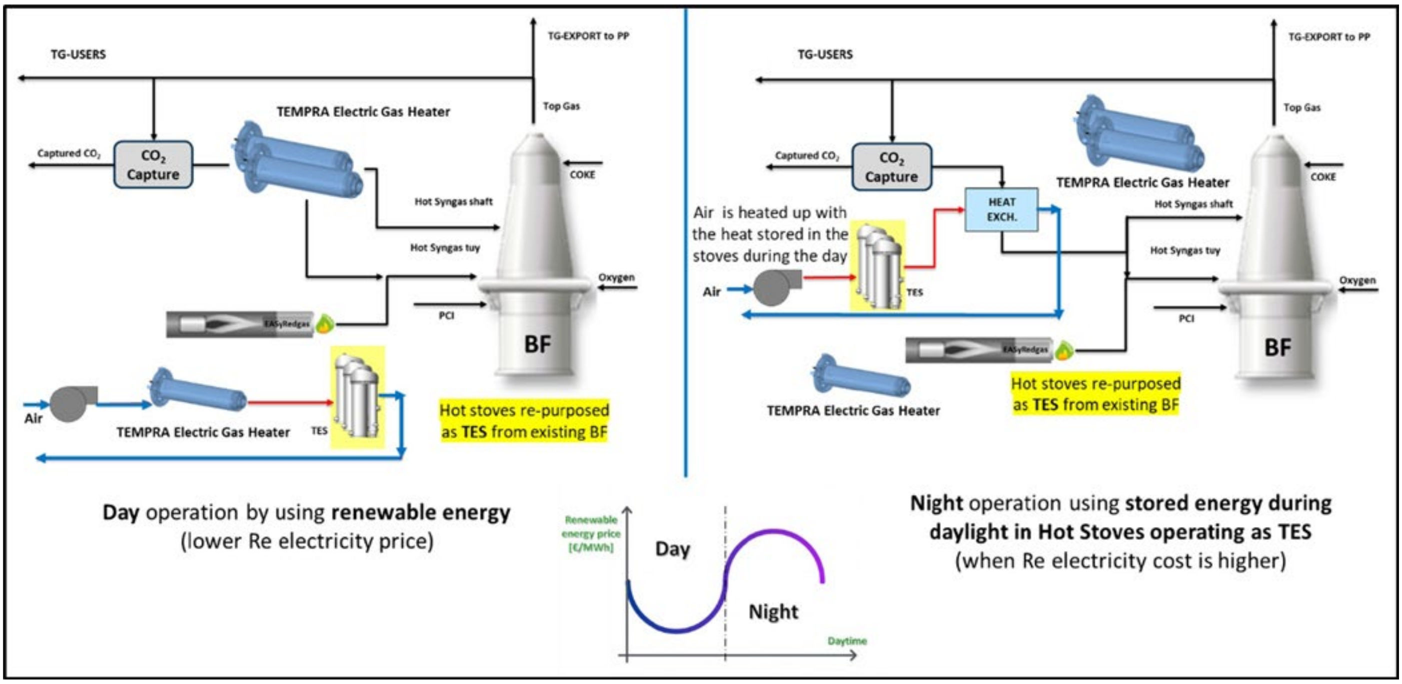


Fig.6 - E-TGR with TES (Thermal Energy Storage) by Hot Stoves.

FURTHER STEPS TO DECREASE CO_2 EMISSIONS FROM EXISTING BF

Figure 7 presents two alternative pathways for further decarbonization once the process scheme of figure 5 and 6 is applied. On the left, deep CO_2 reduction is enabled by adding CO_2 storage to the already foreseen CO_2 removal unit, dropping emissions to 69% below the reference case. A key enabler is the plasma torch, which superheats the reducing gas and allows further coke savings. This technology is a core element of Paul Wurth EASyMelt platform now under industrialization by SMS group, with Tata Steel has recently announced its application in a Blast Furnace in India. Full implementation of this scheme depends on CCUS infrastructure and market readiness, while the technical pathway is already established. On the right, green hydrogen is added to the gas loop as make-up while maintaining the configuration of fig-ure 5 stays achieving a CO_2 reduction of 63% compared to the reference case. This option depends on the availability of affordable, scalable green hydrogen and offers flexibility for deep emission cuts as market conditions evolve. Residual CO_2 emissions are linked to the need to supply part of the top gas to auxiliary units such as coke oven plants and reheating furnaces: a key criterion for benchmarking CO_2 emissions calculations across technologies in integrated steel plants. The energy needs of main users must be accounted for a correct evaluation of effective decarbonization potentials on existing BF based plants.

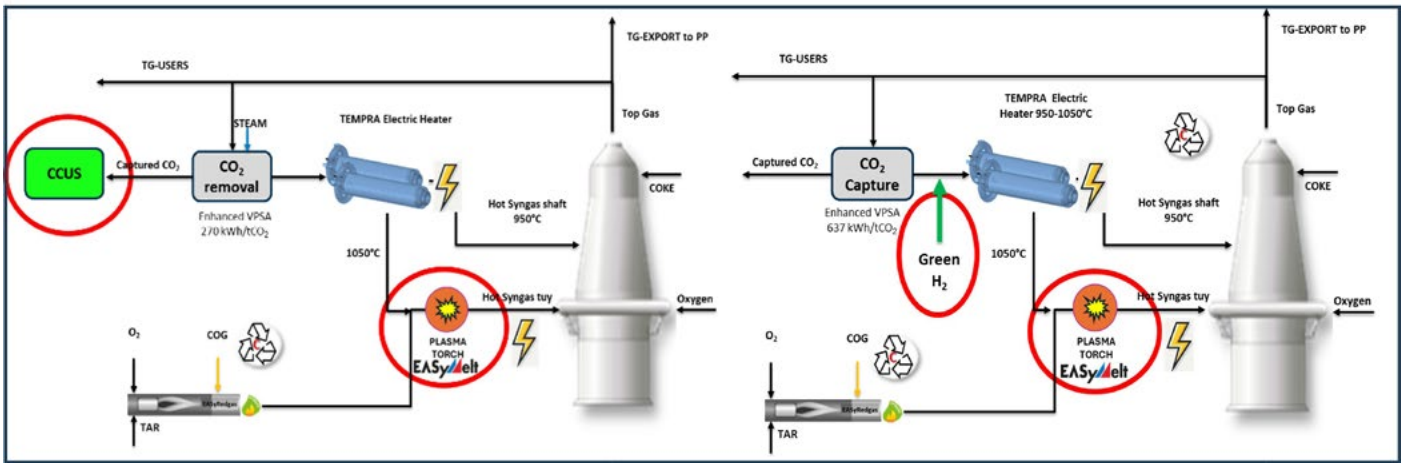


Fig.7 - Further steps for BF decarbonization (CCUS or green Hydrogen use).

ANALYSIS OF OPERATING COST FOR EASYREDGAS AND TEMPRA BASED BF DECARBONIZATION

Based on the raw materials and utilities costs listed in table 1, SMS used proprietary process models to evaluate the operating costs of the configurations shown in figures 3-7. Figure 8 shows CO_2 emissions re-duction on the horizontal axis and OPEX variation on the vertical axis starting from the reference case of figure 3 for each BF decarbonization step. Up to step 2, the roadmap is OPEX friendly under short term, representative cost assumptions, achieving savings of about 20 €/tHM while reducing the CO_2 emissions by 30% at a power cost of 100 €/MWh. As indicated by the dotted lines, combining Tempra and Thermal Energy Storage using repurposed hot stoves doubles the OPEX savings to approximately 40 €/tHM, demonstrating the effectiveness of exploiting renewable electricity price variability. Deeper decarbonization and further OPEX gains depend on the availability of CO_2 storage or affordable green hydrogen. Figure 8 shows that the proposed roadmap enables cost-effective BF decarbonization already in the short term with a 30% CO_2 reduction and paves the way for higher reductions as boundary conditions are satisfied.

Tab.1 - Raw materials and utility costs for OPEX calculation.

Unit Costs		
Coke	333	€/ton
PCI	204	€/ton
CO_2 credit	100	€/ton
Blast steam	16,1	€/ton
Oxygen	0,0765	€/Nm³
TAR	420	€/ton
Electric energy	30*- 100	€/MWh
Green H_2**	3,2	€/kg
CCS	180	€/ton
BFG	2	€/GJ
COG	3,7	€/GJ

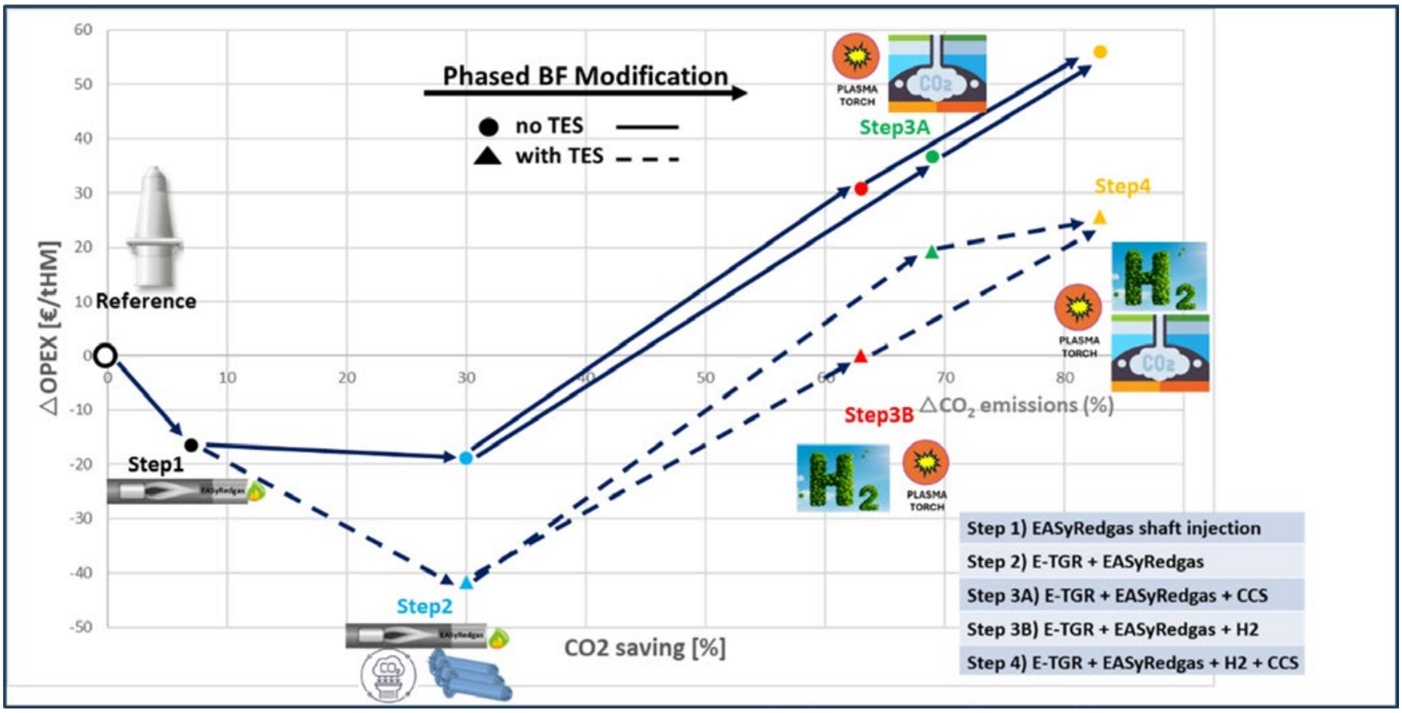


Fig.8 - OPEX evolution throughout the proposed BF decarbonization steps.

CONCLUDING REMARKS AND FUTURE OUTLOOK

In conclusion, the integrated EASyRedgas - Tempra solution offers a pragmatic, scalable retrofit pathway to significantly reduce BF Scope 1 CO_2 emissions while preserving productivity and limiting capital exposure.

By valorizing coke plant by-products into syngas, electrifying high temperature gas heating, and enabling progressive hydrogen and CO_2 management, the concept accelerates the transition toward low carbon ironmaking in existing BF based integrated plants. The paper presented detailed energy and mass balances with ISO compliant CO_2 emission calculations, techno-economic comparisons across deployment stages, and recommendations for sequencing implementation at integrated steel plants. EASyRedgas technology is now ready to be tested in connection with a BF unit to prove its effectiveness in delivering the coke rate reduction anticipated by process calculations. SMS group is ready to cooperate with BF customers to advance the technology to TRL 8 in joint industrialization projects. This would represent a strategic opportunity for those plants having relatively recently installed BF units to avoid them becoming stranded assets in view of the forthcoming decarbonization policies and CO_2 emissions taxation schemes.

REFERENCES

[1] Innovative Decarbonization strategies: thermal dry reforming for enhanced Blast Furnace efficien-cy. Lorenzo Micheletti, Fabio Cravino, Cristiano Castagnola, Ilaria Dagna. 7th ESTAD 2025 – Verona (Italy) Proceedings.

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