DECARBONISING PRIMARY STEEL PRODUCTION IN ROMANIA

LUCIANA MIU

RADU CÎRLIGEANU

February 2024

Decarbonising primary steel production in Romania

A study by:

Energy Policy Group (EPG)
Constantin Noica 159, District 6, Bucharest
www.enpg.ro, office@enpg.ro

About EPG:

Energy Policy Group (EPG) is an independent think-tank, specialized in energy and climate policies. Founded in 2014, EPG brings together experts working in international research projects, focusing on Romania and the Central and Eastern Europe region within the deeper context of European policies and global trends. EPG's aim is to promote a constructive dialogue among all decision makers and wider audiences, and to propose concrete solutions for decarbonising the economy.

Suggested quotation:

Energy Policy Group (2024), Decarbonising primary steel production in Romania

Acknowledgments:

The authors would like to thank Viorel Niță for his input into the analysis of Romania’s steel sector, Valentin Vogl for expert review, and Mihnea Cătuți and Mara Balașa for their constructive comments, inputs and review. EPG is also thankful for the feedback received from Liberty Galați on this report.

Cover image:

Steel production in electric furnaces. Photo by Norenko Andrey on Shutterstock.

Table of contents

List of Tables

List of Figures

Executive Summary

The decarbonisation of primary steel production is one of the most pressing challenges for the future of Romania's industry. A highly carbon-intensive process, conventional primary steelmaking faces increasing pressure to transform in the context of the EU's climate commitments: a phase-out of free allocation under the EU Emissions Trading System, upcoming regulations on sustainable products, and a rapidly rising carbon price. This pressure is insufficiently recognised in Romania's industrial and climate strategies: its Long-Term Strategy, draft National Energy and Climate Plan, and draft national Industrial Strategy all fail to account for the scale of the transformation challenge and the associated opportunities for green steelmaking.

While Romania's steel sector has shrunk since 1990, it still contributes significantly to the national economy and employment, and emits approx. 6.3% of total national carbon dioxide (CO_2) emissions. These contributions are centred on Liberty Galați, Romania's only remaining primary steel producer, which employed nearly 5,000 people in and emitted 4.39 mega-tonnes (Mt) of CO_2 (5.9% of Romania's total CO_2 emissions) in 2021. It is a major contributor to economic activity in the Galați county, a Just Transition region, and is an essential part of any attempt to revive Romania's upstream manufacturing sector and any ambition to supply domestic and foreign downstream sectors, such as the auto industry, with high-quality, low-carbon steel.

The main pathway to deeply decarbonise conventional primary steelmaking is conversion of the conventional blast furnace-basic oxygen furnace (BF-BOF) process to the direct reduction of iron, coupled with melting in electric arc furnaces (DRI-EAF). To achieve deep decarbonisation, the DRI process must use low-carbon hydrogen as a reducing agent, and the whole steelmaking process must be supplied by renewable electricity. Transitioning from BF-BOF to hydrogen-based DRI-EAF production will shift the fuel mix of primary steelmaking from fossil-based to using primarily electricity and hydrogen, and will change raw material requirements, including an increased consumption of scrap steel. Other decarbonisation pathways include a complete conversion to secondary steel production (using scrap steel or imported green iron) or carbon capture, all with their own challenges.

Liberty Galați has publicly announced a decarbonisation pathway involving a conversion from BF-BOF to DRI-EAF, using natural gas as a transitional DRI agent and fully switching to renewable hydrogen by 2030. This deep decarbonisation plan (the "GREENSTEEL plan") will accompany a doubling in production, reaching 4.1 Mt of liquid steel by 2030. According to our estimates, executing the GREENSTEEL plan could slash emissions from the production of liquid steel (responsible for 81% of emissions in primary steel production) by 93% by 2030, a reduction of 3.26 Mt CO_2 per year. This could give Liberty Galați a significant competitive edge as a green steel supplier, meeting increasing demand from downstream sectors such as the auto industry. It could also spur a local green economy, including for the production of renewable electricity and hydrogen to supply the DRI-EAF pathway, which will consume over 160,000 tonnes of hydrogen per year.

To truly achieve deep decarbonisation, the transformation of Liberty Galați under the GREENSTEEL plan will require a massive mobilisation to deploy renewable energy capacities, invest in renewable hydrogen production, and secure a reliable supply of scrap steel. Electricity consumption of the steelmaking process alone would increase ten-fold, and even if hydrogen production is outsourced abroad, meeting the target specific emissions of the GREENSTEEL plan will require the carbon intensity of Romania's electricity grid to halve. Using domestically-produced renewable hydrogen will require an additional 6.35 GW of renewable electricity capacity, 136% of Romania's total installed wind and solar energy in January 2024. The renewable hydrogen requirement of Liberty Galați in 2030 would be more than currently stipulated in Romania's national Hydrogen Strategy for the entire Romanian economy, and scrap steel consumption would increase four-fold, amounting to 80% of Romania's current scrap exports. The investment cost of the transformation itself, including the operating costs of using renewable hydrogen, will likely require state support both directly and indirectly to increase investment certainty.

If Romania's primary steelmaking is to spearhead industrial transformation and revive the competitiveness of manufacturing, urgent action must be taken to provide concrete, detailed transformation plans which are accounted for in national industrial and climate strategies. Targeted and carefully sized public financing instruments, including Green Public Procurement and Carbon Contracts for Difference, will be essential to meet upfront investment costs, especially in the coming decade as industrial operators begin to strain under increasing carbon prices. Infrastructure development will also be crucial, most importantly the deployment of renewable electricity capacities, strengthening of Romania's national electricity grid, installation of electrolysers and construction of hydrogen transport infrastructure. New supply chains for raw materials will also be needed, particularly a rethinking of Romania's export-oriented scrap steel sector. These actions will be necessary regardless how Liberty Galați decarbonises and require a shift in the approach of policymakers to the challenges of Romania's industrial transformation.

Sumar Executiv

Decarbonizarea producției de oțel primar este una din provocările cele mai presante pentru viitorul industriei românești. Producția convențională de oțel primar, un proces cu emisii ridicate de carbon, se confruntă cu o presiune crescândă de a se transforma, în contextul angajamentelor climatice ale UE: eliminarea treptată a alocărilor gratuite sub sistemul de comercializare al certificatelor de gaze cu efect de seră (EU ETS), viitoarele regulamente privind produsele sustenabile, și prețul crescând al carbonului. Aceste provocări sunt insuficient recunoscute în strategiile industriale și climatice ale României: Strategia pe Termen Lung, draftul Planului Național Integrat pentru Energie și Climă și draftul Strategiei Industriale a României 2023-2027 nu consideră îndeajuns magnitudinea provocării generate de transformarea sectorului siderurgic și oportunitățile aduse de producția de oțel verde.

Deși sectorul siderurgic al României și-a redus activitatea comparativ cu 1990, acesta contribuie în continuare în mod semnificativ la economia națională și la forța de muncă, generând aproximativ 6.3% din emisiile naționale de dioxid de carbon (CO_2). Aceste contribuții sunt dominate de Liberty Galați, singurul producător de oțel primar încă activ în România, cu aproape 5,000 de angajați și emisii de 4.39 milioane de tone (Mt) de CO_2 în 2021 (5.9% dn emisiile totale de CO_2 la nivel național). Combinatul siderurgic este un contribuitor important la economia județului Galați, una dintre zonele de Tranziție Justă ale României, dar și un actor esențial pentru încercările de a reînvigora industria grea a României și pentru ambițiile de a furniza oțel de înaltă calitate și cu emisii reduse de carbon către sectoarele prelucrătoare, precum industria auto, atât în România cât și în alte țări.

Traiectoria principală de decarbonizare profundă a producției primare de oțel este înlocuirea procesului convențional *blast furnace-basic oxygen furnace* (BF-BOF) cu procesul de reducere directă a minereului de fier (*direct reduction of iron*, DRI), cu topirea ulterioară în cuptoare cu arc electric (DRI-EAF). Impactul climatic pozitiv al acestei transformări depinde de utilizarea hidrogenului cu emisii reduse de carbon ca agent de reducere în procesul DRI și de alimentarea întregului proces siderurgic cu electricitate din surse regenerabile. Înlocuirea procesului BF-BOF cu un proces DRI-EAF alimentat de hidrogen va transforma mixul de combustibili și resurse al producției primare de oțel prin tranziția de la combustibili fosili la electricitate și hidrogen. De asemenea, materiile prime necesare procesului de producție vor suferi schimbări, inclusiv prin creșterea semnificativă a cererii de fier vechi. Alte rute de decarbonizare sunt conversia completă la producția secundară de oțel (folosind fier vechi sau fier verde importat) sau captarea emisiilor de carbon, ambele înfruntând propriile bariere de implementare.

Liberty Galați a anunțat public planul său de decarbonizare care implică înlocuirea procesului BF-BOF cu DRI-EAF, utilizând într-o fază de tranziție gazul metan ca agent de reducere DRI, urmând ca acesta să fie înlocuit cu 100% hidrogen regenerabil până în 2030. Acest plan (planul „GREENSTEEL”) va fi implementat în paralel cu o dublare a producției de oțel, atingând 4.1 Mt de oțel lichid până în 2030. Conform estimărilor noastre, implementarea planului GREENSTEEL ar putea reduce emisiile din producția de oțel lichid (care generează 81% din emisiile producției primare de oțel) cu 93% până în 2030, adică o reducere de 3.26 Mt CO_2 pe an. Această transformare ar putea oferi un avantaj competitiv semnificativ companiei ca furnizor de oțel verde, contribuind la aprovizionarea unei cereri crescânde de oțel verde, venit mai ales dinspre industria auto. De asemenea, transformarea ar putea lansa o economie verde locală, inclusiv pentru producția de electricitate regenerabilă și de hidrogen, pentru a satisface cererea de 160,000 de tone/an a viitorului proces DRI-EAF la Liberty Galați.

Pentru transformarea profundă a combinatului siderurgic conform planului GREENSTEEL este necesară o mobilizare masivă pentru instalarea de capacități de energie regenerabilă, investiții în producția de hidrogen regenerabil și asigurarea unei aprovizionări fiabile cu fier vechi. Consumul de electricitate al procesului de producție de oțel lichid va crește de zece ori, iar atingerea țintelor de emisii din planul GREENSTEEL, chiar și în cazul în care hidrogenul regenerabil nu este produs domestic, va fi posibilă doar dacă mixul de energie electrică al României își înjumătățește intensitatea emisiilor de carbon. Dacă hidrogenul este produs domestic, vor fi necesare capacități suplimentare de energie regenerabilă de 6.35 GW, 136% din capacitatea totală instalată de energie solară și eoliană la nivel național, în ianuarie 2024. Cererea de hidrogen regenerabil a Liberty Galați în 2030 va fi mai mare decât consumul întregii economii prevăzut în Strategia Națională pentru Hidrogen, iar consumul de fier vechi al companiei va crește de patru ori, ajungând la un necesar egal cu 80% din exporturile actuale de fier vechi ale României. Costul investițional al transformării tehnologice, precum și costul operațional pentru producerea hidrogenului regenerabil, va necesita susținere din partea statului, în mod direct cât și indirect, pentru a crește certitudinea investițiilor.

Pentru ca sectorul siderurgic românesc să poată deveni vârful de lance al transformării industriale și al revigorării competitivității industriei prelucrătoare este necesară elaborarea de planuri concrete și detaliate de transformare, care să fie sincronizate cu strategiile industriale și climatice naționale. Finanțarea publică bine direcționată și inteligent dimensionată, prin instrumente precum cele pentru susținerea pieței pentru oțel verde cum Achizițiile Publice Verzi și Contractele pentru Diferență de carbon (CCfDs) este esențială pentru susținerea costurilor investiționale ridicate, mai ales în următorul deceniu când alocările gratuite pentru operatorii industriali vor fi eliminate treptat. Trebuie de asemenea planificată și dezvoltarea infrastructurii: instalarea de capacități de electricitate regenerabilă și de electrolizoare, modernizarea și consolidarea sistemului energetic național, și construirea infrastructurii de transport pentru hidrogen. Vor fi necesare și noi lanțuri de aprovizionare cu materii prime și mai ales o regândire a exporturilor de fier vechi din România. Toate aceste acțiuni vor fi necesare indiferent de traiectoria de decarbonizare aleasă de Liberty Galați și necesită o schimbare de abordare a problematicii transformării industriale din partea autorităților naționale.

List of Acronyms

BF	blast furnace
BOF	basic oxygen furnace
CBAM	Carbon Border Adjustment Mechanism
CO_2	carbon dioxide
DRI	direct reduction of iron
EAF	electric arc furnace
ETS	Emissions Trading System
GHG	greenhouse gas emissions
GPP	Green Public Procurement
GWh	gigawatt-hours
H2-DRI	hydrogen-based direct reduction of iron
kt	kilo-tonnes
kWh	kilowatt-hours
Mt	mega-tonnes
MWh	megawatt-hours
NG-DRI	natural gas-based direct reduction of iron
Nm^3	normal cubic metre
RFNBO	renewable fuel of non-biological origin
tls	tonne of liquid steel
TWh	terawatt-hours

Introduction

An essential material in numerous industries, steel is one of the most-consumed commodities worldwide. In 2021, global steel production amounted to nearly 2 billion tonnes, half of which was used in buildings and infrastructure development.[i] Steel production is currently in focus on climate change agendas given the intensity of its greenhouse gas (GHG) emissions and resource consumption: in 2021, the global steel industry used 2.3 billion tonnes of iron ore, 1.1 billion tonnes of metallurgical coal, and 680 million tonnes of recycled steel, and emitted 3.7 billion tonnes of carbon dioxide (tCO_2), around 8% of total global CO_2 emissions.[ii]

The emissions of the steel sector are mainly driven by the ongoing widespread use of primary steel production, which processes iron ore into steel most commonly through the blast furnace-basic oxygen furnace (BF-BOF) route. In 2022, 71% of global steel volumes and 56% of EU volumes were produced through this route,[iii] which emits approx. 1.8 tCO_2/tonne of liquid steel (tls). 70% of these emissions are due to the use of coke to reduce iron ore in the blast furnace and produce pig iron, and to balance the carbon content of this pig iron in the basic oxygen furnace (11%) to produce liquid steel.[iv] The remainder of steel is manufactured through secondary production pathways (melting scrap steel and in some cases pig iron in an electric arc furnace, or EAF), which is much less carbon-intensive (0.07 tCO_2/tls), but limited in terms of what final steel products can be produced.[v] Decarbonising secondary steel production will primarily imply switching to low-carbon electricity for powering EAF operations. Finally, very small volumes of steel are produced through the highly polluting open-hearth primary production route, mostly in Ukraine, Russia, and some Asian countries.

Given its high share of production and its emissions intensity, the decarbonisation of primary steel production has come into focus at European and global levels. In the EU, the revision of the Emissions Trading System (EU ETS) will see the full phase-out of the free emissions allowances provided to steel producers by 2034. Coupled with a skyrocketing carbon price and an end to any new emissions allowances entering the ETS primary market after 2039, this is a major lever to build the business case for decarbonising steel, based on avoiding the cost of emissions. Other policy levers target the carbon content of steel products – the revision of the Ecodesign for Sustainable Products Regulation now includes intermediate industrial products, including steel, and a growing interest in green public procurement (GPP) frameworks at Member State level may also incentivise decarbonisation by requiring procurement agencies to primarily buy low-carbon steel for public projects such as housing and infrastructure. Given that green steel producers will likely need to charge a premium to their customers and may struggle to compete with cheaper, dirtier steel imports from non-EU jurisdictions with less stringent climate policies, the Carbon Border Adjustment Mechanism (CBAM) was also launched in October 2023, to tax steel and other industrial imports based on the emissions associated with their production.

The main mature pathways for decarbonising primary steel production are the substitution of the BF-BOF process for a lower-carbon one, and the capture and storage of CO_2 emissions (CCS) from conventional steelmaking. Other decarbonisation pathways, such as iron ore electrolysis, are currently at a very low stage of technology readiness.[vi] In Europe, the most viable method to decarbonise primary steel production is the substitution of BF-BOF production with direct reduction of iron (DRI),[vii] a more energy-efficient process which uses hot gases to reduce the iron ore to an intermediate product (sponge iron), which is then melted in an EAF. The DRI unit and the EAF can replace the BF and the BOF, respectively, of conventional primary steel production. This DRI-EAF pathway is still primary steel production, as it uses iron ore as its main raw material.

The DRI process can use hydrogen, natural gas, or even coal to reduce the iron ore, but deep decarbonisation is only achievable if low-carbon hydrogen is the choice of reducing agent. Although it is a mature process (in 2022, global production of DRI-based liquid steel was approx. 127 million tonnes, or Mt), existing commercial-scale DRI plants use natural gas (71%) or coal (29%) as reducing agents. Commercial announcements for renewable hydrogen-based DRI plants are emerging: in 2022, the H2 Green Steel plant in Sweden was announced as the world's first commercial fully hydrogen-based steel plant, and the Tata Steel plant in Ijmuiden (Netherlands) and Thyssenkrupp plant in Duisburg (Germany) have committed to transition to hydrogen-based steel production,[viii,ix] with the latter recently launching a tender for the purchase of hydrogen.[x] Liberty Steel Galați, Romania's only primary steel producer and the focus of this study, has also announced a plan to fully transition to DRI steelmaking using renewable hydrogen, by 2030.[xi]

Switching from BF-BOF primary steel production to low-carbon DRI-EAF primary steel production encompasses two key decarbonisation measures, which must be deployed together: electrification (by replacing the BOF with an EAF) and the use of low-carbon hydrogen (to replace coke, the conventional BF reducing agent). The lowest-carbon form of hydrogen currently available is renewable hydrogen, produced through the electrolysis of water (electrolytic hydrogen), using renewable electricity to power the process. Beyond investment in new production units (DRI units and EAFs), such a process change will also require supporting infrastructure – low-carbon electricity capacities, a grid capable of delivering the required electrical power, and electrolysers, transport infrastructure, and storage media for hydrogen. The current low availability of renewable hydrogen in Europe also means that many DRI conversions will likely use natural gas in an initial phase, converting to hydrogen at a later stage.[xii]

Maintaining primary steel production while deeply decarbonising it is therefore relatively capital-intensive and requires significant supporting infrastructure. Primary steelmakers in the EU mostly have only one window of opportunity before 2050 to undertake major changes or upgrades.[xiii] Of course, it is also possible to forgo primary steel production completely and replace it with secondary steel production using EAF; however the advantages of doing so must be weighed against the limitations, as will be explored in this study. In this case study, we examine the potential decarbonisation pathways for Liberty Steel Galați, Romania's only primary steel producer and largest industrial emitter.

Background

Romania's steel sector

Today, Romania has five active steel producers: one primary steel producer (Liberty Steel Galați[1]) and four secondary steel producers using EAFs: Tenaris Silcotub Călărași, ArcelorMittal Hunedoara, Artrom Steel Tubes Reșița (formerly TMK Reșița) and COS Târgoviște, recently reopened as Donalam Târgoviște under the ownership of Donalam AFV Beltrame Group.[xiv,2] They manufacture liquid steel, from which semi-finished steel products, such as blooms or billet, are produced and subsequently processed either on site, within integrated steelworks (Liberty Galați, Arcelormittal Hunedoara, Donalam Târgoviște) and/or at separate steel mills owned by the same company. Of these mills, three produce steel pipes (ArcelorMittal Tubular Products Roman, Artrom Steel Tubes Slatina and Silcotub Zalău), and one rolled steel products (Donalam Călărași, processing semi-finished steel products from Donalam Târgoviște) (Table 1).

By far the largest volumes of both liquid steel and final steel products are produced at Liberty Galați (Table 1) using the BF-BOF primary steelmaking process. With only one blast furnace still operational, in 2021 it produced 2.35 mega-tonnes (Mt) of liquid steel and 2.11 Mt of finished products. It is a major employer, accounting for more than of 17% of employees in the basic metals sector in 2021. Its production and emissions have decreased dramatically since 1990, but in 2022 it remained Romania's largest point-source industrial emitter and one of the most important industrial companies in the country.[3]

Table 1.Final product production capacities and output for steel producers and separated processing units in Romania. The most recent year of available data is always used. Source: data from annual environmental reports, environmental permitting documentation, and companies' own statements.

Producer	Final products	Capacity (tonnes/year)	Output (tonnes/year)	Year
Liberty Galați	Sheets, strip, and other products	6,812,000.00	2,114,297	2021
ArcelorMittal Hunedoara	Blooms, rolled products	400,000	181,729	2021
ArcelorMittal Tubular Products Roman	Pipe products	180,000	63,146	2021
Silcotub Călărași	Blooms and billet	535,000	317,073	2018
Silcotub Zalău	Pipe products	260,000[4]	165,309	2016
Artrom Steel Tubes Reșița	Continuous cast products	464,000	251,492	2021
Artrom Steel Tubes Slatina	Pipe products	248,000	187,667	2019
Donalam Târgoviște	Rolled products, semi-finished products	281,825	146,741	2019
Donalam Călărași	Rolled products, heavy profiles	450,000	162,026	2021

---

[1] Referred to as Liberty Galați throughout the remainder of this report.

[2] In addition to these steel plants, Romania also has producers of specialised steel products – Oțelinox (stainless steel products) and Erdemir (electrotechnical strips).

[3] Before 1990, ArcelorMittal Hunedoara and Artrom Steel Tubes Reșița were also primary steel producers, but have since converted from BF-open hearth to EAF production, slashing their production capacities and associated emissions.

[4] Hot rolling capacity.

Economic performance

Romania's steel sector is an important contributor to the national economy. Much of its contribution comes from downstream sectors, such as the production of steel pipes, hollow profiles and related fittings.[5] Yet further downstream, Romania's automotive industry, a major steel user, is now one of the most important contributors to the national economy.[xv] On the other hand, Romania's upstream steel sector (the production of liquid steel and semi-finished products) has been declining since the liberalisation of the Romanian economy in 1990. With some exceptions, steel production capacities halved between 1990 and 2000, and the production of crude and semi-finished steel products decreased by 46% and 61%, respectively.[xvi] This decline is ongoing, with recent shutdowns (such as steel producers Ductil Steel Oțelu Roșu and its mill at Buzău, SMR SA Balș, and Industria Sârmei Câmpia Turzii) and reductions in overall economic contribution and number of employees in the decade to 2020,[xvii] potentially creating import dependencies for downstream steel sectors and a vulnerability to shifts in commodity prices.

This picture is also reflected in Romania's steel trade: downstream steel sectors show an export surplus of most processed steel products (which accounted for approx. 7% of total national exports), but semifinished basic iron, steel, and ferroalloy products are heavily imported. This raises the question of whether Romania could increase steel production capacities or output to satisfy more of its demand for semifinished products, take advantage of the rebound in international steel demand following the Covid-19 pandemic, and supply finished steel products for its ambitious public infrastructure projects. There is an appetite to increase steel production: in 2021, Liberty Galați announced record production levels[xviii] and a plan to increase production capacity, while other producers revived stagnating production[xix] and announced plans for development.[xx] More recently, however, in 2023, the only functional blast furnace at Liberty Galați was temporarily shut down due to difficulties in transporting feedstock and raw materials, as a result of unfavourable navigation conditions on the Danube and the Black Sea.[xxi]

Despite recent announcements and the potential to revive upstream steel production, Romania's steel sector will require significant investments both by companies and the state to keep up with international competition, particularly in the context of a global race for low-carbon steel. In recent decades, investments by the Romanian state have mostly been in the form of unproductive state aid, directed primarily at debt write-offs and penalty restructuring (just over $1 billion between 2003 and 2010).[xxii] Recent investments in plant modernisation have mostly targeted the upgrade of rolling mills,[xxiii] with little visibility on the large-scale investments required for increasing competitiveness, particularly in primary steel production where a deep transformation will be required to enable the production of low-carbon steel.

Emissions and resource consumption

As in other countries, Romania's steel industry is energy and emissions-intensive, primarily due to the presence of a large primary steel producer. Overall, emissions from the iron and steel sector

---

[5] In 2021, the production of pipes, profiles and rolled products contributed 1.1% to Romania's gross value added (GVA), and employed nearly 83,500 people, on an increasing trend over the last decade. Source: Eurostat, National Statistical Institute.

have been declining since 1990, driven primarily by the shutdown of blast furnaces and a decrease in production. The CO_2 emissions intensity (the amount of CO_2 produced for each unit of gross domestic product, GDP) of Romania's steel sector is not specifically known, but that of Romania's basic metals sector has decreased more slowly than the rest of the economy since 1990, and remained well above the EU average in 2020 (6.42 kgCO_2/EUR, compared to 2.69).[xxiv]

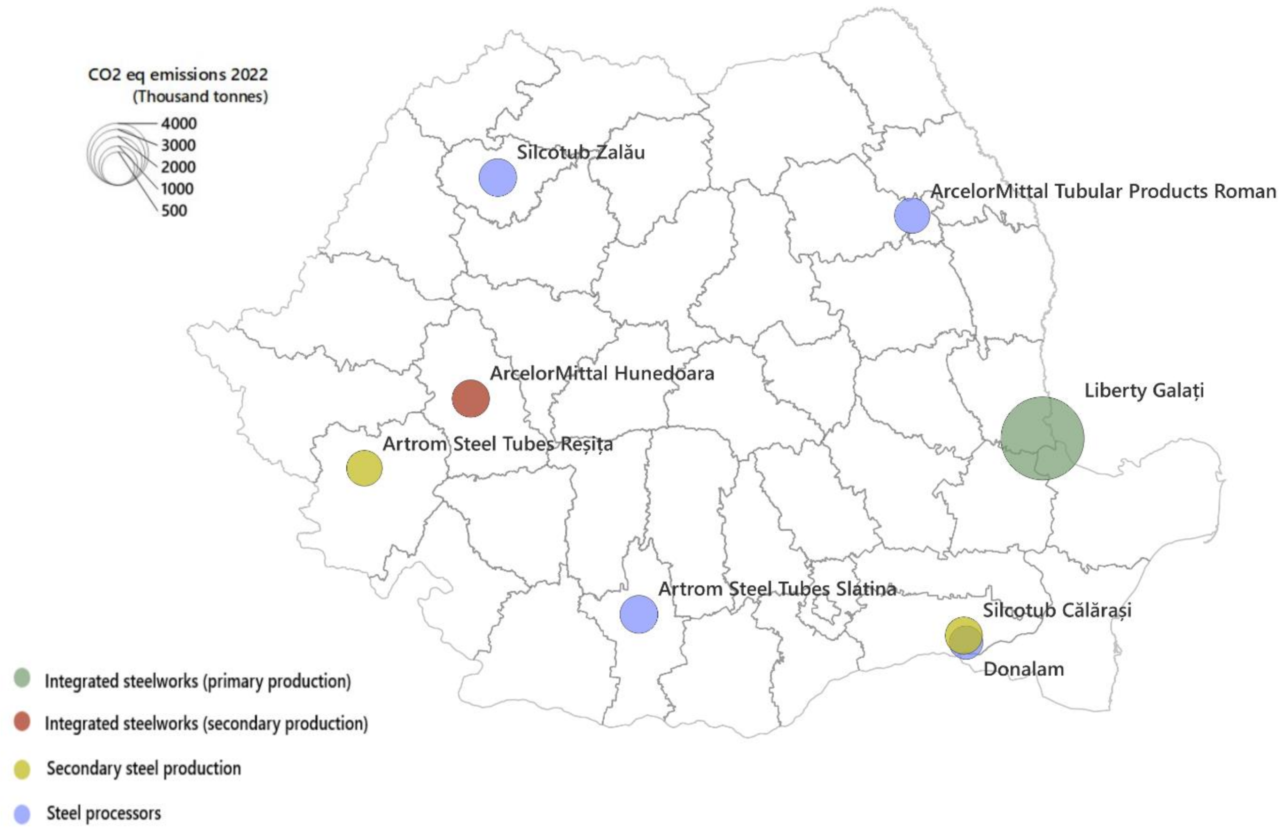
In 2021, iron and steel production in Romania generated 4.87 Mt of CO_2, with the majority (4 Mt) from inherent process emissions (emissions from steel production processes, such as iron ore reduction) and the remainder from fuel combustion.[xxv] These total emissions were equivalent to 6.3% of national total CO_2 emissions, and to 26% of national industrial CO_2 emissions. The largest contributor is primary steel production, with Liberty Galați being by far the largest CO_2 emitter (4.39 Mt CO_2-eq under the EU ETS in 2021[6]). Secondary steel producers have comparatively very low emissions (*Figure 1*), although some have recently reported an increase in their emissions, in line with an increase in production. Steel processing units are also important emitters, primarily due to the heat requirements of rolling mills.

Steel producers also consume significant amounts of energy and resources, directly related to their size and production processes. On average, Romanian steel producers were responsible for nearly a quarter of total industrial energy consumption between 2015 and 2021, with over half of this energy requirement coming from furnaces.[xxvi] In primary steel production, these furnaces are major consumers of natural gas, coke and other types of coal, and are exposed to vulnerabilities in resource availability: Roania no longer produces coke, instead relying on imports primarily from India and Poland,[xxvii] and the steep rise in natural gas prices since Russia's invasion of Ukraine may further constrain natural gas availability. For secondary steel producers, EAFs are significant consumers of electricity and of steel scrap, and may be strained by volatility in electricity prices and low scrap availability (Romania currently exports approx. 40% of its scrap steel).

---

[6] In 2022, this number had dropped to 3.2 Mt CO_2-eq/year due to the temporary closure of the blast furnace for maintenance.

Figure 1. Emissions verified under the EU ETS for Romania's steel producers and processors in 2022. COS Târgoviște is not shown, as the plant had not yet re-started reporting its emissions after reopening in 2022. ArcelorMittal Hunedoara is an integrated steelworks site but also exports semi-finished products to a separate processing site (ArcelorMittal Tubular Products Roman). Source: EPG own work, based on data from the European Commission.[xxviii]



The Romanian steel sector carries a significant economic weight, growth potential, and contribution to national CO_2 emissions. To grow the sector sustainably, a sharp focus is needed on the decarbonisation of primary steel production, where reducing emissions will be crucial for avoiding rising carbon costs while enabling increased production to revive Romania's upstream steel sector and compete in the low-carbon steel market. The transformational technologies and processes required for deep emissions cuts are hampered by a number of barriers: high upfront capital costs, which given the low profit margins of steel production create substantial investment risk, the narrow window of opportunity for investments before 2050,[xxix] and the lack of key materials and infrastructure (such as the low-carbon hydrogen and associated transport infrastructure for direct reduction of iron (DRI), but also the higher-quality iron ore required for DRI steelmaking).

The picture of primary steel production in Romania reflects this overall reticence towards investment in low-carbon steelmaking. Although Liberty Galați recently released a plan to replace its BF-BOF steelmaking with hydrogen-based DRI-EAF (the "GREENSTEEL" plan, part of the company's CN30 initiative[xxx]), no concrete advances have been made yet, and recent investments have mostly focused on incremental improvements to reduce energy consumption and related costs. Recently announced investments to reduce natural gas and power consumption, totalling €20 million,[xxxi] would lead to a 27% reduction in natural gas consumption and a 3.5% reduction in power consumption, but would collectively only reduce CO_2 emissions costs by approx. 1.6% of the total cost of the plant's emissions[7] at today's carbon costs under the EU ETS. Other proposed investments include the on-site installation of 200 MW of renewable energy capacity, which would cover an estimated 250 gigawatt-hours (GWh)/year of the plant's current electricity consumption (870 GWh/year, including steel processing), again generating some energy cost savings, but little in the way of emissions reductions.

This slow pace of decarbonising primary steel production is compounded by the relative apathy of national institutions with a remit for industrial decarbonisation. Romania's recent key strategic documents on climate and industry provide little clarity or commitment to support the transition to low-carbon steelmaking. As a result, the transition plans of Liberty Galați risk being jeopardized by a lack of acknowledgment of the scale of its decarbonisation challenge. In the following chapters, we present the scale of this challenge by estimating the impact of the GREENSTEEL transition plan on the energy, resource, and infrastructure needs of Liberty Galați. Our estimates are based on publicly available data, primarily from academic literature and environmental reports of Liberty Galați, and although they indicate the order of magnitude of the GREENSTEEL impact, they should be interpreted as a starting point for more detailed estimates.

Decarbonizing primary steel production at Liberty Steel Galați

First opened in 1966 as Sidex Galați, Liberty Galați remains one of Romania's largest industrial complexes. It was originally designed with four units: a coke production site (no longer active); an ironmaking unit (including a sintering unit and 6 blast furnaces), a steelmaking plant (including 6 BOFs and two continuous steel casting units), and a rolling mill. Its production capacity stood at 10 Mt liquid steel and 11 Mt finished products, and it employed over 20,000 people. After 1990, the plant was first bought by ArcelorMittal, and then re-purchased by Liberty Steel Group in 2019.

Since 1990, the steel plant has progressively shut down all but one of its blast furnaces (furnace no. 5, which has been modernised several times, most recently in 2023). The plant now stands at a capacity of 4.4 Mt for liquid steel and 6.49 Mt for finished products, and is Romania's largest industrial point-source emitter: in 2021, it emitted 4.39 Mt of CO_2-eq and received 3.14 million

---

[7] It should be noted that at the moment, the actual cost to Liberty Galați of its emissions under the EU ETS is mostly covered by free emissions allowances. These allowances will be phased out under the most recent revision of the EU ETS, and from 2034 none of the companies receiving free allowances will do so anymore.

free emissions allowances under the EU ETS.[xxxii] It is a major consumer of energy and resources, importing iron and coke[8] from a variety of locations through riverine and maritime transport via the Danube River and the Black Sea. It is a major employer, with nearly 5,000 employees in 2021, the largest industrial company in Romania in terms of personnel and included in the Territorial Just Transition Plan of the county of Galați.

By 2030, Liberty Galați is aiming to increase its production of liquid steel to 4.1 Mt/year, as well as targeting a near-complete decarbonisation of its steel production process and net-zero CO_2 emissions by 2030, through its GREENSTEEL plan.[xxxiii] The decarbonisation pathway outlined in this plan involves replacing BF-BOF steelmaking with DRI-EAF using renewable hydrogen, by 2030. Liberty Steel Group has signed an agreement to purchase the Dongbu Steel plant in South Korea and transport the associated steel production equipment to Galați, including two modern EAFs, two continuous casters, and a hot strip mill. Supplemental EAF capacities may be needed to reach the GREENSTEEL production target, and Liberty Galati has launched a tender process for hybrid EAFs to replace the existing BF by 2025.[xxxiv]

In the following section, we present the current steelmaking process at Liberty Galați and the implications of continuing with conventional production. The boundaries of the study are the manufacturing of liquid steel from agglomerated iron ore, excluding the mining and transport of iron ore, the continuous casting and processing of liquid steel into semi-finished and finished products, and auxiliary processes such as lime production.

Conventional process and business-as-usual scenario

The production of liquid primary steel involves the agglomeration (sintering) of iron ore, the production of pig iron in the BF, and the production of steel from pig iron in the BOF and ladle furnace, including vacuum degassing (Figure 2). These three major processes are responsible for 81% of emissions from the steel production process, and at Liberty Galați their specific consumption of raw materials and energy per tonne of liquid steel (tls) is 23.5 normal cubic metres (Nm^3) of natural gas, 154.2 kilowatt-hours (kWh) of electricity, 517 kg of coke and coal, 1.04 tonnes of iron ore, 214 kg of iron pellets, and 330 kg of steel scrap. The system boundary of this study is the sinter-BF-BOF process chain (including the ladle furnace and vacuum degassing unit) and excludes auxiliary processes: the continuous casting of liquid steel and downstream processing of cast steel in the rolling mill (not shown in Figure 2) and the production of lime as a key input into the BOF.

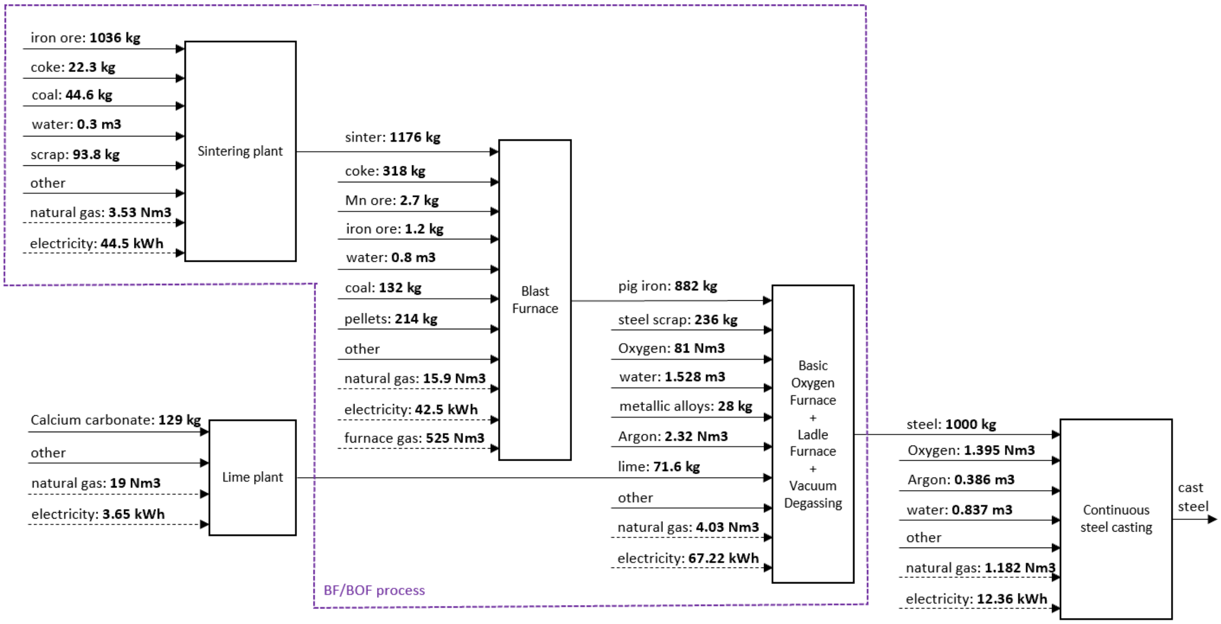
The direct (Scope 1) CO_2 emissions from the BF-BOF process (including sintering) (Figure 2) are process emissions (emissions originating from the reactions of the BF-BOF process), and emissions from the combustion of natural gas and coke for generating process heat. Indirect

---

[8] Recently, Liberty partially replaced its Russian imports of coke and coal (720 kt) for the Galați plant, by acquiring the Dunaferr steel plant in Hungary, whose blast furnace was decommissioned, but the coke production line is maintained and could deliver 200 kt of coke annually to the Galați plant.

(Scope 2) emissions result from the generation of electricity[9] used in the steelmaking process. They are not considered in the system boundary of steelmaking emissions in this analysis but are referred to in the context of economy-wide decarbonisation. Assuming specific CO_2 emissions based on reference values[10] results in specific emissions of 1.494 tCO_2/tls from the BF-BOF and sintering processes (including from the combustion of blast furnace gas), in good agreement with other values from the literature,[xxxv] or 3.51 Mt CO_2 for a yearly production of 2.35 Mt of liquid steel. Emissions from auxiliary processes (lime production, continuous casting, and downstream steel processing) amount to 135.62 $kgCO_2$/tls, also using reference values.[xxxvi]

Figure 2. Material and energetic consumption (per tonne of individual process output) in the current steel manufacturing process at Liberty Galați. The data source is primarily from a 2023 application for an integrated environmental authorisation by Liberty Galați, with data mostly from 2021. Between the BF and the BOF there is a desulphurisation plant, not shown below but included in this analysis. Annex 1. Input materials used in conventional steel production at Liberty Galați *shows the detailed consumption of inputs per tonne of output.*



Maintaining conventional production at Liberty Galați, particularly if production is increased, will result in significant levels of energy consumption, CO_2 emissions, and associated costs (Table 2). Even when excluding the Scope 2 emissions generated by electricity consumption, which are not borne by Liberty Galați under the EU ETS, for a production of 2.35 Mt/year the cost of full-chain direct emissions could be as high as €325.6 million per year at current carbon prices of

---

[9] Emissions from electricity production at Romania's current grid carbon intensity (349 kg CO_2-eq/MWh, representative of October 2022-September 2023), would amount to 60 kg CO_2/tls.

[10] The specific CO_2 emissions estimated here are informed by the IEA-GHG Steel CCS study: 289.46 $kgCO_2$/tls for the sintering plant, 434.92 $kgCO_2$/tls for the BF, 7.76 $kgCO_2$/tls for the desulphurisation plant (intermediate step between the BF and BOF), and 51.02 $kgCO_2$/tls for the BOF and ladle furnace. In addition to these process emissions, we also consider the carbon content of the blast furnace gas evacuated from the BF; this is quantified based on the volume reported by Liberty Galați for evacuation to its on-site energy units (2,009 million Nm^3 in 2021), assuming a total carbon content of 42.05% of CO_2 in the combusted blast furnace gas and a CO_2 mass density of 1.977 kg/Nm^3.

approx. €85/tonne. In a scenario of achieving target production of 4.1 Mt by 2030, this cost would rise to €568 million/year, assuming carbon prices remain static, which is unlikely given that the phase-out of free allocations under the EU ETS will generate increased demand for emissions allowances and likely result in an increase in price to as much as €160/tCO_2.[xxxvii]

Table 2. Energy consumption and CO_2 emissions for current and planned production volumes, assuming continued use of the BF-BOF process, based on Figure 2. The full-chain process refers to the entire plant (i.e., the process shown in Figure 2, plus downstream steel processing), while the BF-BOF process refers to the processes within the system boundary. All emissions exclude Scope 2 emissions.

Production (Mt/year)	**Process**	**Natural gas consumption (million Nm3)**	**Electrical energy consumption (GWh)**	**CO_2 emissions (Mt CO_2-eq)**
2.35	BF-BOF	55.13	362.42	3.51
	Full chain	102.56	400.04	3.83
4.1	BF-BOF	96.35	632.22	6.13
	Full chain	178.76	697.82	6.68

The following section analyses the implications of Liberty Galați's proposed decarbonisation pathway (the GREENSTEEL plan). In this analysis, only the processes within the above-mentioned system boundary are considered, as they are the source of the majority of CO_2 emissions of the liquid steel production process.

The GREENSTEEL plan: DRI-EAF at Liberty Galați

The GREENSTEEL plan for decarbonising steel production at Liberty Galați, released in 2022,[xxxviii] broadly outlines a pathway for decarbonisation by 2030, by switching from the BF-BOF route to the DRI-EAF route, using natural gas in a transitional phase before switching to 100% renewable hydrogen by 2030. The switch in primary production route is accompanied by a planned increased in liquid steel output, from 2.35 Mt/year today to 4.1 Mt/year by 2030. The following sections explain the DRI-EAF route, summarise the GREENSTEEL plan, and present the implications of the plan for energy consumption, CO_2 emissions, costs, infrastructure requirements, and socio-economic aspects.

The DRI-EAF process in detail

DRI steelmaking involves reducing iron ore in a DRI unit, using a reducing agent such as hydrogen, natural gas, or even coal, to produce sponge iron. This intermediate product is then melted and chemically adjusted to create liquid steel, most commonly in an EAF (although it is also possible to connect a BOF to a DRI unit, via a melting unit,[11] or feed the sponge iron into a BF, reducing the use of coking coal[xxxix,12]). DRI technology has been commercially available since the 1970s, in particular coal-based DRI, whereas the natural gas-based process (NG-DRI) are more recent and advantageous in regions where natural gas is readily available.

In 2022, the global DRI production of 127.4 Mt was mostly driven by India (coal-based in rotary kilns) and Iran (NG-DRI in shaft furnaces).[xl] Hydrogen-based DRI (H2-DRI), one of the most promising routes for decarbonising primary steel production, is also not a new technology (the first H2-DRI plant was launched in Trinidad in 1999, but was suspended due to numerous problems with the fluidized bed reactor used in the process[xli]). If using renewable hydrogen, H2-DRI could potentially provide zero operational emissions, and has good scale-up potential with little to no effect on the quality and efficiency of the process. Additionally, hydrogen can be progressively mixed into a NG-DRI unit with minimal changes to the process architecture (up to 30% proportion of hydrogen[xlii,13]).

The main phases of a H2-DRI-EAF production route are outlined in *Figure 3*, assuming that electrolytic hydrogen (renewable or otherwise) is used**.** Essentially, iron ore pellets are used as a raw material input into the shaft furnace, where heated hydrogen reduces the oxygen in them to produce solid sponge iron. This sponge iron is then introduced into an EAF, together with a variable fraction of steel scrap, and melted to obtain molten (liquid) steel. Small amounts of natural gas and coal are also burned in the EAF, and other elements such as lime and carbon powder are introduced to ensure that the correct steel composition is obtained. As with the conventional BF-BOF pathway, auxiliary processes to prepare the iron ore pellets, produce lime, and continuously cast the liquid steel are also present (but are excluded from the system boundary for analyses in this study). The H2-DRI-EAF production route has significant potential for the recovery of waste heat from unreacted hydrogen in the shaft furnace, and investigations are underway to increase this recovery rate.

There are a variety of configurations of the H2-DRI-EAF process which impact its overall environmental and economic performance. Firstly, hydrogen production may occur on- or off-site. If production occurs on-site and the hydrogen is renewable, the configuration must necessarily contain a hydrogen storage sub-system due to the variability of renewable electricity. Secondly, additional installations can reduce energy consumption and emissions, for example recovering and recycling waste heat from the shaft furnace or capturing CO_2 emissions from the EAFs. Finally, the DRI-EAF process can be integrated or separated: in the former, the DRI and EAF are co-located and the sponge iron is fed to the EAFs shortly after production on a continuous basis

---

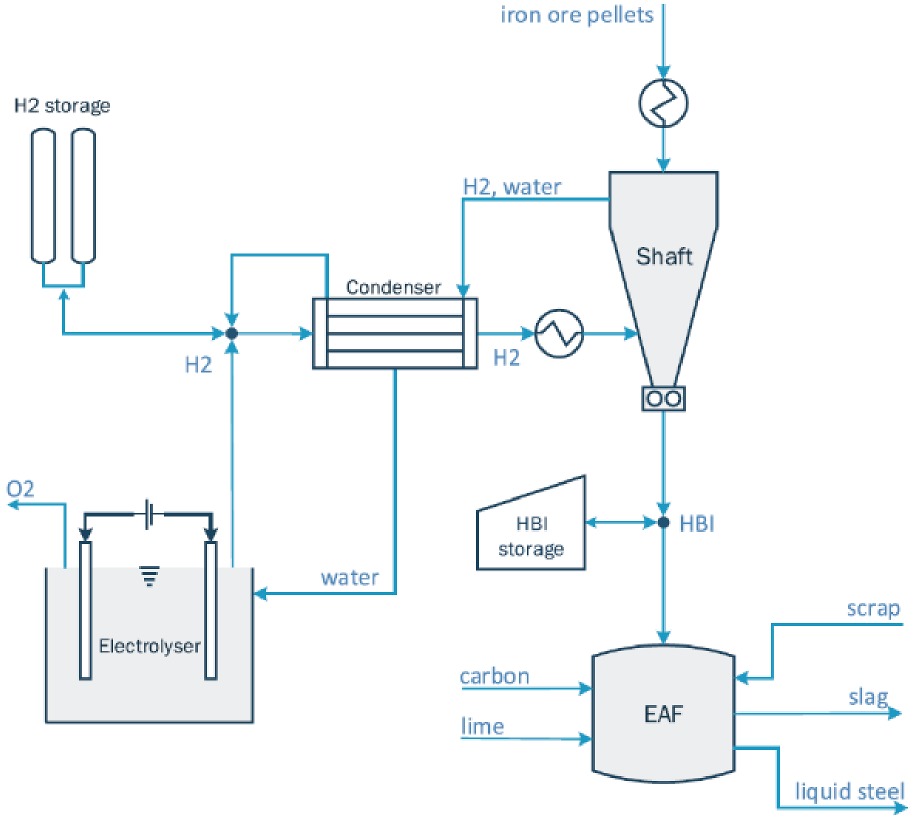
[11] For example, in the Thysenkrupp tkH2Steel project.

[12] Theoretically, coke can be replaced with hydrogen in a BF, but this only results in a small CO_2 reduction. There are some studies on the effects, and Tata Steel has tested injecting 40% hydrogen in a BF.

[13] It should be noted that this ratio of 30% hydrogen/70% natural gas (energetic ratio) is applicable to the gases used for the DRI process, and not to the total gas input to the system. The natural gas required for heating is only marginally affected by the above ratio. Moreover, more hydrogen requires more heat input in the shaft furnace, produced by injecting more natural gas and oxygen into the furnace, but theoretically also attainable by other energy sources, including hydrogen, waste heat, or electricity.

and at a high temperature[xliii], lowering the energy requirements of the EAF.[xliv] In the latter case, the DRI plant and EAFs may be at different locations, and the sponge iron needs to be temporarily stored and transported, resulting in a cooling of this intermediary product and a higher energy demand to re-heat it for melting in the EAFs. The transport of sponge iron over long distances requires it to be compacted into hot briquetted iron (HBI) or cold briquetted iron (CBI) and a controlled atmosphere due to its reactivity with atmospheric oxygen.[xlv]

Figure 3. Basic configuration of a H2-DRI route using electrolytic hydrogen, reproduced from Vogl et al, 2018, assuming on-site production of hydrogen through electrolysis. Pellet preparation, lime production, and continuous casting are not included in the system boundaries of this configuration. The useful output of the system is liquid steel from the EAF. H2 refers to hydrogen, and O2 to oxygen. "HBI" refers to hot briquetted iron, a compacted form of sponge iron that can be transported to an offsite EAF.



The above is not an exhaustive list of all possible configurations of a H2-DRI-EAF process, and performance will depend on the particular configuration. The system characteristic with the highest impact on the process performance is whether or not hydrogen electrolysis is integrated into the steel production process; other characteristics have a marginal role.

Applications of H2-DRI-EAF

Although the H2-DRI process is mature and well understood, it is yet to be implemented at industrial scale worldwide. Recently, a number of projects have been launched in Europe for implementing H2-DRI using renewable hydrogen at industrial scale, including the flagship project HYBRIT in Sweden, H2future in Austria, and H2ermes in the Netherlands. Other relevant initiatives include Energiron, testing DRI with more than 90% hydrogen in a test facility in Monterrey and Arcelormittal's H_2-DRI demonstration unit.

The main barriers to widespread implementation of H2-DRI-EAF are the lower cost of the BF-BOF route (likely to change in the EU with progressive increases in emissions costs), the complexity of the H2-DRI process (in particular the significant requirement for low-carbon hydrogen and associated infrastructure), and the quality of the iron ore required for the process (unlike the BF-BOF route, DR-grade ore is required to contain a high content of iron and low amounts of gangue minerals[xlvi,xlvii]). One solution for overcoming some of these barriers is to use NG-DRI in a transitional period and progressively switch to H2-DRI as renewable hydrogen becomes available in the required volumes. NG-DRI is already widely used in parts of the world where natural gas is abundant, and the H2-DRI process is similar in configuration.[14] Switching from NG-DRI to H2-DRI would require relatively minor changes in the design of the DR unit reactor.[xlviii]

The H2-DRI process may be particularly suitable for decarbonising steel production at Liberty Galați. The plant is situated in an area of good renewable energy potential to supply electricity to EAFs and for hydrogen production, including the adjacent Dobrogea region which has good potential for large-scale renewable hydrogen production[xlix]. The processing in steel mills of liquid steel is largely unaffected by the switch from BF-BOF to H2-DRI-EAF, and can produce the superior steel grades required by the automotive sector, among others, that were originally only possible in integrated mills with BF-BOF.[l] High-volume, integrated DRI-EAF mills are thus capable of competing in product quality with conventional BF-BOF processes on the steel market, which Liberty Galați has good access to thanks to its land, riverine, and maritime transport corridors.

The GREENSTEEL plan in detail

The GREENSTEEL plan aims to reduce full-chain CO_2 emissions from steel production from 1.8 tCO_2/tls to 0.75 tCO_2/tls (by the end of phase 3) and finally to 0.22 tCO_2/tls (by the end of phase 4), in parallel with increasing production to 4.1 Mtls/year. The ambition of the company is to also transform the Galați region, a Just Transition territory of Romania, into a hub for green steel, renewable hydrogen, and clean energy production.[li] As of 2021, Liberty Galați had signed an MOU with various R&D service providers to investigate "research, innovation and business development of novel energy production technologies and fuels, particularly hydrogen."[lii]

As outlined in its GREENSTEEL plan, the decarbonisation of Liberty Galați will occur in a series of phases (Table 3),[liii] further broken down by the authors of this study into sub-phases. Phases 1 and 2 are primarily concerned with improving the quality of final products[15] and an initial increase

---

[14] The NG-DRI process involves reforming natural gas to produce hydrogen and carbon monoxide, subsequently used as reducing agents in a shaft furnace. In a H2-DRI process using electrolytic hydrogen, the hydrogen source would simply change from natural gas reforming to electrolysis.

[15] Liberty Galați has announced plans to invest €30 million to install an accelerated cooling unit for its thick sheet mill, to improve product quality and expanding its range of high-value products. The installation is planned to be completed in 2024.

in production to 3.2 Mt/year of liquid steel. In phase 3 (sub-phases C-D), the DRI-EAF process replaces the BF-BOF process,[16] initially using NG-DRI, and production increases to 4.1 Mt/year. In the final phase 4 (sub-phases E-F) renewable hydrogen is progressively mixed in, reaching 100% by the end of the transformation in 2030. Phase E (DRI with a blend of natural gas and hydrogen, or NG/H2-DRI) is not specifically mentioned in the GREENSTEEL plan, but has been assumed by the authors to facilitate the transition to 100% hydrogen. A blend of 30% hydrogen and 70% natural gas (by energy content) is assumed for Phase E. Annex 2. Process diagrams for the GREENSTEEL transformation phasesshows the process diagrams of each transformation phase.

Table 3. Phases of the GREENSTEEL transformation plan of Liberty Galați. Phases 1-4 are as publicly stated by the company, while subphases A-F are based on the authors' assumptions of the progressive increase in capacity and replacement of natural gas with hydrogen as a reducing agent.

Phase	**1**	**2**	**3**		**4**	
Sub-phase	**A**	**B**	**C**	**D**	**E**	**F**
Steel manufacturing process	BF-BOF	BF-BOF	NG-DRI	NG-DRI-EAF	NG/H2-DRI-EAF	H2-DRI-EAF
Production	2.35 Mt/year	3.2 Mt/year	3.2 Mt/year	4.1 Mt/year	4.1 Mt/year	4.1 Mt/year
Phase description	Improve product quality	Increase capacity	Change process (NG-DRI)	Increase capacity	Blend H_2 in natural gas (30%/70%)	Change process (100% H2-DRI)

The following section presents an analysis of the energy consumption and emissions of the steelmaking process across all transformation subphases. For each subphase using hydrogen, energy consumption and emissions are estimated both for the scenario of producing renewable hydrogen entirely on site (i.e., Liberty Galați bears the associated electricity consumption) and of purchasing it from an external supplier (i.e., the associated electricity consumption is borne by a third-party producer). Liberty Galați has indicated a preference for producing hydrogen locally, however, it remains unclear whether hydrogen would be produced on-site, off-site, or a mix of the two (and if the latter, in what proportion). The energy consumption and emissions from the EAF are analysed for three scenarios, based on the fraction of steel scrap used: 0% scrap (unlikely, for reference only), 0.36 Mt/year (current use), and 1.45 Mt/year (projected use by 2030 under the GREENSTEEL plan[liv]).

The main assumptions of the analysis are outlined in Annex 3. Assumptions used in case study estimations. The most important assumption is that the transformation process will proceed as outlined in the GREENSTEEL plan. As the most popular DRI technology, the MIDREX ® DRI process

---

[16] As stated by Liberty Galați, the progressive replacement of BF-BOF by DRI-EAF will begin with the installation of two hybrid EAFs.

is used to underpin the system configuration for the DRI-EAF production route. Auxiliary processes (lime production and downstream processes: continuous casting, cast steel processing) are not considered; as such, the energy consumption and emissions of the GREENSTEEL transformation phases are analysed relative to those of the current sinter-BF-BOF process chain (Figure 2).

Implications of the GREENSTEEL plan

Energy consumption

In the initial phases of the GREENSTEEL plan (phases A and B), energy consumption will increase in line with the increase in production. For an output of 3.2 Mt liquid steel/year, the natural gas consumption of the BF-BOF process increases from 41.5 kilotonnes (kt)/year to 56.55 kt/year, and its electricity consumption from 362.37 GWh to 493.44 GWh. The energy consumption of the auxiliary processes obviously also increases, but is not covered in this analysis.

In phases C and D, where the BF-BOF process is replaced by NG-DRI-EAF and production increases from 3.2 to 4.1 Mtls/year, coke use is slashed by nearly 95%, and electricity is primarily consumed by the EAFs and for heating iron pellets (Table 4). Natural gas is primarily used to produce syngas for the DRI process, to increase process temperature in the shaft furnace, and in residual amounts in the EAF. The specific consumption of natural gas is reported as a range due to data uncertainty in the specific consumption of the DRI unit (150.27 kg/tls[lv] - 191.8 kg/tls[lvi]).

Transitioning to NG-DRI-EAF, coupled with the increase in production, means that the electricity consumption of liquid steel production will increase nine-fold by the end of Phase D, relative to the end of phase B (assuming the use of 1.45 Mt of steel scrap; if less is used, electricity consumption would be even higher, as shown in Table 4), without accounting for auxiliary processes. Natural gas consumption also increases substantially, with consumption also higher the less scrap steel is used (Table 4).

Table 4. Energy consumption for phases C and D (only for the DRI-EAF process, excluding auxiliary processes). Note that the quantities of steel produced from scrap are slightly different than the quantities of scrap used (1.1 tonnes of steel scrap are used to produced 1 tls), and correspond to 0, 0.36 and 1.45 Mt of steel scrap, respectively. The ranges of natural gas consumption correspond to estimates by Millner et al (lower range) and Rechberger et al (higher range).

		Phase C			Phase D		
Steel production	Annual steel production (Mt)	3.2			4.1		
	Steel produced from scrap (Mt)	0	0.33	1.32	0	0.33	1.32
	Steel produced from ore (Mt)	3.20	2.87	1.88	4.10	3.77	2.78
Electricity consumption	Electricity consumption (EAFs) (GWh)	2409.6	2381.5	2296.2	3087.3	3059.2	2973.9
	Electricity consumption (pellet heating) (GWh)	1395.2	1252.5	820.5	1787.6	1644.9	1212.9
	Electricity consumption (NG-DRI unit) (GWh)	384.0	344.7	225.8	492.0	452.7	333.8
	Total electricity consumption (GWh)	3203.2	3021.2	2470.3	4104.1	3922.1	3371.2
Natural gas consumption	Total natural gas consumption (million Nm3)	666.1-842.8	599.1-757.7	369.2-500.2	853.4-1079.8	786.4-994.8	583.6-737.2

In phase E, renewable hydrogen is introduced into a mix with natural gas in a proportion of 30%, resulting in an annual requirement of 48,400-65,100 tonnes of hydrogen/year if 1.45 Mt steel scrap is used (if less steel scrap is used, the hydrogen requirement will be higher). The production of these volumes of hydrogen would require between 2,193-2,949 GWh/year of electricity (Table 5), which must be from renewable sources if renewable hydrogen is to be used. In this phase, natural gas consumption begins to decrease, due its partial replacement with hydrogen.

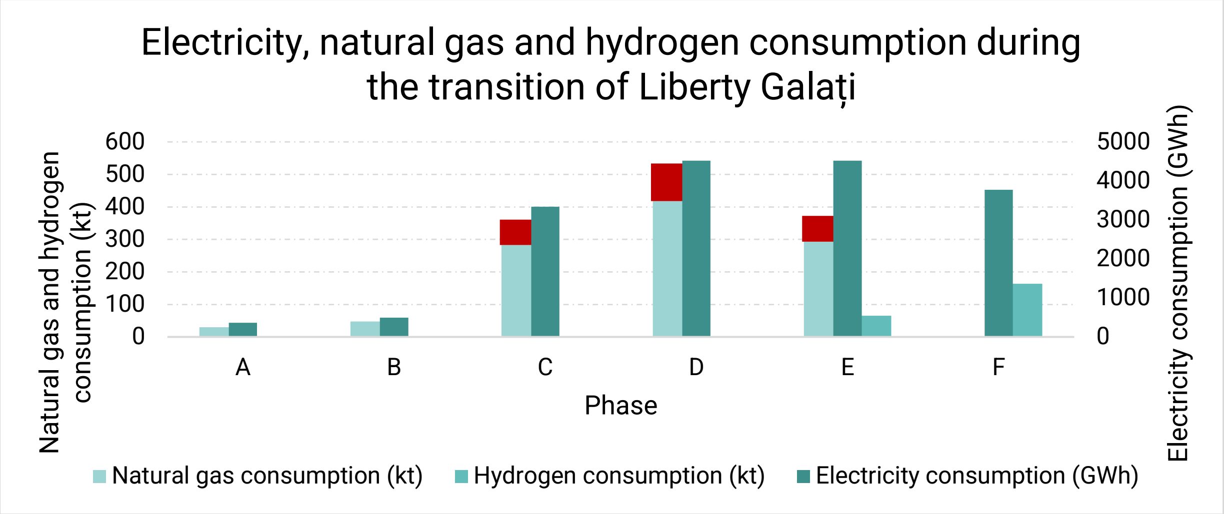
Table 5. Energy consumption for phase E (only for the DRI-EAF process, excluding auxiliary processes). Note that the quantities of steel produced from scrap are slightly different than the quantities of steel scrap used (1.1 tonnes of steel scrap are used to produced 1 tls), and correspond to 0, 0.36 and 1.45 Mt of steel scrap, respectively. The ranges of natural gas consumption correspond to estimates by Millner et al (lower range) and Rechberger et al (higher range).

		Phase E		
Steel production	Annual steel production (Mt)	4.1		
	Steel produced from scrap (Mt)	0.00	0.33	1.32
	Steel produced from ore (Mt)	4.10	3.77	2.78
Electricity consumption	Electricity consumption: EAFs (GWh)	1824.5	1824.5	1824.5
	Electricity consumption: iron ore pellet heating (GWh)	1787.6	1644.9	1212.9
	Electricity consumption: NG-DRI (GWh)	492.0	452.7	333.8
	Electricity consumption: hydrogen production (GWh)	3232.1-4346.7	2974.1-3999.7	2193.0-2949.2
	Total electricity consumption at Liberty Galați (GWh) (hydrogen produced on-site)	7336.2-8450.8	6896.3-7921.8	5564.2-6320.4
	Total electricity consumption at Liberty Galați (GWh) (hydrogen produced off-site)	4104.1	3922.1	3371.2
Natural gas consumption	Total natural gas consumption (million Nm3)	574.5 - 730.0	528.7-671.8	389.8-495.3
Hydrogen consumption	Total hydrogen consumption (kt)	71.3-95.9	65.6-88.3	48.4-65.1

In Phase F, the final phase of the transformation process, hydrogen consumption increases to 164,100 tonnes per year. Small amounts of natural gas, coke and coal are required for the H2-DRI process and the EAFs. Electricity consumption of the steelmaking process decreases slightly, and similar to Phase E varies depending on the amount of scrap used in the EAF. By far the largest component of electricity consumption is the production of hydrogen through electrolysis: if using 1.45 Mt of scrap steel annually, the electricity consumption of the steel production site would range between 10,935 GWh/year if hydrogen is produced on-site, and 3,483 GWh/year if it is purchased from a third party.

Across the GREENSTEEL transformation, the fuel mix of the steelmaking process will have changed from primarily fossil-based (coke, natural gas) to primarily based on electricity and hydrogen, with electricity consumption increasing dramatically even if hydrogen is assumed to be produced off-site (*figure 4*). The increase in electricity and hydrogen demand at Liberty Galați will be significant, as stressed by the company itself,[lvii] and will require a significant amount of new energy capacity to be installed. If this hydrogen is to be entirely renewable (as is the ambition of the GREENSTEEL plan), the required additional renewable energy capacity of the steel plant in phase F would range between 2.02 GW (if the hydrogen is produced outside Romania and imported), and 6.35 GW (the electricity capacity required for steel production and that for hydrogen production, if the hydrogen is produced inside Romania, whether at Liberty Galați or not).[17] These are equivalent to approx. 43% and 136%, respectively, of the total installed renewable energy capacity (wind and solar energy) in Romania as of January 2024.[lviii] Should a mix of renewable and non-renewable hydrogen be used (e.g., a minimum of 42% renewable hydrogen from 2030, and 60% from 2035, as per the revised EU Renewable Energy Directive), the required installed capacity would decrease correspondingly.

Figure 4. Evolution of yearly electricity, natural gas and hydrogen consumption across the phases of the GREENSTEEL plan, assuming offsite hydrogen production and 1.45 Mt scrap steel use in phases C-F. Only the energy requirements of the BF-BOF/DRI-EAF systems are shown. For natural gas consumption, the range is from Millner et al (lower range, orange bars) and Rechberger et al (higher range, orange plus red top bars).



CO_2 emissions

The emissions associated caused by steel production at Liberty Galați are of the Scope 1 type (emissions generated on-site) and of the Scope 2 type (emissions generated in the production of electricity consumed by the plant). The GREENSTEEL plan foresees a reduction in specific CO_2 emissions to 0.22 tCO_2/tls after a complete switch to renewable hydrogen.[18] These values are assumed to be Scope 1 emissions from the full-chain process; in this study, only Scope 1

---

[17] These estimations are based on the assumptions of Romania's National Hydrogen Strategy, which assumes an electrolyser load factor of 3445 hours/year, corresponding to the requirements of the revised Renewable Energy Directive (RED III). The Strategy estimates that the production of 152,900 tonnes of green hydrogen will require an installed renewable power capacity of 4.2 GW and 2.1 GW of electrolysers operating with a load factor of 3445 hours/year. This allows the calculation of the average load capacity for renewable energy assumed in the Strategy (19.658%).

[18] The GREENSTEEL plan sets a target of 0.22 tCO_2/tls for the ultimate carbon intensity of its steel production (although the timeline for this is not clear, and in other parts of the plan the target is referred to as 0.3 tCO_2/tls).

emissions within the system boundaries are analysed,[19] as the BF-BOF process and associated sintering are the primary drivers of emissions in conventional primary steel production.[lix]

In subphases A and B, emissions within the system boundary of the BF-BOF and sintering process increase in line with the ramp-up in production, from 3.51 Mt CO_2/year to 4.78 Mt CO_2/year (using the reference value of 1.494 tCO_2/tls mentioned above). The transition to subphase C comes with a massive reduction in emissions due to the process change from BF-BOF to NG-DRI-EAF, and emissions continue to decline across subsequent subphases (Table 6). Our estimations indicate that if the transformation plan is successfully implemented, the only remaining Scope 1 emissions from liquid steel production would be process emissions from the EAFs, as low as 0.085 tCO_2/tls by the end of Phase F (a 94% reduction compared to conventional production). As shown in Table 6, CO_2 emissions in phases C-F vary with the amount of scrap steel used – higher proportions of scrap result in lower emissions due to the decreased consumption of fossil fuels in the EAF.[lx] Even if Liberty Galați were to use no scrap in its steelmaking, emissions from liquid steel production in phase F would be 93% lower than current values (Table 6).

Table 6. Direct (Scope 1) CO_2 emissions from Liberty Galați across transformation phases. Emissions are from the BF-BOF/DRI-EAF processes only. In sub-phase D, production increases from 3.2 Mt liquid steel/year to 4.1 Mt. The ranges in emissions for phases C, D and E are due to the use of a lower and higher range of values for natural gas consumption in the NG-DRI process, as per Millner et al and Rechberger et al.

Amount of steel scrap used (Mt/year)	**Phase**	**3**		**4**	
	Sub-phase	**C**	**D**	**E**	**F**
0	Specific CO_2 emissions (kg CO_2/tls)	246.6-285.2	246.6-285.2	167-193.5	106.94
	Total CO_2 emissions (Mt CO_2)	0.79-0.91	1.01-1.17	0.68-0.79	0.438
0.36	Specific CO_2 emissions (kg CO_2/tls)	225.3-259.9	230-265.5	155.6-180	101.4
	Total CO_2 emissions (Mt CO_2)	0.72-0.83	0.94-1.09	0.64-0.74	0.415
1.45	Specific CO_2 emissions (kg CO_2/tls)	160.7-183.4	179.6-205.8	121.2-139.2	85
	Total CO_2 emissions (Mt CO_2)	0.51-0.59	0.74-0.84	0.5-0.57	0.348

An essential note is that the above estimates refer to Scope 1 emissions only. However, the GREENSTEEL transformation will not contribute to deep decarbonisation of the Romanian steel sector unless the electricity consumed is 100% renewable (including for any domestic hydrogen production), and thus Scope 2 emissions are minimised.[20]Indeed, as a future hydrogen consumer,

---

[19] These emissions cover direct emissions (i.e., process emissions and on-site fuel combustion for process heat) of the sintering (agglomeration) plant, BF, BOF, desulphurisation, ladle furnace, and vacuum degassing units. They also include the emissions associated with the blast furnace gas evacuated from the BF to the on-site heat and steam plants (2,009 million Nm^3 in 2021, assumed to result in a volumetric proportion of 42% CO_2 when combusted).

[20] Low-carbon hydrogen can be produced through methods other than renewable electrolysis, but they come with their own sets of challenges. For example, blue hydrogen, a non-electrolytic type of hydrogen relying on conventional production methods with added CO_2 capture, presents efficiency issues, questionable emissions reductions, and a reliance on natural gas, including associated challenges with fugitive methane emissions. Pink hydrogen, an electrolytic type of hydrogen which uses nuclear energy, is a more credible option, especially if a hydrogen production unit is attached to the Cernavodă NPP to also provide nuclear curtailment benefits, or if using a small modular reactor

Liberty Galați will be obliged by the revised EU Renewable Energy Directive to meet the targets for consumption of Renewable Fuels of Non-Biological Origin (RFNBOs) and ensure that at least 42% of the hydrogen it consumes is renewable from 2030 onwards, rising to at least 65% after 2035.[lxi] If electricity from Romania's grid is used to make up the remaining electricity demand, the result is a large discrepancy between planned and actual reductions in specific emissions per tonne of liquid steel (Table 7). At the current carbon intensity of Romania's national electricity grid, using grid electricity to both power the EAFs and produce the remaining necessary hydrogen would lead to specific emissions of 0.83 tCO_2/tls in 2030, propagating to emissions of nearly 3.1 Mt CO_2/year in the Romanian economy; these specific emissions would reduce to 0.688 tCO_2/tls by 2035 in line with the increased requirements of the Renewable Energy Directive, or 2.56 Mt CO_2/year (Table 7). This means that even if RFNBO targets are met, in 2035 primary steelmaking would still be contributing approx. 3.3% of Romania's total CO_2 emissions, a substantial amount given Romania's commitment to reduce emissions by 95% by 2050.[lxii]

Table 7. Scope 1 and Scope 2 CO_2 emissions from Liberty Galați DRI-EAF process by the end of subphase F, depending on the source of electricity used and the associated cost of emissions at €85/tCO_2. Assumes the use of 1.45 Mt of scrap for steel production.

Direct electricity and hydrogen sources	**Associated CO_2 emissions for final (Phase F) operations (tCO_2/tls)**	**Annual emissions cost (€/year, at 4.1 Mtpa production)**
Renewable electricity and electrolytic renewable hydrogen	0.085	29,622,500
Grid electricity and electrolytic renewable hydrogen	0.381	132,778,500
Renewable electricity and electrolytic hydrogen meeting minimum RFNBO targets	0.453 (2030-2035)	157,847,979
	0.307 (2035 onwards)	106,999,944
Grid electricity and electrolytic hydrogen meeting minimum RFNBO targets	0.834 (2030-2035)	290,753,550
	0.688 (2035 onwards)	239,855,125

As shown in Table 7, the annual carbon cost of Liberty Galați's transformation could be as high as €290.8 million per year at current average ETS costs of €85/tCO_2. Only a small part of these costs would be borne by Liberty Galați directly: the direct emissions associated with the EAF, equivalent to €29.6 million/year at current ETS costs. The remaining costs (those of Scope 2 emissions from producing the electricity used for powering the EAFs and for producing the hydrogen) would be distributed across Romanian electricity and hydrogen producers, and assuming a well-functioning market, would eventually be passed through to customers. This means that even if Liberty Galați does not bear the cost of Scope 2 emissions, it may still be cheaper to use renewable electricity and hydrogen, rather than grid electricity, particularly if ETS prices keep rising as predicted.[lxiii]

(SMR), many of which are still in the design phase and face technical and cost challenges. However, the costs of pink hydrogen production may be higher than green hydrogen if supplied by new energy capacities, as the levelised cost of electricity (LCOE) is higher for nuclear energy than for renewables. Source: Romanian National Hydrogen Strategy.

It follows that deep decarbonisation at Liberty Galați and alignment with Romania's trajectory to achieve net zero emissions by 2050 will be impossible unless the plant's future hydrogen demand can be fully met by renewable hydrogen, and its future electricity demand by renewable electricity. Liberty Galați's current plans to install 200 MW of solar and wind energy on-site would only generate approx. 10% of the DRI-EAF's total electricity requirement in 2030; if renewable hydrogen is produced on-site, this renewable capacity would only cover 2.2% of the electricity requirement of the DRI-EAF and the electrolysers, leaving a substantial gap to be covered from self-produced or purchased renewable electricity. Even if the electricity used for hydrogen production is ignored, achieving Liberty Galați's target of 0.22 tCO_2/tls using grid electricity for steelmaking would require the carbon intensity of Romania's grid to almost halve. If hydrogen production is included, this carbon intensity would need to decrease by 85%, equivalent to generating an additional 9.3 terawatt-hours (TWh) of clean energy, in turn equivalent to an additional capacity of 8 GW of solar energy, 4.4 GW of onshore wind energy, or 2.7 GW of offshore wind energy (assuming capacity factors of 13.2% for solar PV panels[lxiv] and 24% for onshore wind turbines[lxv], for the Galați region, and 40% for offshore wind turbines in the Black Sea).

It is worth reinforcing that this study only looks at emissions from the BF-BOF (including sintering) and DRI-EAF processes of steelmaking. Emissions from auxiliary processes could be reduced through other decarbonisation technologies, for example by capturing the CO_2 emissions from lime kilns and replacing residual natural gas with green hydrogen for generating process heat, for example in the continuous casting process. Substituting natural gas for green hydrogen as a heating fuel would of course increase the overall hydrogen demand Liberty Galați.

Costs

It is difficult to estimate the costs of the transition to net-zero steelmaking, given that they will depend heavily on the particularities of the site and the country and question, as well as the uncertainties around the cost of key components, such as hydrogen production. In this section, we briefly present high-level estimates for the costs of key components of the GREENSTEEL plan, based on values from the literature, with a more detailed analysis of cost implications due to be conducted in 2024. Only the technology costs (i.e., investment costs for the H2-DRI-EAF pathway) and fuel costs of renewable hydrogen are estimated. Further analysis is required to determine the cost of electricity consumption, given its staggering increase, any potential additional costs due to a change in raw material inputs (higher-quality iron ore, scrap steel) and resulting auxiliary processes (decontamination of steel scrap), and labour costs. All additional costs should also consider avoided costs (for example, the cost of emissions certificates) and other additional revenues (for example, tax rebates or premiums charged on green steel) as sources of credit, to build a complete picture of the business case for the GREENSTEEL plan.

The average cost of steel production via the integrated BF-BOF route in the EU is currently estimated in the €400-€450/tonne range,[lxvi,lxvii] with the largest cost component being raw materials such as iron ore and scrap (38.4% of total costs). Today, the H2-DRI-EAF route is estimated to be the most expensive at €659[lxviii]-€756[lxix]/tonne, with 36%-39% of the cost being from raw materials (iron ore and scrap), and another 38%-40% from the cost of electricity for renewable hydrogen production.[21] Although the BF-BOF route is currently the cheapest of all steel production routes, the cost gap begins to close in 2030, when BF-BOF production costs are estimated to rise to €538/tonne due to the increase in carbon costs. By 2050, the BF-BOF route is no longer competitive in the EU due to staggering carbon costs, and the H2-DRI-EAF production route, at €565/tonne, becomes the cheapest way to produce steel, mostly driven by a reduction in the cost of electricity for hydrogen production (under the assumption of decreasing electricity costs in parallel with an increase in electrolyser efficiency and lifetime).[lxx]

If a typical European steel plant operates the BF-BOF route today and switches to the H2-DRI-EAF route by 2030, as is the aim of Liberty Galați, its specific costs of steel production are estimated to be 29% higher in 2030.[lxxi] However, this assumes that a full switch happens in 2030, taking advantage of the future lower costs of hydrogen production; if a switch from BF-BOF to H2-DRI-EAF were to happen today, steel production costs would increase by 61%,[lxxii] given the higher costs of hydrogen production and the relatively low cost of CO_2 emissions which keep the BF-BOF route cheap today. This would lead to steel costs of €531.5 - €663.3/tonne if we assume a cost of €412/tonne for current BF-BOF production; given the timeline of the GREENSTEEL plan the actual cost would probably lie somewhere in the middle. The increase is primarily driven by higher operating (OPEX) costs (mainly the cost of hydrogen), with capital costs for greenfield H2-DRI-EAF actually estimated as being lower than for greenfield BF-BOF sites today.[lxxiii] For switching to NG-DRI, estimates of cost increases are less clear, with some suggesting that an NG-DRI plant equipped with carbon capture (an expensive installation) would be cheaper than an NG-DRI plant with no carbon capture, even today (€575[lxxiv] and €616/tonne[lxxv], respectively).

Within these general cost increases expected from the transition to low-carbon steelmaking, including the GREENSTEEL plan, there are several main costs that should be considered: the capital costs of the new units themselves, the cost of new fuels (renewable hydrogen), and the increase in cost of electricity consumption. The main new units required for a transition to DRI-EAF steelmaking are the DRI unit and the EAFs. The cost of the DRI unit will depend on the amount of sponge iron produced in the DRI-EAF pathway; assuming the use of 1.45 Mt of steel scrap, as outlined in the GREENSTEEL plan, and an investment cost of €185/tonne of sponge iron,[lxxvi] the estimated investment cost of a DRI unit at Liberty Galați would be €514.3 million. EAF investment costs are estimated in the literature at reference values of €184/tonne of crude steel,[lxxvii] resulting in an EAF cost of just under €755 million, and the use of 1.45 Mt of steel scrap (the latter equivalent to 1.32 Mt of liquid steel). Other investment costs are associated with auxiliary units for the DRI-EAF process (e.g., pelletising and decontamination units); while they are not detailed in this study, they will be included in a future cost assessment.

Table 8. Costs of DRI and EAF units, based on estimates from the literature and assuming the use of 1.45 Mt of steel scrap for a total production of 4.1 Mt liquid steel. For the EAFs, a specific cost of €184/tonne of liquid steel is assumed.

Unit	**Assumed size (yearly production, Mtls)**	**Estimated cost (million €)**
DRI unit	2.78	514.3
EAFs	4.1	754.4
Total	4.1	1,268.7

---

[21] The range in shares shown here is due to different estimates from the literature.

The second main cost component of the GREENSTEEL plan, and as shown above one of the most important cost drivers of H2-DRI-EAF steel production today, is the cost of renewable hydrogen. This cost component depends significantly on the particularities of renewable hydrogen production (how close it is to the steel production site, what the renewable energy potential of the relevant geography is, etc.), and the operational cost of steel production is highly vulnerable to its variations given its large share in final costs. By 2030, the levelised cost of renewable hydrogen production in Romania is estimated by the National Hydrogen Strategy to reach €3.59/kg (from a current cost of €4.56 for alkaline electrolysis or €5.4 for proton exchange membrane, or PEM, electrolysis); our estimates indicate a lower cost range of €1.6-€2.4/kg of hydrogen.[lxxviii] These costs include the capital costs of electrolysers and therefore may be lower if Liberty Galați does not own and operate on-site hydrogen production, and if the electrolyser capital cost is not passed through into the price of hydrogen by a third-party producer. It should also be noted that these costs are estimated at national level; if hydrogen production is located in areas of high renewable energy potential (for example, the Galați or Dobrogea regions), costs could further decrease.

Table 9. Estimates of annual cost of renewable hydrogen to Liberty Galați, assuming a consumption of 164,100 tonnes of renewable hydrogen per year.

Source of data	**Total annual cost of hydrogen for Liberty Galați in 2030 (million €/year)**
Romania's National Hydrogen Strategy	587.47
Energy Policy Group, 2021 (lower range)	262.56
Energy Policy Group, 2021 (higher range)	393.84

The cost of hydrogen transport and on-site storage will also bring additional capital and operational costs associated with the GREENSTEEL plan; although some of these costs may not be borne directly by Liberty Galați, they must be considered in the context of developing a hydrogen economy in Romania. Transport estimations are highly uncertain, and will depend on the method of transport used and the sizing of the pipeline or shipping containers. Estimates from the literature show costs of $0.3/kg of hydrogen for long-distance pipeline transport (3,000 km or more) and $0.7-$2.1/kg of hydrogen for seaborne transport,[lxxix] equivalent to annual costs of $49.2 million/year for long-distance pipeline transport and $114.8-$344.4 million/year for seaborne transport. If hydrogen storage sub-systems are installed at the steel production site, their capital cost must also be included and will depend on their sizing. If 5 working days' worth of on-site hydrogen storage capacity is considered reasonable, this would translate into hydrogen tank costs of €1.6-€1.9 billion at current tank costs, which are expected to decrease by 2030.[22] Compressor costs are highly variable[lxxx] and too uncertain to be estimated in this study, but should also be considered going forward.[lxxxi]

The final major cost component of this analysis is the increase in electricity costs due to the massive electrification of primary steelmaking. According to a modelling exercise,[lxxxii] by 2030

---

[22] This assumes a tank cost of €500-600/kg of hydrogen, as described by ECCO, 2022.

average electricity prices in Romania will be €112.4/megawatt-hour (MWh) in a reference scenario. Assuming off-site hydrogen production, this equates to a total electricity cost of €424.3 million/year from the H2-DRI-EAF process if grid electricity is used, which is over €380 million higher than current electricity costs from the BF-BOF process (estimated at €42.12 million assuming an average cost to industrial producers of €192/MWh, as quoted by the Association of Large Energy-Intensive Consumers of Romania[lxxxiii]). If Liberty Galați installs on-site hydrogen production, the cost of using grid electricity would be much higher.

This very rough cost estimate of the GREENSTEEL transformation shows significant capital and operational costs for Liberty Galați, even when using the lowest ranges of estimates and assuming off-site, but local, hydrogen production (therefore no investment in electrolysers or operational costs for long-distance hydrogen transport). This is reflected in estimates in the literature for primary steelmaking: despite the BF-BOF route no longer being a competitive steelmaking route in the EU by 2050, the cost of steel production through the cheapest steelmaking route (H2-DRI-EAF) will still be higher in 2050 than the cheapest steelmaking route today (BF-BOF). This implies that steel costs will overall increase in the coming three decades, raising the critical importance of competitiveness and a robust lead market for low-carbon steel. It should be noted that these costs are by no means exhaustive, and importantly must be viewed in conjunction with the avoided costs of emissions certificates in 2030 (estimated at €491 million/year in savings even after a doubling of production, at current certificate prices[23]), and the potential premium to be charged on green steel products, particularly from the automotive industry which represents around half of Liberty Galați's customer base. However, it is clear that state intervention will be required to support the investments required for the GREENSTEEL plan, as well as potentially support some of the plant's operational costs over a limited time period.

Table 10. Lowest estimates of selected costs of the GREENSTEEL transformation plan at Liberty Galați, based on reference values from the literature and assuming no electrolyser ownership or long-distance hydrogen transport.

Capital costs	
Cost component	**Lowest-range estimate (million €)**
DRI unit	514.3
EAFs	754.4
Hydrogen storage system	1,600
Total capital costs analysed	2,868.7
Operating costs	
Cost component	**Lowest-range estimate (million €/year)**
Hydrogen costs	262.4
Electricity costs	424.3
Total operating costs analysed	686.7

One cost not covered in the above analysis is the investment cost of the additional renewable energy capacity required to supply steelmaking operations and renewable hydrogen production.

---

[23] Assuming carbon costs of €520.66 million/year for emissions of 1.494 tCO_2/tls from the BF-BOF process, and carbon costs of €29.6 million/year for emissions of 0.085 tCO_2/tls from the H2-DRI-EAF process.

If this renewable energy capacity is produced domestically, it will likely also imply significant costs, supported by a mix of state and private actors. Investments in required infrastructure (see section below), including the electricity transmission grid, potentially hydrogen transport pipelines, and road infrastructure, will also be required.

Infrastructure requirements

Successfully implementing the GREENSTEEL plan could result in deep emissions cuts and increased competitiveness for Romania's primary steel sector, as well as benefitting the wider regional and national economies. However, significant infrastructure deployment will be necessary to achieve deep decarbonisation, for renewable electricity and renewable hydrogen supply as well as transport infrastructure for accessing new markets for green steel products.

Renewable electricity infrastructure

As outlined above, the increase in electricity consumption at Liberty Galați by the end of the GREENSTEEL transformation will be significant. The additional electricity demand from EAFs and electrolytic hydrogen production (assuming domestic production) is equivalent to an additional installed capacity of 2.91 GW for meeting the direct electricity needs of the plant, and an additional 6.52 GW if electrolytic hydrogen production is also included. To align with Romania's net-zero trajectory and avoid very high carbon costs, the majority of this additional electricity capacity must be zero-carbon.

Beyond decarbonising primary steel production, it is also worth noting the potential increase in demand for renewable electricity from secondary steel producers. If EAF producers ArcelorMittal Hunedoara and Donalam Târgoviște, which are operating significantly under their design capacities, returned to their full production capacities, this could add an estimated 630 GWh of annual electricity consumption to the grid. While this is nowhere near the magnitude of the electricity demand from Liberty Galați's future DRI-EAF process, it does add implications for pressure on the electricity grid and for the future geographical distribution of electricity demand.

To effectively decarbonise steel production, Romania will need to both strengthen and modernise its electricity network, and install large-scale capacities of solar PV and wind energy. Firstly, the decarbonisation of Liberty Galați means that the national electricity network will need to accommodate an additional demand of between 3,483 and 10,935 GWh/year, geographically concentrated in south-eastern Romania if hydrogen is to be produced domestically in the high-potential Dobrogea region. This means increasing the grid capacity at transmission and distribution level, increasing interconnection capacity (currently below 10%[lxxxiv] and with a target of 15% by 2030[lxxxv]), elaborating a clear forecast of the evolution of electricity demand, and investigating the possibility of industrial clusters to aggregate demand. Of course, modifications at the steel production site will also be necessary (Liberty Galați is currently connected to the transmission grid through four 110-kV stations).

Secondly, the pace of installing zero-carbon energy capacities must be significantly accelerated. With a slow and uncertain expansion of nuclear energy (conventional and otherwise) and limited prospects for significant new hydropower capacities, the increasing demand for clean electricity must be satisfied by renewable sources. As shown in the estimations of this study, Romania might need to install more than its total currently installed renewable capacities (4.3 GW) to decarbonise the steel production at Liberty Galați. This additional capacity needs to be appropriately accounted for in Romania strategic planning and the national energy targets. In all likelihood, the required energy needs will not be met without the development of Romania's Black Sea offshore energy potential, which still faces bottlenecks in planning and permitting, as well as incoherence across environmental and energy legislation.[lxxxvi]

Hydrogen

If the GREENSTEEL plan is implemented, by 2030 Liberty Galați would consume 164,100 tonnes of hydrogen annually. This will require a significant amount of renewable electricity (over 7,452 GWh per year), electrolyser capacity (approx. 2.1 GW) and infrastructure for transporting and storing hydrogen. Current ambitions for hydrogen development fall significantly short of these requirements, with the national Hydrogen Strategy making provisions for only 23,700 tonnes of renewable hydrogen per year for the steel industry, by 2030.[lxxxvii] Even if Liberty Galați limits itself to meeting the requirements on use of renewable fuels of non-biological origin (RFNBOs) outlined in the revised Renewable Energy Directive, the Hydrogen Strategy provisions would still leave the steel plant with a shortfall of just over 45,000 tonnes of renewable hydrogen in 2030, rising to nearly 83,000 tonnes by 2035.

It is not clear where the required volumes of hydrogen would be produced, nor how they would be transported to Liberty Galați. Hydrogen production close to the consumption site would be the most efficient, avoiding high transport costs and taking advantage of the good renewable energy potential of the Galați region. Galați is also well-positioned to receive hydrogen from the Dobrogea region, where renewable hydrogen potential is high. Even over short distances, the hydrogen supply would need to be matched to demand at the steel plant, either by ensuring a continuous flow regime through pipelines or by uncoupling hydrogen supply from demand using on-site buffer storage.

If hydrogen is to be transported to Liberty Galați over long distances via pipeline, Romania needs to rapidly develop its currently non-existent hydrogen infrastructure. This will require a clear plan for adapting or modernising existing natural gas pipelines and building new ones, where necessary. Liberty Galați is located in a good position, close to existing natural gas transport corridors identified by Transgaz (Romania's gas transport system operator) as requiring little investment for transporting hydrogen. These include the three parallel pipelines linking Isaccea to Negru Vodă, which traverse Dobrogea, and connect to the grids of Ukraine and the Republic of Moldova. In a wider sense, Romania must also look to the EU's plans for regional and European hydrogen infrastructure,[lxxxviii] and how developing a hydrogen supply chain for steel production could launch these efforts. Finally, if non-pipeline hydrogen transport is to be considered, an assessment must be conducted on the cost-effectiveness of importing hydrogen by ship (which implies efficiency losses), compared to that of importing green sponge iron produced abroad (see next chapter).

Transport of green steel to new markets

The global market for green steel is growing, with most demand coming from the automotive industry, where manufacturers are regulated on a life-cycle basis in Europe and margins are large enough that the premium cost of green steel can be absorbed or passed onto consumers more easily, compared to the construction sector. Recent examples are the purchase of SSAB's first batch of green steel by Volvo Trucks, and an agreement between Mercedes-Benz and H2 Green Steel for 50,000 tonnes of steel produced using hydrogen. These type of offtake agreements are crucial for the development of green steel production capacities, and should be put in place even before the design of the plant.[lxxxix]

Although not limited to green steel, the ability of a steel producer to supply products to its customers is dependent, among other factors, on the existence of reliable transport infrastructure for delivering steel products on time. Steel products are generally transported on trucks (over short distances), rail, or ships or barges,[xc] with the three harbours of the Galați port, adjacent to Liberty Galați's facilities, providing access to all three types of transportation[xci]. Maritime transport through the Black Sea is currently under question due to Russian aggression in the area, including piracy concerns[xcii] and mines.[xciii] Riverine transport on the Danube River may require infrastructure investments to increase transport capacity and better connect Romania to other EU countries. In particular, the Baltic Sea-Black Sea naval corridor concept, conceptualized in the 1920s and revived in the last decade by requests from industry, could reduce the distance between the riverine ports of Galați and Gdansk, in northern Poland, by nearly 4,000 km,[xciv] improving access to the Baltic Sea and Northern European markets. For land transportation, Romania's road and rail transport could also benefit from improvements to increase transport capacity and provide better connections with potential buyers, through the modernisation and electrification of rail infrastructure and the construction of new railway tracks.[xcv] In addition to infrastructure connecting green steel suppliers to customers, it will be important to develop new trade agreements to support strategic investments for decarbonising primary steel production.[xcvi]

Socio-economic aspects

The decarbonisation of primary steel production, like any industrial transformation, has wider socio-economic implications. The county of Galați suffered a contraction of its local economy and a shrinking of the industrial workforce following successive periods of restructuring and privatisation after the end of the communist regime in 1990, which led to a massive reduction in the capacity and output of Liberty Galați, the heart of its local economy. However, today Liberty Galați is still the primary economic engine of Galați county: it is the largest employer in Romanian heavy industry,[xcvii] it generates three-quarters of exports and more than a third of GDP of the county, and it provides business for over 200 local suppliers.[xcviii]

Romania's Territorial Just Transition Plan for Galați county aims to avoid job losses driven by the transition to net zero emissions by supporting the decarbonisation plan of Liberty Galați and the reskilling of employees to manage the new low-carbon processes and technologies, in partnership with the local university and vocational schools. [xcix] Indeed, maintaining primary steel production, as envisioned by the GREENSTEEL plan, is an important safeguard of local jobs, as primary steelmakers generally employ more people due to higher production volumes (on the other hand, secondary steel production is more labour-intensive[c]). Although the labour distribution within a steelmaking plant varies significantly by country, a study on German steelmakers finds that iron- and steelmaking make up 15% of jobs (4% and 11%, respectively) at an integrated steel plant, with the remainder in steel finishing.[ci] Maintaining primary steel production would thus safeguard a portion of existing jobs, as well as keeping jobs in steel finishing through enabling a similar range of products and quality standards as current conventional production, as opposed to secondary steel production which results in a lower range of products with potentially lower quality. Evidently, increasing production output to 4.1 Mtls/year would also generate additional jobs, tackling the unemployment rate of Galați county, which in 2019 was nearly twice as high as the national average.[cii]

Beyond safeguarding current jobs and adding new ones due to higher production, employment could be created by the GREENSTEEL transformation itself. Net job creation is difficult to predict, due to the lack of clarity on the actual configuration of the plant. The use of smaller production units (a DRI unit and two EAFs, rather than a single BF-BOF furnace system) could increase labour intensity with a significant effect on local employment. One study finds that transitioning from BF-BOF to hydrogen-based DRI in the Great Lakes region of the United States could result in a shift in employment between –3.8% and +26% throughout the supply chain, including operating upstream renewable energy and hydrogen resources.[ciii] If hydrogen is supplied locally, for which Liberty Galați has indicated an ambition,[civ,cv] its production and storage could also generate new jobs. Temporary jobs from construction and installation should also not be discounted: Thyssenkrupp estimates that construction of the DRI plant and equipment for its Duisburg facility will create more than 400 jobs.[cvi]

Positive knock-on effects for regional value creation could also be driven by a carefully planned transition to low-carbon steelmaking, but it is heavily dependent on adequate reskilling of the workforce. The projected annual demand of 164,100 tonnes of green hydrogen could spur new investments in the Galați county and south-eastern Romania, kick-starting new businesses and attracting investment. Up-skilling existing steel workers and training new ones to manage and maintain low-carbon production processes could lead to increased revenues for local educational and vocational centres, and launch research, development, and innovation locally and nationally. Liberty's GREENSTEEL Academy[cvii] could act as a launchpad for up-skilling and training steel workers, and a higher impact could be achieved through close collaboration with labour unions and research and education institutions.

Alternative Decarbonisation Pathways

The GREENSTEEL plan is not the only option to decarbonising steel production at Liberty Galați. This section outlines the three main alternative pathways: complete conversion to secondary steel production; import of green iron for EAF-based steel production; and BF-BOF production or NG-DRI with carbon capture and storage (CCS). Additional decarbonisation pathways, such as DRI-BOF production or using electrowinning to reduce iron ore are considered unsuitable for Liberty Galați and not analysed in this study.

Conversion to secondary steel production

As the vast majority of steel-related emissions are due to conventional primary steel production, one increasingly debated decarbonisation pathway is the abandonment of primary steel production in favour of secondary steel production. This effectively implies no longer producing steel from iron ore, and instead using primarily scrap steel as an input into EAFs. Secondary steel production using EAFs has much lower emissions than primary steel production (in our calculations, emissions from an EAF are 85 $kgCO_2$/tls, compared to 1,494 $kgCO_2$/tls in the BF-BOF process),[cviii] and relies on a negligible fraction of fossil fuels.

A complete switch to scrap-based EAF steel production at Liberty Galați has several advantages. Firstly, this pathway would avoid the significant investment cost in a DRI unit, as well as the need to source higher-grade iron ore as a raw material. Secondly, it would remove the need for such significant quantities of green hydrogen and associated renewable electricity, meaning less pressure on Romania's national electricity grid and development of renewable energy capacities, already struggling to keep up with EU and national ambitions, than a DRI-EAF pathway powered by renewable hydrogen. If Liberty Galați were to produce 4.1 Mt of liquid steel from scrap alone, the total electricity requirement of the EAFs would be 2 GWh, much lower than the total electricity demand of the DRI-EAF process.

On the other hand, the challenges of switching to scrap-based EAF production are manifold. Firstly, electricity consumption would still increase tenfold compared to current values, and would require the development of new zero-carbon electricity capacities and strengthening of the grid. Secondly, scrap-based steel production cannot achieve the high-grade quality of primary steel, mostly due to the risk of contamination, particularly with copper, of the input scrap steel, and higher-purity streams of scrap will be required to achieve high-quality crude steel and finished steel products. This can be partly mitigated by mixing HBI with scrap steel as an input,[cix] but this comes with its own challenges (see next section). Thirdly, the availability of steel scrap as an input cannot be taken for granted. As mentioned above, Romania already exports over 40% of its scrap steel; if Liberty Galați aims for an annual production of 4.1 Mtls, it would require 4.51 Mt of scrap steel each year, 1.4 times Romania's total yearly scrap generation in 2021.[cx]

Lastly and perhaps most significantly, it is unclear if achieving production volumes of 4.1 Mtls/year is even possible with secondary steel production. Switching to scrap-based secondary steel production invariably leads to a reduction in liquid steel output;[24] total EAF steel production in the EU was 66.5 Mt in 2021, with the largest capacity being 3.85 Mt/year (Cremona, Italy) and most plants having a capacity below 1 Mt/year.[cxi] As such, it may be necessary to maintain at least some amount of primary steel production to continue providing the required volumes of steel to customers in the EU and abroad and to safeguard jobs.

Importing green iron for secondary steel production

It is possible to separate the production of iron and that of steel within a DRI-EAF production process, producing sponge iron offsite and transporting it to EAFs at a different location. In its raw form, sponge iron is porous and prone to re-oxidation (i.e., the reversal of the iron reduction reaction) upon contact with air, and therefore must be compacted for handling and

---

[24] If the BF-BOF steelmaking route is phased out, demand will need to be cut for it to be realistically met by secondary steelmaking and low-carbon primary steelmaking in the forms available today. Source: Fivel, J.D., 2019. Achieving a decarbonised European steel industry in a circular economy.

transportation,[cxii] generally in the form of hot briquetted iron (HBI, compacted at temperatures above 650°C) or cold briquetted iron (CBI, compacted at below 650°C). HBI generally has a higher value to steelmakers compared to CBI due to its higher total iron content.[cxiii]

At a global level, importing "green iron" (i.e., sponge iron produced in a H2-DRI using renewable hydrogen) in the form of HBI could be more efficient and require less infrastructure than a full switch to DRI-EAF steel production, especially if this switch replaces a need to import expensive low-carbon hydrogen. Transporting hydrogen, particularly by ship over long distances, requires conversion to a hydrogen carrier, such as ammonia, which is then cracked and reconverted to hydrogen at the point of import, implying costs, infrastructure needs and efficiency losses at each conversion step. Instead, shipping "embodied hydrogen" in green iron for EAF steel production could present substantial cost advantages (as much as 16% of steel production costs[cxiv]), with savings depending on the availability of cheap hydrogen in the country producing the green iron, and the cost of transport of the HBI (which should be comparable to the cost of transporting iron ore pellets for a full DRI-EAF route). Importing green HBI also introduces additional energy requirements from pre-heating HBI before feeding into the EAF (up to 160 kWh/tls[cxv]) compared to pure scrap-based EAF production.

Importing green iron rather than installing a DRI plant could present cost advantages for Liberty Galați, by removing the need for investment in a DRI unit and the operational costs associated with hydrogen consumption. It would also remove dependence on the highly concentrated DRI technology market, which is prone to bottlenecks.[cxvi] It could also alleviate the pressure to develop significant infrastructure for electricity and hydrogen in Romania, as electricity demand would be much lower (even the additional energy requirement for pre-heating HBI, approx. 656 GWh assuming no scrap use and a production of 4.1 Mt per year[cxvii], is much lower than the electricity requirement for producing hydrogen for a H2-DRI-EAF pathway). The easier storage of HBI compared to hydrogen could reduce dependence on dispatchable energy and increase the use of intermittent renewables in green steel production.[cxviii] Although demand for hydrogen as a reducing agent would drop to zero, small amounts of domestically-produced renewable hydrogen could still be used, for example as a heat source for pre-heating the HBI. This could kick-start a local hydrogen economy while keeping production and infrastructure at a manageable scale in the near future. Furthermore, a transition to green iron imports is likely still a better safeguard to jobs than a transition to secondary steelmaking, with a study on German steelmakers showing the potential to safeguard over 90% of jobs.[cxix]

Nonetheless, there are several disadvantages associated with importing green iron to Liberty Galați, compared to fully switching to an integrated DRI-EAF route. Firstly, the absence of a DRI unit may result in a small decline in the number of created jobs (4% to 8% in the case of German steel plants[cxx]), and the lack of a significant hydrogen requirement may hold back economic development around a local hydrogen economy,[cxxi] including job creation from renewable electricity projects. Secondly, the full energy balance of this pathway must be weighed carefully against that of others, because while DRI (and by extent HBI) is less contaminated than steel scrap, it does have a higher concentration of gangue minerals and iron oxide which needs to be melted and reduced, respectively.[cxxii] Higher gangue concentrations can also lead to more slag (the main waste product from the EAF) which if excessive can lead to less space for liquid steel and an excess of impurities requiring removal (and associated energy needs).[cxxiii] Finally, although substituting steel scrap for green HBI can partially relieve the pressure on scrap flows in Romania compared to secondary steel production, worldwide exporters of HBI are also restricted to a few key geographies, some of them currently under trade sanctions (Russia was the largest exporter of DRI in 2022[cxxiv]). With demand continuing to increase, the global supply of HBI may be squeezed and purchasing costs may be high as a result. Furthermore, transport distances might be long: aside from planned expansions of the Liberty Group in Australia, most of the world's volumes of HBI are produced in the Middle East, North Africa, and Asia.[cxxv] It is most efficient to produce sponge iron as part of an integrated process where it can be transported hot or cool directly to the EAF.[cxxvi]

Ultimately, the feasibility of a decarbonisation pathway involving imported green iron depends first and foremost on its availability at a competitive import cost. This is directly linked to the site of green iron production, which must be abundant both in renewable electricity potential (for green hydrogen production) and in iron ore. Recently, the federal government of Germany backed a green iron production plant in Namibia,[cxxvii] a country with abundant solar resources[cxxviii] and deposits of high-grade iron ore;[cxxix] the plant is currently at pilot stage and will only produce around 15,000 tonnes/year of green iron. For Liberty Galați, there may be green iron available for import from within the Liberty Group itself, as the group is planning to achieve 10 Mt/year green iron production by 2030 as part of its CN30 plan, [cxxx] at least partially through expansion of its Australian iron ore mining operations and associated HBI production at the Whyalla integrated steelworks.[cxxxi] The company's plant at Ostrava, Czech Republic, is already planning a phased switch from BF-BOF production to EAF-based production, potentially using up to 40% HBI alongside steel scrap.[cxxxii]

BF-BOF or NG-DRI with carbon capture

A final decarbonisation route to consider is that of conventional steel production with carbon capture, where the CO_2 emissions from steel production are captured and sequestered away from the atmosphere. CO_2 emissions can either be permanently stored in geological formations (carbon capture and storage, CCS), or sequestered in long-life products, such as concrete. CO_2 emissions from steel production could be captured both from BF-BOF and DRI processes (particularly NG-DRI), with the deepest emissions cuts resulting from a combination of carbon capture and innovative lower-carbon steelmaking processes (for example, the HISarna process, a carbon-based smelting process which generates an almost pure CO_2 stream from the smelter). CO_2 capture can also be applied to on-site utilities such as hot stoves, steam generation plants, and lime kilns.[cxxxiii] Today, only one steel plant is currently operating with carbon capture: the Emirates Steel plant, a DRI producer in the United Arab Emirates,[cxxxiv] with questionable results in terms of emissions avoidance.[cxxxv]

For carbon capture technologies for BF-BOF facilities, the International Energy Agency estimates a technology readiness level of between 5 and 8 and expected market readiness between 2025 and 2030.[cxxxvi] The extent to which carbon capture can contribute to reducing BF-BOF emissions is unclear, and there is little effort to commercialise carbon capture technologies for the steel industry,[cxxxvii] with most projects at pilot or demonstrator stage[cxxxviii] and some commercial-scale project plants having been abandoned.[25] Several pilot projects in Western Europe aim to capture a portion of waste blast furnace gases and use them as a feedstock for chemicals production. Another demonstration project at the Jamshedpur steelworks in India aims to combine the HIsarna process with CCS for the production of 400,000 tonnes of pig iron.[cxxxix]

Carbon capture can also be applied to DRI steel production, in particular NG-DRI. The first step of the NG-DRI process is to reform the natural gas into syngas to be used for iron ore reduction, resulting in a highly concentrated stream of CO_2, suited for pre-combustion capture.[cxl] Currently, there are no known pre-combustion carbon capture projects on DRI steel production. If the H2-DRI process is fully implemented at Liberty Galați, the rationale for carbon capture becomes even less clear. Recently, the European STRATEGY CCUS project[cxli] reviewed the potential for capturing residual emissions from Liberty Galați after conversion to H2-DRI-EAF production; however, the supporting case for this pathway is unclear given the relatively small and disaggregated amounts CO_2 emissions from H2-DRI-EAF steelmaking (mostly from the EAFs, lime production, and residual emissions from small amounts of natural gas and carbon use). Carbon capture also introduces an energy penalty, with mature capture technologies requiring substantial quantities of heat for operation.

Beyond the low appetite and questionable business case for carbon capture from steel production, it is important to note that this pathway may not be aligned with emissions reductions trajectories. Multiple modelling exercises for the Paris-compatible decarbonisation of the global steel sector indicate that retrofitting existing blast furnaces with CCS should only be considered as an option only in areas with relatively new installations (i.e. Asia)[cxlii] or that it can be avoided completely, with a complete phaseout of coal use in the steel sector possible by 2040.[cxliii] Given the age of European facilities, major investment projects should rather concentrate on processes that can almost completely eliminate the use of fossil fuels. One final note is that the impact on jobs of BF-BOF with CCS is likely to be small (30-40 operational jobs depending on the volumes of captured CO_2), and DRI-EAF with CCS may actually cause job losses.[26]

Carbon capture also faces numerous challenges, not least the associated investment costs: the HISarna process combined with CCS is estimated to drive a 16% increase in the price of steel, while applying carbon capture and utilisation (CCU) to BF steel production can more than double the final steel price.[cxliv] Even if carbon capture were economically viable at Liberty Galați, the prospects for sequestering captured emissions is highly uncertain in Romania. Despite significant theoretical potential for storing CO_2 in Romania, there is still a high degree of uncertainty associated with the suitability of both onshore and offshore formations as storage sites. Furthermore, much like hydrogen, the transport and subsequent storage of CO_2 (in the case of CCS) requires a massive amount of infrastructure to essentially be built from zero in Romania. Significant strategic and regulatory barriers to the development of this infrastructure are causing a continued lagging and unclear prospects for CCU and CCS in general in Romania, and

---

[25] For example, the Dutch Athos project, originally involving Tata Steel.
[26] Opportunities for Near-Zero-Emissions Steel Production in the Great Lakes - RMI

overcoming them is a higher priority for other industries, such as cement and lime production, where the case for carbon capture is much clearer.

Advantages and challenges of alternative pathways

Alternative decarbonisation pathways may be possible for Liberty Galați, but they all face important challenges. They are all able to deliver significant emissions reductions for steel production, theoretically close to 100% for in most pathways, but the highest potential emissions reductions all depend on the use of at least some EAF-based secondary steel production for producing crude steel. Table 11 summarises the main advantages and disadvantages of the GREENSTEEL plan and three alternative decarbonisation pathways presented above.

Table 11. Overview of main advantages and disadvantages of decarbonisation pathways for primary steelmaking.

Decarbonisation route	Advantages	Disadvantages
H2-DRI-EAF	Production targets are theoretically achievable	Significant investments required in DRI unit and potential technology bottlenecks
	Can help stimulate Romania's hydrogen economy	Relies on renewable hydrogen and renewable electricity in significant volumes
	Emissions reductions of ~94% (liquid steel production process only)	Requires high-grade iron ore
	Impact on jobs is unclear	
Scrap-EAF	No investment required in DRI unit or dependence on DRI technology market	Restricted range of final steel products
	No need to source higher-grade iron ore	Challenging scrap steel availability
	Lower total electricity demand than H2-DRI-EAF process	Still requires significant new renewable energy capacities
	No hydrogen required	Production targets may be unachievable
	Emissions reductions of ~96% (steel production process only)	Potential direct job loss and stifling of indirect job creation
HBI-EAF	Production targets possibly more achievable than scrap-based EAF production	Depends on (potentially constrained) HBI supply at competitive costs
	No investment required in DRI unit or dependence on DRI technology market	Long transport distances for HBI
	HBI is less contaminated than steel scrap	HBI has a higher concentration of gangue minerals and iron oxide than steel scrap
	No hydrogen required	May lead to a small decline in jobs and stifle indirect job creation
	Emissions reduction is unclear, but likely over 90% compared to BF-BOF production	
CC(U)S on BF-BOF or NG-DRI	BF-BOF production can theoretically be maintained	Unlikely to align with emissions reduction trajectories unless converted to NG-DRI
	No hydrogen required	Continued dependence on fossil fuels (coke and natural gas)
	Potential to reduce residual and auxiliary emissions	High costs and no infrastructure
		Emissions reductions likely lower than in other pathways[1]
		Additional energy consumption
		Potential negligible or negative impact on jobs
	Unclear impact on local economic development	

Conclusions and Recommendations

Transforming primary steel production in Romania comes with enormous implications. If Liberty Galați is to survive in an increasingly low-carbon world, never mind reach its ambitions for doubling current steel production by 2030, it must undergo a complex transition from conventional production through the BF-BOF route. This study has reviewed the implications of decarbonising steel production as outlined in Liberty's GREENSTEEL plan; other decarbonisation pathways are feasible, but may lead to a downscaling of production, further jeopardizing the competitiveness of Romanian primary steelmaking and squandering the opportunity to revive upstream steel sectors as an integral part of the vision for national economic growth. Under the strategic considerations of maintaining at least some primary steel production in Romania and the region, the challenge of low-carbon transformation is sizeable.

If Liberty Galați implements its GREENSTEEL decarbonisation plan, emissions from primary steelmaking could fall by 90%, from 3.51 Mt CO_2 in 2021 to 0.349 Mt by 2030, all while doubling steel production. This could make a significant contribution to reducing Romania's industrial emissions, slash direct emissions costs, and maintain Liberty's contribution to the national economy and employment. At the same time, by the end of this transformation the steel plant would require different raw materials, its direct electricity consumption (just for the production of liquid steel) would be 1,600% higher than today, and it would consume more hydrogen than foreseen for all of Romania in 2030 in the National Hydrogen Strategy. If this hydrogen is produced in Romania, Liberty's transformation would add over 10,000 GWh of electricity demand to the national energy system, generating additional emissions of nearly 2.6 Mt CO_2 if the national grid maintains its current emissions intensity, even if minimum RFNBO targets are met past 2035. Meeting this entire electricity demand with renewable energy would require an additional 6.35 GW of renewable energy capacity, equivalent to more than the total installed renewable capacity in all of Romania in 2023. Not least, consumption of steel scrap would increase from 0.36 to 1.45 Mt/year by 2030, equivalent to 80% of Romania's current scrap exports and requiring an urgent rethinking of the current export-oriented trade landscape for scrap, particularly if demand is further squeezed by increases in secondary steel production at other sites in Romania.

While transforming primary steel production at Liberty Galați will come with significant investment costs (particularly if the required renewable hydrogen will be domestically produced) and will have huge implications for the national energy system, it is a vital undertaking for boosting Romania's economic competitiveness, safeguarding nearly 5,000 jobs and a significant portion of the local economy of Galați county, and aligning with ambitious climate targets as well as avoiding the associated penalties of non-compliance. Even more strikingly, the opportunities for leveraging a transition to low-carbon steel are immense – this transformation could kick-start a national hydrogen economy, attract investment in renewable energy production, propel the Galați region into the position of a hub for low-carbon R&D, and most evidently position Romanian steelmaking as a competitive industry both in Europe and globally. Facilitating an increase in production while lowering emissions means that Liberty Galați could become a competitive supplier and exporter of green steel, as well as propping up Romania's ambitions for public infrastructure development and enabling Romania to meet its upcoming requirements for sustainable construction, for example on embodied carbon in building materials.

While the benefits of transforming Liberty Galați are somewhat acknowledged, the scale of the required transformation is significantly underplayed on the national stage. The National Industrial Strategy (2023-2027) offers little more than superficial mentions of the need for decarbonising steel production, referring only to the need for renewable hydrogen, and does not point to any clear funding or financing support to back up the ambition of reducing emissions from steel production to 0.3 tCO_2/tls.[cxlv] Romania's draft National Energy and Climate Plan makes no reference to decarbonising steel production, short of repeating the above carbon intensity target,[cxlvi] and has attracted criticism from the European Commission regarding the lack of specific and ambitious targets for decarbonising industry, including promoting industrial hydrogen use.[cxlvii] Romania's Draft National Hydrogen Strategy foresees only 23,700 tonnes of hydrogen being used by steelmaking by 2030, only 14% of what Liberty Galați will actually require for its current plans. The deficit would likely need to be made up from imports, generating yet another trade vulnerability, missing the opportunity to develop and scale renewable hydrogen production in Galați and Dobrogea, and facing challenges posed by a lack of detail regarding Romania's hydrogen import and export expectations in the Hydrogen Strategy. The Territorial Just Transition Plan for Galați county, meant to underpin social and economic safeguarding through the transition to net zero emissions, at most vaguely refers to the decarbonisation of Liberty Galați and the effort required to re-skill and up-skill the local workforce.[cxlviii]

Current levels of engagement of policymakers with the decarbonisation of primary steel production fall well below the levels required for the scale of the transformation. To close this gap and move Romania's steel decarbonisation forward, both national institutions and Liberty Galați must urgently take concrete steps:

1. **Clear plans and supportive strategies for decarbonising steel production**. Liberty Galați must provide a detailed plan for its GREENSTEEL transformation, with consistent emissions targets and a clear business case, including planned new revenue sources to cover its significant investment costs. A coherent national vision, such as a revised Industrial Strategy, is needed for the future of the entire steel sector, including secondary steel production, but with a focus on the particularities and the magnitude of the challenge of transforming Liberty Galați. Public institutions must ensure coherence of national and regional strategies with this plan, including but not limited to the Industrial Strategy, National Hydrogen Strategy, National Energy and Climate Plan, Territorial Just Transition Plan, and upcoming legislation for renewable energy, such as offshore wind.

2. **Targeted and efficient public funding, particularly for upfront costs**. Based on a clear investment plan and business case for transformation, the Romanian Ministries of Economy, Investments and European Projects, and Energy must collectively agree on support mechanisms to manage the high upfront costs of low-carbon steelmaking technologies, as well as a system of time-limited subsidies to cover the initial operational

costs of a transformed Liberty Galați: a Carbon Contracts for Difference (CCfD) system could be a suitable instrument. Public funding should always aim to leverage private financing, for example through state-backed loan guarantees and other forms of blended finance used for industrial decarbonisation worldwide. The magnitude of financial support should be calibrated in way that ensures a fair burden-sharing of costs between public finances and the private economic operator.

3. **Demand creation for green steel products**. Both Liberty Galați and the Romanian state can play a role in kick-starting the Romanian market for green steel products. Offtake agreements with domestic steel users, such as automakers and shipyards, will need to be reached by Liberty Galați in order to provide investment certainty for its transformation plans. At the same time, the Romanian state can gradually become a prime purchaser of green steel by adopting a system of Green Public Procurement (GPP), committing to using low-carbon steel especially in its infrastructure projects – likely to be major in the coming decades. Romania's current GPP legislation does not target industrial products but could become a launchpad for an expanded GPP system including steel and other products.

4. **New renewable capacities and infrastructure development for hydrogen production**. As shown above, the GREENSTEEL transformation plan will drive a significant increase in electricity demand at Liberty Galați, which even on its own will require an increase in transmission capacity of the national electricity system. If this electricity is to be clean, and if the required quantities of renewable hydrogen are to be produced domestically, the Romanian state needs to create the right investment framework for significant new renewable electricity capacities, in addition to what is foreseen in current plans. If hydrogen is produced off-site in Romania, public support for hydrogen pipelines will be needed; if hydrogen is to be imported, investments will be required in long-distance pipelines or port infrastructure for importing hydrogen by ship. Regardless of the chosen pathway, the supply of 164,100 tonnes/year of renewable hydrogen, whether produced by Liberty Galați or otherwise, will require a significant revision of targets in the National Hydrogen Strategy and a clear plan for how to achieve them.

5. **Raw material supply chains**. Switching the steelmaking process means that new supply chains for raw materials will be needed. Liberty Galați has already rerouted its supply chains for iron ore in the wake of the Russian invasion of Ukraine, but more will be needed to ensure that the high-quality iron ore required for DRI production is available in high volumes. Most importantly, the quantities of scrap steel demanded by a transformed Liberty Galați will require targeted policies to disincentivise scrap exports, for example by reclassifying steel scrap as a key raw material for low-carbon industry, rather than a waste product, as well as setting standards for scrap steel collection and handling.

Annexes

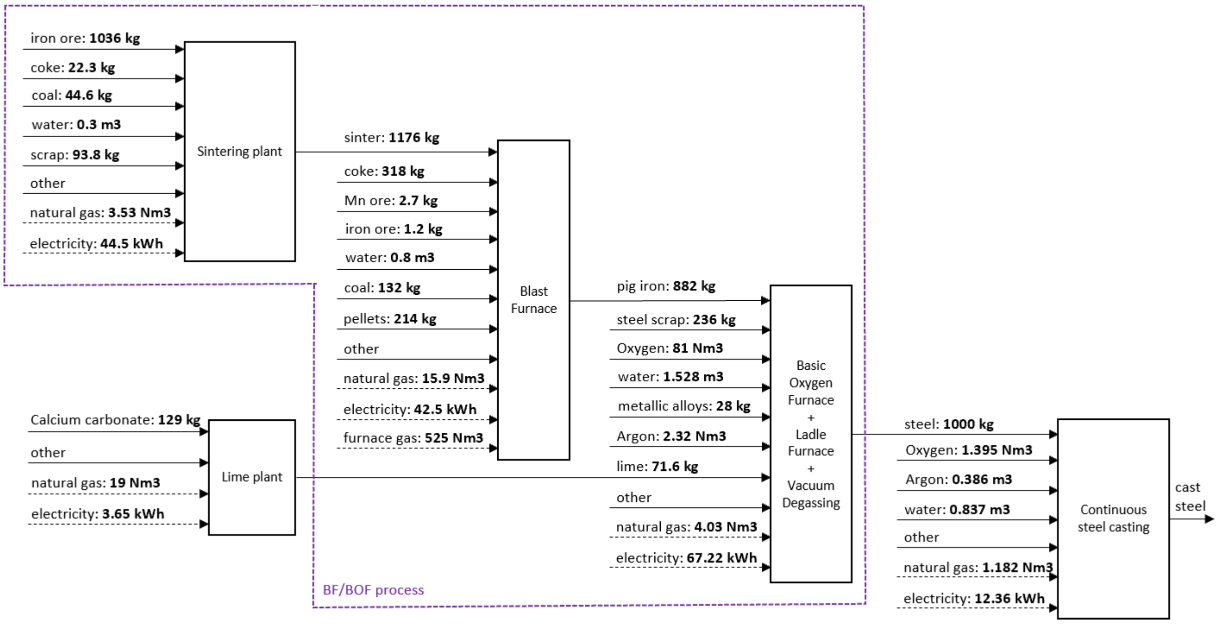
Annex 1. Input materials used in conventional steel production at Liberty Galați

Table 12. Quantities of input materials used in the stages of steel production at Liberty Galați, per tonne of output. Source: integrated environmental authorization of Liberty Galați, 2023.

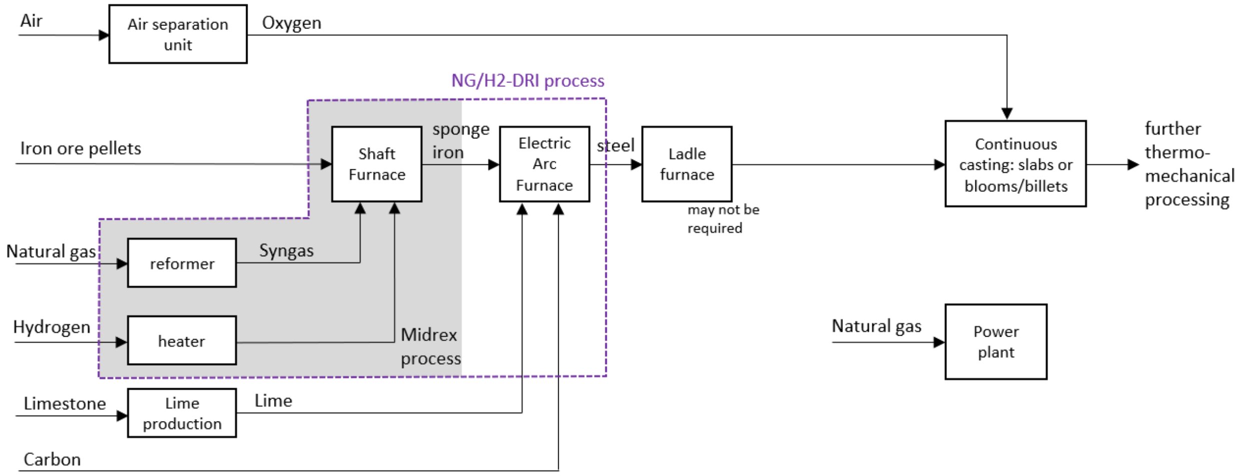
Process	Output	Input	Quantity (per tonne of output)
Agglomeration	Sintered iron ore	Iron ore	880.98 kg
		Coke	18.93 kg
		Coal	37.9 kg
		Water	0.25 m^3
		Natural gas	87 MJ
		Electricity	136 MJ
		Scrap steel	79.8 kg
Lime production	Lime	Limestone	1,800 kg
		Natural gas	8408 MJ
		Electricity	47.9 kWh
Blast furnace	Pig iron	Agglomerate	1,333 kg
		Coke	360 kg
		Manganese ore	3.1 kg
		Iron ore	1.4 kg
		Water	0.9 m^3
		Natural gas	606.56 MJ
		Blast furnace gas	2334 MJ
		Electricity	173.53 MJ
		Coal	150 kg
		Pellets	242.5 kg
Basic oxygen furnaces (including Ladle Furnace and Vacuum Degassing)	Steel	Pig iron	882 kg
		Steel scrap	236 kg
		Oxygen	81 Nm^3
		Water	1.388 m^3
		Demineralised water	0.14 m^3
		Natural gas	4.03 NM^3
		Electricity	67.22 kWh
		Metallic alloys	28 kg
		Lime	71.6 kg
		Argon	2.32 Nm^3
Continuous steel casting	Cast steel	Liquid steel	1,000 kg
		Natural gas	1.182 Nm^3
		Electricity	12.36 kWh
		Oxygen	1.395 Nm^3
		Argon	0.386 Nm^3
		Water	0.583 m^3
		Demineralised water	0.254 m^3

Annex 2. Process diagrams for the GREENSTEEL transformation phases

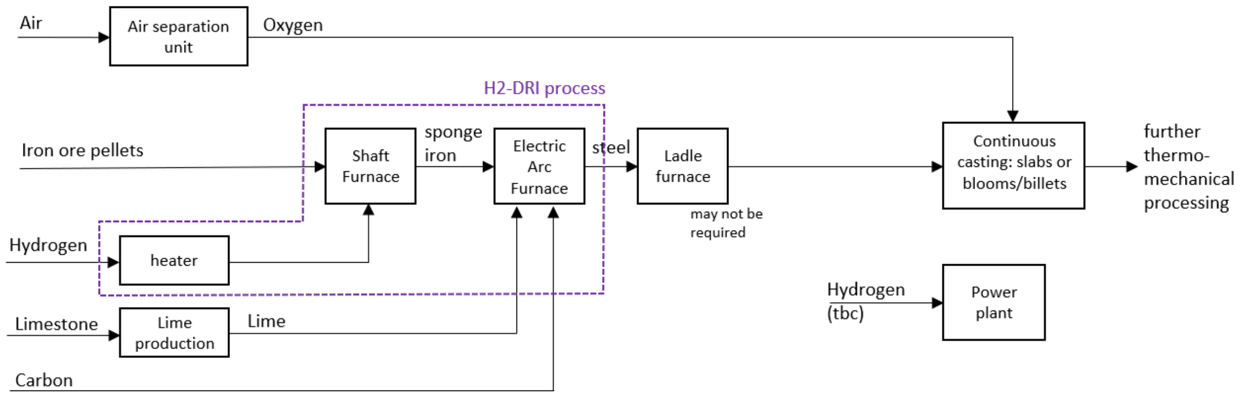
Process diagram for phases A and B. The boundaries of the BF-BOF process are shown in a dotted line. Source: EPG own work.



Process diagram for phases C, D and E. The boundaries of the NG-DRI process are shown in a dotted line. Source: EPG own work.



Phase F process diagram. The boundaries of the H_2-DRI process are shown in a dotted line. Source: EPG own work.



Annex 3. Assumptions used in case study estimations

System configuration

- For this study, the MIDREX ® DRI process is used as a basis for elaborating a potential system configuration for a DRI-EAF production route at Liberty Galați.
- Unless otherwise specified, the hydrogen used for the DRI-EAF process is assumed to be electrolytic (i.e., produced by the electrolysis of water, using electricity).

System boundaries

- The process boundaries are those shown in the figures in Annex 2. Lime production and downstream processes (continuous steel casting, processing of cast steel) are not considered as part of the GREENSTEEL transformation.

Specific energy consumption

- The main data sources used for calculating energy consumption in the MIDREX ® DRI process are Millner et al and Rechberger et al. Where there are differences in results, these are highlighted.
- For energy consumption related to iron pellet heating and EAF operations (not reported in Millner et al and Rechberger et al), the following values are used:
  - Iron pellet heating: electricity consumption 436 kWh/tls[cxlix]
  - EAF operations: electricity consumption 445 kWh/tls[cl], total energy consumption ranges between 667 kWh/tls (if processing only scrap steel and 0% sponge iron) or 753 kWh/tls (if processing only sponge iron and 0% scrap steel).[cli] Based on reference proportions of non-electric input energetic streams (chemical reactions, natural gas, coal),[clii] the non-electric energy consumption of the EAF is:
    - For 100% scrap in the EAF: 222 kWh/tls (87 kWh – chemical reactions, 34 kWh – burning natural gas, 101 kWh – burning coal)

        - For 0% scrap in the EAF: 531 kWh/tls (208 kWh – chemical reactions, 82 kWh – burning natural gas, 241 kWh – burning coal)
        - The energy content is assumed to be 9.11 kWh/kg for coal (characteristic for simple carbon) and 13.1 kWh/kg for natural gas, resulting in:
            - For 100% scrap: a consumption of 2.59 kg of natural gas and 11 kg of coal.
            - For 0% scrap: a consumption of 6.26 kg natural gas and 26.5 kg of coal.
- Electricity consumption for electrolytic hydrogen production is estimated at 45.41 kWh/kg H_2.[cliii]

Emissions factors

- Unless otherwise specified, CO_2 emissions are those generated directly from the steel production process (Scope 1 emissions) outlined in the figures in Annex 2. The sources of process emissions are:
    - BF-BOF process: emissions from the agglomeration plant, combustion of coke in the blast furnace and from treatment of pig iron in the basic oxygen furnace. Estimated emissions from this process are 1,494 kg CO_2-eq/tls.[cliv]
    - NG-DRI-EAF process: emissions from the combustion of natural gas in the reformer (139.7-178.3 kg CO_2/tls[27]), and from the EAF (ranging from 44.37 kg CO_2/tls for 100% scrap and 0% sponge iron, to 106.94 kg CO_2/tls for 0% scrap and 100% sponge iron, based on own calculations using reference quantities of natural gas, input coal, and coke powder as shown above[clv] and assuming a 50%-50% coke-carbon ratio in the input coal. A linear relationship between emissions and the quantity of scrap is assumed and thus for 1.45 Mt of scrap used, as indicated in the CN30 plan, the ratio of scrap to sponge iron is 35%, equivalent to approx. 85 kg CO_2/tls)
    - H_2-DRI-EAF process: emissions from the EAF (see above).
- Where referred to, indirect emissions from the steel production process outlined in Figures 6, 7 and 8 are as follows:
    - Scope 2 emissions from the main steel production process: emissions from the production of electricity required for power steel production and, where relevant, electrolytic hydrogen production (the electrical grid emissions index of Romania is 349 kg CO_2-eq/kWh[clvi]).
    - From auxiliary processes (Scope 1 and Scope 2 emissions): lime production (68.4 kg CO_2/tls), continuous casting (6.75 kg CO_2/tls, of which 4.31 are Scope 2 emissions from grid electricity[clvii]))

---

[27] The consumption of natural gas per tls in a NG-DRI-EAF process varies between authors (150.27 kg/tls in Millner et al – 191.8 kg/tls in Rechberger et al. Only one-third of consumed natural gas produces CO_2 emissions vented into the atmosphere according to Rechberger et al and Rosner et al, 2023. The emissions factor for natural gas combustion if considered to be 2.75 kg CO_2/kg natural gas combusted.

Process characteristics

- The transition from NG-DRI to NG/H_2-DRI occurs in three sub-phases:
    - 100% natural gas for iron ore reduction and process heat provision;
    - 30% hydrogen/70% natural gas blend (by energy content) for reduction, and 20.2% hydrogen/79.8% natural gas blend (by energy content) for process heat;
    - 100% hydrogen for reduction, and 72.8% hydrogen/27.2% natural gas blend (by energy content) for process heat.
- There are no leakages from the shaft furnace or top gas scrubber (a significant assumption which may not be representative of reality).[28]
- Two-thirds of the gases evacuated from the shaft furnace are reinjected as process gas for a new cycle of iron ore reduction, and one-third is injected into the reformer, mixed with natural gas and combusted.
- The DRI system operates at full load, and the input power does not fluctuate.
- The excess of hydrogen is set at 50% (i.e., 50% more hydrogen than actually needed is injected in the shaft furnace[clviii])
- Electrolyser efficiency for hydrogen production is set at 74% as indicated in Bhaskar et al, 2020.[29]

---

[28] Additionally, while the impact of hydrogen emissions on the climate is not well-understood, according to the Hauglusteine et al (2023), 1 kg of hydrogen released in the atmosphere would have an environmental impact equivalent to 13 kg of CO_2.

[29] A value of 74% is stated as a hypothesis for the study. Based on the mass and energy flows resulting from the numerical study, this efficiency is based on the lower heating value (LHV) of the hydrogen. In this context, it is more accurate to quote an efficiency based on the higher heating value (HHV) of the gas, as the hydrogen is used in an oxygen reduction chemical reaction and not for producing energy. The corresponding electrolyser efficiency of the electrolyser would be 86.7% (based on the HHV). Nevertheless, within the electrolysis unit one can identify equipment for water and hydrogen/oxygen processing that consume power, leading to a decrease in efficiency. From this point of view, the quoted efficiency is overestimated. When considering the two effects, one can conclude that the 74% efficiency considered in Bhaskar et al, 2020 for the electrolysis unit is realistic.

References

[i] Statista, 2021. Distribution of steel end-usage worldwide in 2022, by sector.
[ii] World Steel Association, 2022. Sustainability performance of the steel industry 2003-2021.
[iii] World Steel Association, 2023. World Steel in Figures 2023.
[iv] Sohn, H.Y., Mohassab, Y., 2016. Greenhouse Gas Emissions and Energy Consumption of Ironmaking Processes.
[v] World Steel Association, 2023. Fact sheet: Steel and raw materials.
[vi] Agora Energiewende, 2021. Breakthrough Strategies for Climate-Neutral Industry in Europe.
[vii] E3G, 2021. 1.5°C Steel - Decarbonizing the steel sector in Paris-compatible pathways.
[viii] MIDREX, 2022. World Direct Reduction Statistics.
[ix] Agora Energiewende, 2021. Breakthrough Strategies for Climate-Neutral Industry in Europe
[x] Laity, E.., 2024. thyssenkrupp issues tender for 143,000 tonnes of hydrogen to decarbonise steel production
[xi] Liberty Galați, 2022. Our journey to GREENSTEEL and CN30.
[xii] Agora Energiewende, 2021. Breakthrough Strategies for Climate-Neutral Industry in Europe
[xiii] Somers, J., 2022. Technologies to decarbonise the EU steel industry.
[xiv] Adevărul, 2023. Donalam Târgoviște renaște: a depășit producția de 155.000 de tone de armaturi în primele 9 luni din 2023.
[xv] Eurostat, 2023. National accounts aggregates by industry.
[xvi] Energy Policy Group, 2023. Decarbonising Romania's industry.
[xvii] Eurostat, 2023. Annual detailed enterprise statistics for industry.
[xviii] Liberty Steel Group, 2022. LIBERTY Galati hits record production levels in 2021.
[xix] Marica, 2022. Beltrame's Romanian subsidiary seeks to hire 250 at its steel plant in Târgoviște.
[xx] Economedia, 2023. Compania de investiții Hefestos Capital cumpără producătorul de țevi TMK ARTROM. Compania nu mai face parte din Grupul TMK
[xxi] Europa Liberă, 2023. Cu zeci de cereri de insolvență și furnalul oprit, Combinatul Liberty Galați vrea 150 milioane de euro credit garantat de stat.
[xxii] Energy Policy Group, 2023. Decarbonising Romania's industry.
[xxiii] National Statistical Institute, 2023. Industrial statistics series: activity of the metallurgical sector.
[xxiv] Eurostat, 2023. Air emissions intensities by NACE Rev. 2 activity.
[xxv] Eurostat, 2023. Greenhouse gas emissions by source sector.
[xxvi] National Statistical Institute, 2023. Activitatea sectorului metalurgic 2014-2022.
[xxvii] Liberty Galați, 2022. Our journey to GREENSTEEL and CN30.
[xxviii] European Commission, 2023. Climate Action – Union Registry.
[xxix] OECD, 2019. Low and zero emissions in the steel and cement industries.
[xxx] Liberty Galați, 2022. Our journey to GREENSTEEL and CN30.
[xxxi] Liberty Galați, 2022. Our journey to GREENSTEEL and CN30.
[xxxii] National Agency for Environmental Protection, 2021. Lista instalațiilor care intră sub incidența schemei de comercializare a certificatelor de emisii de gaze cu efect de seră.

[xxxiii] Liberty Galați, 2022. Our journey to GREENSTEEL and CN30.
[xxxiv] Eurometal, 2022. Liberty acquires Dongbu EAF, strip mill for Galati.
[xxxv] ArcelorMittal, 2010. Global Technology Roadmap for CCS in Industry: Steel Sectoral Report.
[xxxvi] IEA-GHG, 2013. Iron and Steel CCS Study (Techno-Economics Integrated Steel Mill).
[xxxvii] Kopernikus Projekt Ariadne, 2022. The EU-ETS price through 2030 and beyond: A closer look at drivers, models and assumptions.
[xxxviii] Liberty Galați, 2022. Our journey to GREENSTEEL and CN30.
[xxxix] Bellona, 2021. Hydrogen in steel production: what is happening in Europe – part two - Bellona.org
[xl] MIDREX, 2022. World Direct Reduction Statistics 2022.
[xli] Bhaskar et al, 2020. Decarbonisation of the Iron and Steel Industry with Direct Reduction of Iron Ore with Green Hydrogen.
[xlii] MIDREX, 2017. MIDREX H2: Ultimate Low CO2 Ironmaking and its place in the new Hydrogen Economy.
[xliii] International Iron Metallics Association. Direct Reduced Iron (DRI).
[xliv] Muscolino et al, 2016. Introduction to direct reduction technology and outlook for its use.
[xlv] International Iron Metallics Association, 2022. Direct Reduced Iron (DRI): Guide to Shipping, Handling and Storage.
[xlvi] Ramakgala and Danha, 2019. A review of ironmaking by direct reduction processes: Quality requirements and sustainability.
[xlvii] MIDREX, 2022. The Iron Ore Challenge for Direct Reduction On Road to Carbon-Neutral Steelmaking.
[xlviii] HYBRIT, 2023. HYBRIT.
[xlix] Bălan, M., and Cătuți, M., 2021. Dobrogea – developing the first clean hydrogen valley in Central and Eastern Europe.
[l] Muscolino et al, 2016. Introduction to direct reduction technology and outlook for its use
[li] Ovidiu, A., 2023. Era oțelului verde. Sandip Biswas și Ajay Aggarwal, top manageri ai LIBERTY Steel Group, dezvăluie schimbările de paradigmă ale companiei.
[lii] Tudorache, B., 2021.LIBERTY Galati reports an EBITDA growth by 60% in Q2, supports green transition.
[liii] Liberty Galați, 2022. Our journey to GREENSTEEL and CN30.
[liv] Liberty Galați, 2022. Our journey to GREENSTEEL and CN30.
[lv] Millner et al, 2021. MIDREX H2 – The Road to CO2-free Direct Reduction.
[lvi] Rechberger et al, 2020. Green Hydrogen for Low-Carbon Steelmaking.
[lvii] Reuters, 2023. Liberty Steel Romanian plant's power needs to jump fivefold for green output by 2030.
[lviii] National Authority for the Regulation of Energy, 2024. Puteri instalate.
[lix] IEA-GHG, 2013. Iron and Steel CCS Study (Techno-Economics Integrated Steel Mill).
[lx] Chesnokov, Y.N., et al, 2014. Evaluating the Carbon Footprint from the Production of Steel in an Electric-Arc Furnace.
[lxi] Romanian Parliament, 2023. Legea nr. 237/2023 privind integrarea hidrogenului din surse regenerabile şi cu emisii reduse de carbon în sectoarele industriei şi transporturilor.
[lxii] Ministry of Environment, 2023. Strategia pe termen lung a României pentru reducerea emisiilor de gaze cu efect de seră.
[lxiii] Kopernikus Projekt Ariadne, 2022. The EU-ETS price through 2030 and beyond: A closer look at drivers, models and assumptions

---

[lxiv] European Commission, 2023. Photovoltaic Geographical Information System.
[lxv] Wind Europe, 2022. Wind energy in Europe: 2022 statistics and outlook for 2023-2027.
[lxvi] European Parliamentary Research Service, 2021. Carbon-free steel production Cost reduction options and usage of existing gas infrastructure.
[lxvii] JRC, 2020. Production costs from iron and steel industry in the EU and third countries.
[lxviii] European Parliamentary Research Service, 2021. Carbon-free steel production Cost reduction options and usage of existing gas infrastructure.
[lxix] Agora Industry, FutureCamp, Wuppertal Institute and Ecologic Institute, 2022. Transforming industry through carbon contracts: Analysis of the German steel sector.
[lxx] European Parliamentary Research Service, 2021. Carbon-free steel production Cost reduction options and usage of existing gas infrastructure.
[lxxi] European Parliamentary Research Service, 2021. Carbon-free steel production Cost reduction options and usage of existing gas infrastructure.
[lxxii] Agora Industry, FutureCamp, Wuppertal Institute and Ecologic Institute, 2022. Transforming industry through carbon contracts: Analysis of the German steel sector.
[lxxiii] Agora Industry, FutureCamp, Wuppertal Institute and Ecologic Institute, 2022. Transforming industry through carbon contracts: Analysis of the German steel sector.
[lxxiv] European Parliamentary Research Service, 2021. Carbon-free steel production Cost reduction options and usage of existing gas infrastructure.
[lxxv] Agora Industry, FutureCamp, Wuppertal Institute and Ecologic Institute, 2022. Transforming industry through carbon contracts: Analysis of the German steel sector.
[lxxvi] ECCO, 2022. A Green Steel Strategy: Options and Challenges of Decarbonisation. Technical Report.
[lxxvii] Santis et al, 2021. Investment Needs.
[lxxviii] Energy Policy Group, 2021. Clean Hydrogen in Romania: Elements of a Strategy.
[lxxix] Agora Industry, FutureCamp, Wuppertal Institute and Ecologic Institute, 2022. Transforming industry through carbon contracts: Analysis of the German steel sector.
[lxxx] Luyben, W.L., 2018. Capital cost of compressors for conceptual design.
[lxxxi] Department for Business, Energy and Industrial Strategy, 2021. Hydrogen production costs 2021.
[lxxxii] Romanian Wind Energy Association, 2019. Renewable energy in Romania: Potential for development by 2030.
[lxxxiii] Gheorghe, L., 2023. Prețurile energiei în România îngroapă competitivitata industriei grele: Asociația marilor consumatori prezintă o comparație cu statele concurente.
[lxxxiv] European Commission, 2023. Answer given by Ms. Simson on behalf of the European Commission.
[lxxxv] European Comission, 2023. Electricity interconnection targets.
[lxxxvi] Energy Policy Group, 2023. Offshore wind – the enabler of Romania's decarbonisation.
[lxxxvii] Ministry of Environment, 2023. Romania's National Hydrogen Strategy and Implementation Plan.
[lxxxviii] Lopez, G., et al, 2023. Towards defossilised steel: Supply chain options for a green European steel industry.
[lxxxix] Bloomberg New Energy Finance, 2023. Green Steel Demand is Rising Faster Than Production Can Ramp Up.
[xc] POSCO, 2020. [STEEL Talk] How Is Steel Delivered?

[xci] Administration of Maritime Danube Harbours, 2023. Portul Galați.
[xcii] Işık, Y., 2023. Russia's aggressive behavior in the Black Sea can be challenged.
[xciii] Andrei, V., 2023. Bulgaria, România și Turcia vor curăța împreună minele din Marea Neagră. Erdogan vrea să relanseze transportul de cereale.
[xciv] Costea, S., 2023. Canalul navigabil Gdansk - Galați va scurta cu 4.000 km distanța de la Baltica la Marea Neagră.
[xcv] Scarișoreanu, D.I., Ghiculescu, L.D., View of Strategic Forecast for Rail Freight Transport in Romania using the Relevant Tree Method and Scenario Method.
[xcvi] Devlin, A., et al, 2023. Global green hydrogen-based steel opportunities surrounding high quality renewable energy and iron ore deposits.
[xcvii] Totalfirme.ro, 2023. Liberty Galați S.A.
[xcviii] Ministry of Investment and European Projects, 2023. Management Authority for the Just Transition Programme 2021-2027.
[xcix] Ministry of Investment and European Projects, 2023. Management Authority for the Just Transition Programme 2021-2027.
[c] OECD, 2017. Mapping support for primary and secondary metals.
[ci] Agora Industry, 2023. 15 Insights on the Global Steel Transformation.
[cii] Frankfurt School of Finance and management, 2021. Support to the preparation of the Territorial Just Transition Plans in Romania.
[ciii] Carey, L., et al, 2023. Opportunities for Near-Zero-Emissions Steel Production in the Great Lakes.
[civ] Amălinei, O., 2023. „Combinatul poate absorbi toată energia bazată pe hidrogen". Interviu cu Ajay Aggarwal, președinte Europa Liberty Steel Group.
[cv] Ardeleanu, A., 2023. Radu Ionescu, LIBERTY Galați: Avem nevoie de o politică energetică clară și sustenabilă pentru a ajuta industria siderurgică românească să fie competitivă în prezent.
[cvi] Thyssenkrupp, 2023. Climate-neutral steel - Our strategy | thyssenkrupp Steel.
[cvii] GREENSTEEL ACADEMY - LIBERTY Steel Group
[cviii] Bellona Europa, 2022. Circularity in steel.
[cix] Honeyands et al, 2000. Performance of HBI in scrap pre-heating systems.
[cx] Liberty Galați, 2022. Our journey to GREENSTEEL and CN30
[cxi] Eurofer, 2019. Map of EU steel production sites.
[cxii] IspatGuru, 2013. Direct Reduced Iron and its Production Processes.
[cxiii] MIDREX, 2020. Direct from MIDREX – 1st quarter 2020.
[cxiv] Agora Industry and Wuppertal Institute, 2023. 15 Insights on the Global Steel Transformation
[cxv] Pimm et al, 2021. Energy system requirements of fossil-free steelmaking using hydrogen direct reduction.
[cxvi] Agora Industry and Wuppertal Institute, 2023. 15 Insights on the Global Steel Transformation
[cxvii] Pimm et al, 2021. Energy system requirements of fossil-free steelmaking using hydrogen direct reduction.
[cxviii] Pimm et al, 2021. Energy system requirements of fossil-free steelmaking using hydrogen direct reduction.
[cxix] Agora Industry, 2023. 15 Insights on the Global Steel Transformation.

[cxx] Agora Industry, 2023. 15 Insights on the Global Steel Transformation.
[cxxi] Agora Industry and Wuppertal Institute, 2023. 15 Insights on the Global Steel Transformation.
[cxxii] Honeyands et al, 2000. Performance of HBI in scrap pre-heating systems.
[cxxiii] Birley, R.I., 2021. Decarbonising the DRI feed for EAFs using H2.
[cxxiv] MIDREX, 2022. World Direct Reduction Statistics 2022
[cxxv] MIDREX, 2023. The New Age of Hot Briquetted Iron (HBI): How will the Steel Industry Transform?
[cxxvi] MIDREX, 2023. Forms of DRI.
[cxxvii] Nyaungwa, N., 2023. Namibia starts construction of Africa's first decarbonised iron plant.
[cxxviii] Global Solar Atlas, 2023. Global Solar Atlas
[cxxix] Meza, E., 2023. Germany funds Africa's first green ironworks in Namibia.
[cxxx] Liberty Galați, 2022. Our journey to GREENSTEEL and CN30
[cxxxi] GFG Alliance, 2023. New electric arc furnace and direct reduction plant for Whyalla.
[cxxxii] Liberty Steel Group. LIBERTY Ostrava's transformation to GREENSTEEL and CN30.
[cxxxiii] OECD, 2015. Greening Steel: Innovation for Climate Change Mitigation in the Steel Sector.
[cxxxiv] Global Energy Monitor. GHC Emirates Steel Industries Abu Dhabi plant.
[cxxxv] Hiar, C., and Schonhardt, S., 2023. Carbon capture is in the climate deal. But the UAE's only plant traps just 28% of emissions.
[cxxxvi] Global Energy Monitor, 2021. Pedal to the Metal.
[cxxxvii] Agora Industry and Wuppertal Institute, 2023. 15 Insights on the Global Steel Transformation.
[cxxxviii] Agora Energiewende, 2021. Breakthrough Strategies for Climate-Neutral Industry in Europe.
[cxxxix] Agora Energiewende, 2021. Breakthrough Strategies for Climate-Neutral Industry in Europe
[cxl] Berstad, E., et al, 2023. Current state of CCS technologies and the EU policy framework.
[cxli] CORDIS, 2023. Strategic planning of regions and territories in Europe for low-carbon energy and industry through CCUS.
[cxlii] Yu, S., Lehne, J., Blahut, N., & Charles, M. 2021. 1.5°C Steel: Decarbonizing the Steel Sector in Paris-Compatible Pathways.
[cxliii] Agora Industry, 2023. 15 Insights on the Global Steel Transformation.
[cxliv] Agora Energiewende, 2021. Breakthrough Strategies for Climate-Neutral Industry in Europe
[cxlv] Ministry of Economy, Entrepreneurship, and Tourism, 2023. Strategia Industrială a României 2023-2027 a fost publicată în transparență decizională!
[cxlvi] Government of Romania, 2023. Romania – draft updated NECP 2021-2030.
[cxlvii] European Commission, 2023. Commission Recommendation of 18/12/2023 on the draft updated integrated national energy and climate plan of Romania.
[cxlviii] Ministry of Investment and European Projects, 2023. Management Authority for the Just Transition Programme 2021-2027.
[cxlix] Bhaskar et al, 2020. Decarbonisation of the Iron and Steel Industry with Direct Reduction of Iron Ore with Green Hydrogen.
[cl] Bhaskar et al, 2020. Decarbonisation of the Iron and Steel Industry with Direct Reduction of Iron Ore with Green Hydrogen.
[cli] Vogl et al, 2018. Assessment of hydrogen direct reduction for fossil-free steelmaking.

[clii] Santangelo, N., Tomadin, L., & Arrigo, B. (2015). Clean Heat Recovery From EAF Hot Fumes Into Electric Energy, With Consequent Fuel Saving and Reduction of Greenhouse Gas Emission.
[cliii] Vogl et al, 2018. Assessment of hydrogen direct reduction for fossil-free steelmaking.
[cliii] Bhaskar et al, 2020. Decarbonisation of the Iron and Steel Industry with Direct Reduction of Iron Ore with Green Hydrogen.
[cliv] IEA-GHG, 2013. Iron and Steel CCS Study (Techno-Economics Integrated Steel Mill).
[clv] Chesnokov, Y.N., et al, 2014. Evaluating the Carbon Footprint from the Production of Steel in an Electric-Arc Furnace.
[clvi] Electricity Maps, 2023. Romania.
[clvii] Greco-Coppi et al, 2023. Negative CO2 emissions in the lime production using an indirectly heated carbonate looping process.
[clviii] Vogl et al, 2018. Assessment of hydrogen direct reduction for fossil-free steelmaking.

Energy Policy Group (EPG) is a non-profit, independent think-tank specializing in energy and climate policy. EPG does evidence-based policy analysis on the decarbonization of the energy, industry, buildings and transport sectors. Its geographical focus is mostly the European Union and Southeast Europe, yet its analyses are informed by the global market, technology, and geopolitical trends. EPG is based in Bucharest, Romania, where it was founded in 2014.

EPG

Scan for more publications