Circularity for rails

Final Draft Report - UPDATE

ProRail

Utrecht, April 14th, 2023

Contents

A. Project background

ProRail wants to ensure rails are produced and recycled in a sustainable and circular manner – Evaluation of options and a way forward are needed

Project background and objectives

Background of the project

- **ProRail** is currently primarily buying its rails from **voestalpine**, which is producing **steel** rails in **Donawitz, Austria**, as well as from other suppliers, e.g. Vossloh
- The rails **are produced** using **mainly virgin material**
- The lifetime of the rails is **~30 years** – ProRail is actively working on **prolonging** the **lifetime** as much as possible (e.g. by **reusing rails** on **lower-end applications** or "lagere berijdingsklasses")
- Railway tracks are **removed** by **various contractors** on a **project basis** – ProRail has **limited visibility** and **control over the treatment** and **recycling** of its **used rails**
- **ProRail** now wants to **evaluate different approaches** to **increase circularity**, with the **targets** to **(1)** use as **little virgin material** as **possible** and **(2) reduce** the **CO_2 footprint**

Project objectives

1. **Definition** of different approaches to increase the circularity of ProRail's rails, incl. **identification** of **potential partners**
2. **High-level evaluation** of **circularity approaches** based on **(1) virgin material usage**, **(2) CO_2 reduction potential** and **(3) (economic) feasibility**
3. **Recommendation** for **circularity approach** based on the **criteria above** and a **recommended way forward**

By 2030, ProRail aims to reduce the carbon footprint of its rail by 55% and use 50% fewer primary materials

ProRail sustainability objectives

Reduce carbon footprint of assets

2030 55% reduction of CO_2 emissions
176 kton reduction of CO_2 required[1)]

2050 CO_2 neutrality

Achieve circularity of materials

2030 50% reduction of primary materials

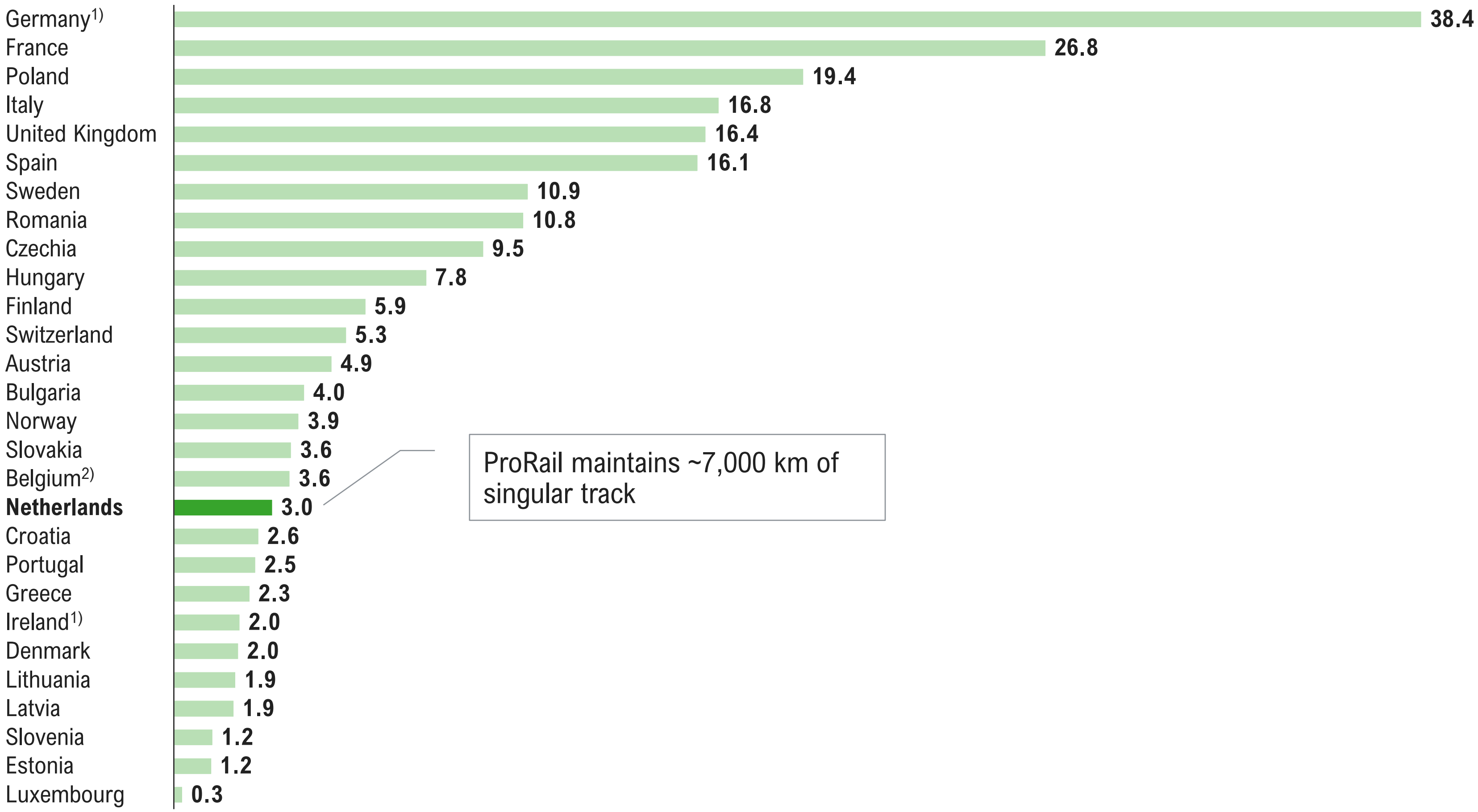
2050 Complete circularity

1) Emission reduction target ProRail scope 1,2,3 – Based on reduction from estimated emissions in 2015 of 320 kton to target in 144 kton in 2030

Source: ProRail

ProRail is a mid-sized infrastructure manager maintaining c. 7,000 km of railway track along its c. 3,000 km network

Market overview of railway infrastructure network length Europe, 2020 ['000 km]



1) Latest available 2019; 2) Latest available 2009

Source: UNECE, Interviews

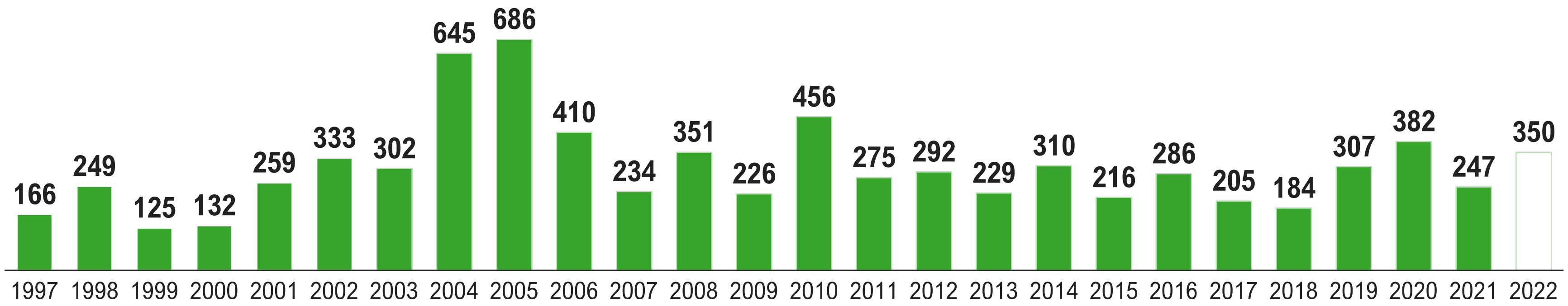
Comments

- The European railway network is managed by national railway network managers
- Germany and France have the largest railway networks in Europe, managed by DB Netze in Germany and RFF (subsidiary of SNCF) in France
- ProRail is the manager of the Dutch railway network
- About 200-400 km or 22 ktons of new steel rail is needed annually for the principal rail infrastructure
- Data for length of rail network is based on UN Economic Commission for Europe – A unit length of rail network may consist of multiple singular rail tracks

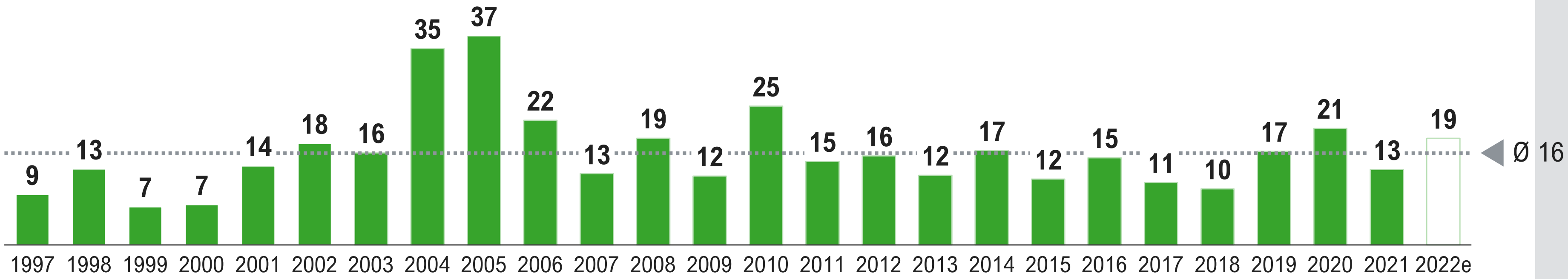
On average ProRail procures an annual 16 ktons of rail beam

ProRail rail usage, 1997-2022

Rail usage in km



Rail usage in '000 metric tons



Comments

- Increasing the lifetime of rail assets can decrease the required rate of renewal and need for new rails
- ProRail implemented maintenance and renewal programs based on track usage, e.g. renewal after 1,500 MT of trainload, which helped to decrease annual procured rail from 686 km in 2005 to an estimated 350 km in 2021
- However, an analysis of emergency repairs in the rail network showed specific rail track sections require renewal more frequently than others, suggesting improvements are still possible
- Increasing the use of maintenance data can further extend the lifetime of assets
- No planned procurement volume for 2023 is available

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Source: Expert interviews, ProRail

Example players are non-exhaustive

Contractors are responsible for procuring rails, mostly through RailPro and Vossloh

Rail value chain – ProRail perspective

Production

- Rails are produced from virgin steel at steel plants in Europe

Distribution

- Rails are sold to contractors to be installed in infrastructure projects
- Rails are transported by rail to construction site

Installation

- Rails are installed in new projects or used to replace existing railway tracks

Service life

- Rails are monitored bi-annually for damage and overall wear and tear
- Plans and regulation exist to reuse rails on low-intensity railway tracks, but execution still restricted to pilots

Removal

- Rail ownership is transferred to infrastructure contractor
- Rail may be re-used in lower-end applications or "lagere berijdings-klassen"
- Steel is recycled in arc furnace

Rail Suppliers: voestalpine, Lucchini SA, Tata Steel, ArcelorMittal

Distributors: railpro[1)], vossloh

Contractors: Strukton, Dura Vermeer, VolkerRail, bam

Recyclers: van Roon spoorwegmaterialen, Fred Prinsen b.v. & Zn

Rail ownership status

Supplier/distributor	Installer	ProRail	Recycler

1) RailPro is subsiadry of voestalpine, active as voestalpine Track Solutions Netherlands

Source: Interviews, ProRail, Roland Berger

Comments

- ProRail does not procure rails directly this is done via its contractors
- ProRail has a limited view on what happens with rails after transfer of ownership

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Steel is the world's most important construction material, but faces challenges due to high process emissions and energy requirements

Steel market definition and overview

Definition

- Steel is an **alloy of iron and carbon**. Other elements and alloys may be present or added. The carbon share is below 2.06%. Material with a carbon share above 2.06% is called cast iron
- Steel is not a single product. There are more than **3,500 different grades of steel** with many different physical, chemical and environmental properties
- Depending on the carbon content, steel can be **soft and easy to deform or hard and more brittle**
- **Properties can be changed** by alloying, heat treatment or (cold) forming

Benefits

- **High durability** and quality compared to other materials
- **Design flexibility** – Very flexible regarding the end products, which is confirmed by the many industries that use steel
- 100% **recyclable**
- Currently has **lower production costs** compared to other materials of its type, e.g. aluminum

Challenges

- One of the most **CO_2 intensive industries** – approx. 6% of total EU CO_2 emissions
- Production process incurs **high energy costs** due to the large amount of energy required (e.g. heat)
- Susceptible to **corrosion**, therefore, special coatings or alloys (e.g. nickel-based stainless steel) need to be applied
- **Capital-intensive** industry

Examples of steel applications

Automotive

Construction

Oil & gas

Packaging

Machine parts

Transportation

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Source: Eurofer, World Steel Association, Roland Berger

B. Definition of circularity options and CO_2 impact

There are different options to reduce CO_2 footprint and improve the circularity of rails

Options to reduce emissions and improve circularity

Option	Description	Impact: Recycling	Impact: CO_2 reduction
1 Traditional	Current steel production process[1)2)]	-	-
2 Green steel	Use direct reduction technologies and zero-carbon electricity for production of steel for new rails	Recycled steel can be mixed with virgin steel	✓
3 Open loop recycled	Use recycled scrap from market for new rails	✓	✓
4 Closed loop recycled[3)]	Use recycled scrap from ProRail for new rails	✓	✓

1) Not taking rail lifetime extensions into account; 2) In traditional steelmaking and green steel production recycled scrap steel can be added in the process; 3) As primary supplier of rail steel for ProRail was an important source to clarify closed loop approach, however this report does not state this approach is exclusively possible with voestalpine

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B **Definition of circularity options and CO_2 impact**

ProRail can realize both its CO_2 reduction target for rails as well as its target for the share of recycled content by pushing manufacturers to use recycled steel

CO_2 footprint of rail production methods per metric ton rail [metric ton]

	Production Difference based on type of steelmaking	Transport Similar for all options	Usage Similar for all option Includes installation and maintenance	Removal Similar for all options Usually removed in 6 m sections[2)]	Transport Closed loop recycling requires transport to Austria	Recycle[3)] Prevents up to 2 metric tons CO_2 for third-party companies using recycled steel	Recycling share Compared to traditional	CO_2 reduction Compared to traditional
1 Traditional[1)] ∑ 2.2-2.4	2.00	0.04	0.20	0.02	0.03	0.10		-
2 Green steel ∑ 0.3-0.5	0.10	0.04	0.20	0.02	0.03	0.10	**Recycled steel can be mixed with virgin steel**	**~83%** Up to 2 metric tons
3 Open loop recycled[4)] ∑ 0.4-0.6	0.10 / 1.10[5)]	0.04	0.20	0.02	0.03	0.10	**< 100%**	**~79%** Up to 2 metric tons
4 Closed loop recycled ∑ 0.4-0.6	0.10 / 1.10[5)]	0.04	0.20	0.02	0.04[2)]	2.00 / 0.10	**< 100%** If total steel stock increases, virgin steel is required, reducing share of recycled steel	**~78%[5)]** Up to 2 metric tons

Closed loop recycling at this moment can help to ***guarantee high quality*** *of steel scrap, but requires other recycling parties* ***to procure virgin steel as alternative*** *as rail scrap does not enter the scrap market*

1) Figure indicates 0% recycled steel, i.e. virgin, in practice in traditional process up to 30% can be added; 2) Assumed to be equal to CO_2 impact of lifting activities; 2) Closed loop recycling has larger footprint as it requires transport to Austria done by train – Other transport by truck, which has higher CO_2 footprint, but shorter distance; 3) CO_2 footprint of recycling is attributed to the production step; 4) Use of 100% recycled steel that adheres to technical specifications confirmed by supplier – If ProRail uses recycled steel, it comes at expense of others wanting it; 5) According to voestalpine, a maximum of 50% recycled steel can be achieved in its rail making process, leading to higher CO_2 emissions than in case of 100% recycling

Source: Keten-analyse DHV, voestalpine, Roland Berger

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C. Evaluation of CO_2 footprint and circularity of materials

Open loop recycled steel is preferable for its lower CO_2 footprint and more efficient logistics than closed loop, and green steel supply is limited in the short term

Assessment of rail options

	CO_2 reduction and circularity potential	Operational feasibility	Economic feasibility	Overall assessment
1 Traditional	• Highest CO_2 intensity	• Existing supply chain is available • In future, emissions regulation might affect current operation	• Current setup of value chain is proven and efficient	
2 Green steel	• Low CO_2 intensity • No circularity if 100% virgin steel is used, but scrap steel can be mixed in	• Limited supply in coming years • Automotive players are expected to pay premium to secure initial supply	• Green steel is expected to be EUR 100-200 per ton more expensive than traditional steel	
3 Open loop recycled	• Low CO_2 intensity (with renewables) • Market efficiently uses scrap steel for recycling	• Scrap steel market is mature • Scrap can be used in existing steel manufacturing processes, max share to keep currently quality unknown	• Scrap is readily available in the market and can be sourced from the most cost-efficient location	
4 Closed loop recycled	• Low CO_2 intensity (with renewables) • True circularity can be approached for replacement of materials, but 10-20% of materials lost during lifetime needs to be replaced from outside closed loop • Complex logistics results in add. emissions	• Longstanding partnership with voestalpine enables setup of closed loop. According to voestalpine, it can meet existing standards if up to 50% recycled steel is used	• Scrap needs to be transported from construction site to factory, which might not be the most cost-efficient	

High attractiveness — Low attractiveness

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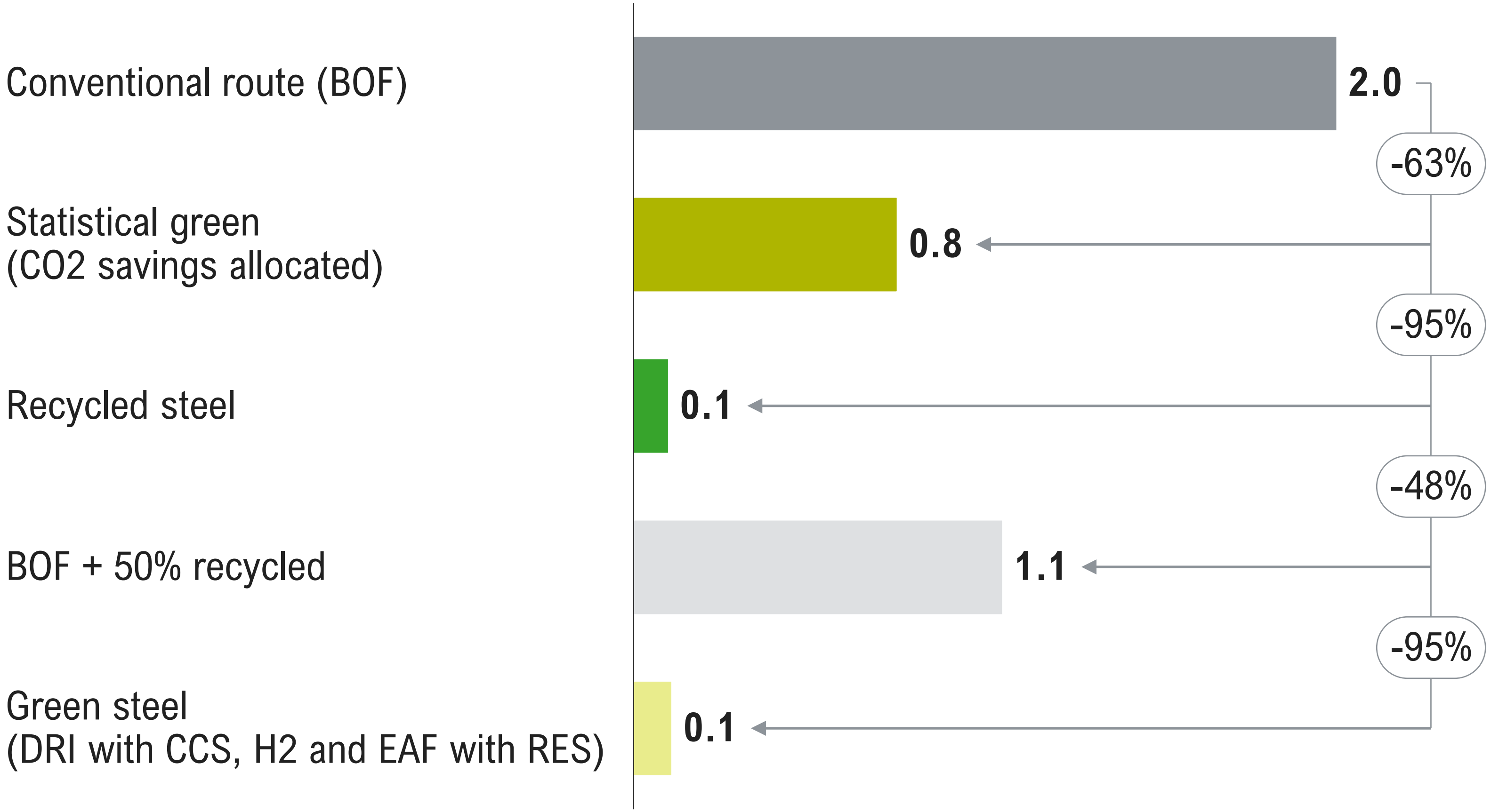
Source: Keten-analyse DHV, Expert interviews, Roland Berger

ProRail can already reach its CO_2 footprint reduction target for rails if they are produced in a "green" manner or if they come from recycled steel

Emissions per ton of material [t CO_2e]



Primary

- **Primary materials** are produced for their first use phase by an end user (e.g. virgin plastics). They are typically using 100% "newly" extracted raw materials, direct reduction of iron ore is the most CO2 intensive step in the steelmaking process, which is not required if recycled steel is used

CO_2 reduced materials

- **Primary materials** with improved CO_2 footprint compared to conventional materials (e.g. green steel)

Secondary/recycled

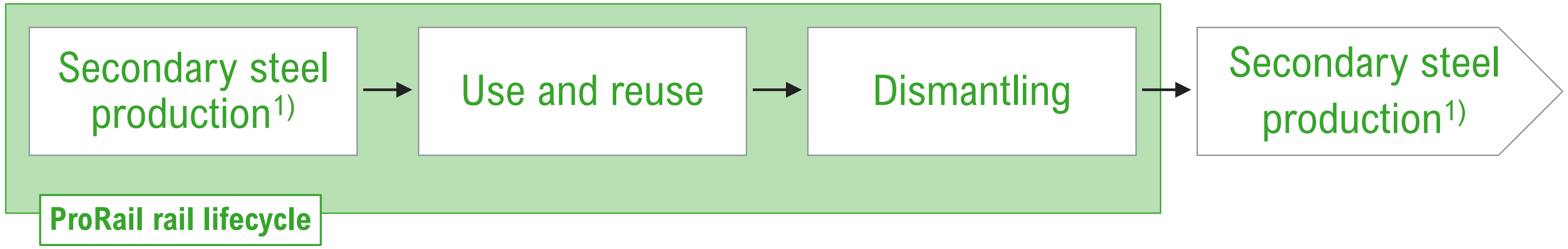
- **Pre-consumer/post-industrial materials** derived from residual/waste materials from production ("scrap") and processed for reuse (risk of greenwashing)
- **Post-consumer materials** are materials that are recycled after use and reprocessed for further use. Ideally, they circulate repeatedly from production to consumption to recycling

Source: Desk research, Roland Berger

To increase circularity, ProRail needs to control material input and recycling, either in a closed loop with single supplier or in an open loop with multiple partners

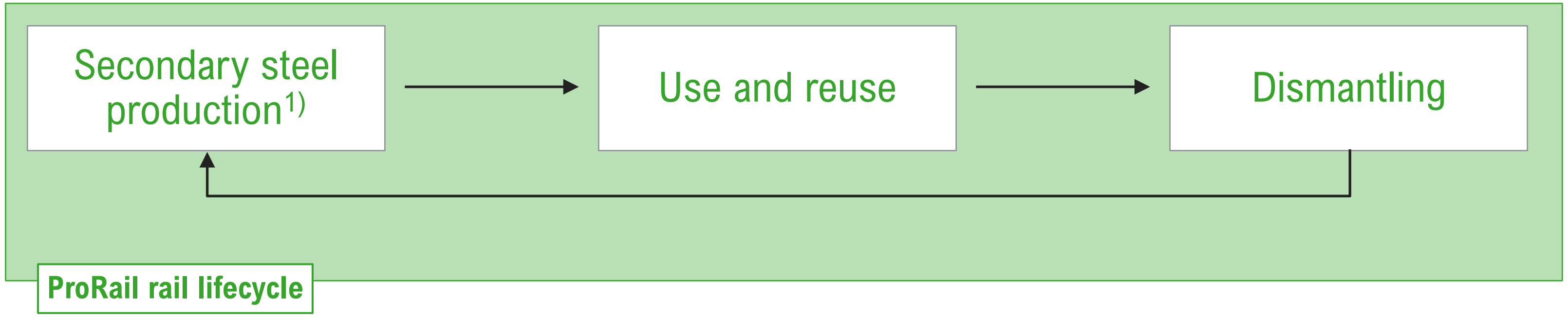
Two options to increase the circularity of ProRail's rails

3 Open loop recycling process



Ensuring that **supplier** (e.g. voestalpine or other) uses the **maximum amount** of **recycled material to produce rails** while working with **contractors ensuring** that **dismantled rails** are **recycled** in an **electric arc furnace**

4 Closed loop recycling process



Delivering **dismantled rails** to **supplier ensuring** that they are used as **input** for steel produced with an **electric arc furnace** – Steel is then **turned into new rails**

1) Assuming usage of an electric arc furnace

Source: Frauenhofer, voestalpine, ProRail, Roland Berger

We expect the overall environmental and economic efficiency of open loop recycling for ProRail to be higher as it allows for more flexibility

Benefits and drawbacks of open and closed loop recycling for ProRail

	3 Open loop recycling process	4 Closed loop recycling process
Efficiency	(+) **Flexibility** to choose **most environmentally friendly offtaker** of **scrap steel** on project basis **(incl. voestalpine)**	(–) **Exclusion** of **possibly more efficient recycling** providers **with more environmental technology** or shorter **transport routes**
Availability of scrap steel	(–) **Reliance** on **high-quality scrap steel** available on the **global market**	(+) **Self-insurance** that **scrap steel** is available **as a raw** material for **rail production**[1)] **Recycling** occurs at **same quality level – No degradation of steel**
Process complexity	(–) **Continuous evaluation** of **multiple providers**, adding **complexity** to the **process**	(+) **One time setup** of **process** with **single point** of **contact**

(+) Benefit (–) Drawback

1) Keep in mind not all material inflow can be recovered at end of life – Circa 10% is lost due to wear and tear during operational life as well as sharpening and milling during maintenance activities

Source: Interviews, Roland Berger

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D. Recommendation

ProRail can reach its targets for CO_2 reduction and recycled share by reusing rail more and procuring rails made from scrap metal

Recommendations for ProRail

- **ProRail can reduce the CO_2 footprint of its rails by ~79% if 100% reuse of scrap becomes possible. For this, agreements with rail producers are required that ensure recycled steel is used to the maximum extent possible (voestalpine claims to be able to go up to 50%). ProRail should consider teaming up with other rail network managers (e.g. DB Netze) in discussions with rail steel suppliers**
  - Steel from recycled scrap has ~90% lower CO_2 footprint than virgin steel. A 50/50 combination of virgin steel (0% recycled steel added – In practice up to 30% of recycled steel can be added) and scrap reduces the CO_2 footprint by up to ~45%
  - Recycled scrap does not necessarily need to originate from ProRail rail scrap. There is a large global market for scrap steel that can be technically and economically processed to meet the technical requirements of the final product
  - Recycled rail scrap from a closed loop set up by the supplier can be more complex and less efficient than an open loop, but does guarantee recycled steel maintains the same quality level (limited steel degradation)
  - Closed loop set up by the supplier requires: 1) investment in (reverse) logistics and warehousing, 2) financial agreements, 3) operational realization
- **Once rail producers have switched their production processes to green steel (expected gradually from 2030 onwards), ProRail can consider purchasing rails made of virgin green steel which reduces the CO_2 footprint. To increase the circularity share, scrap steel can be mixed into the steelmaking process**
  - Green steel can be procured when it is readily available on the market
  - The share of recycled steel can be managed by agreeing with producers that they mix in a certain percentage of scrap steel
- **ProRail can extend the lifetime of its rail assets in cooperation with contractors, reducing the footprint of rail per year used**
  - ProRail policy is to reuse rail sections from "berijdingsklasse" 1 and 2 for lower "berijdingsklassen". In practice, this is rare as it is easier (and likely more profitable) for contractors to cut out rail in sections of 6 meters, sell as scrap and buy new rail, than to cut out longer sections, store and reuse them in other parts of the network
  - Tender processes can be set up such that reuse of materials is incentivized, reducing the need for new materials
  - PGOs can be set up to incentivize contractors to invest in monitoring and predictive maintenance to efficiently replace only necessary materials

ProRail can together with other network managers enter discussions with rail steel suppliers to increase use of scrap and continue effort to extend asset lifetime

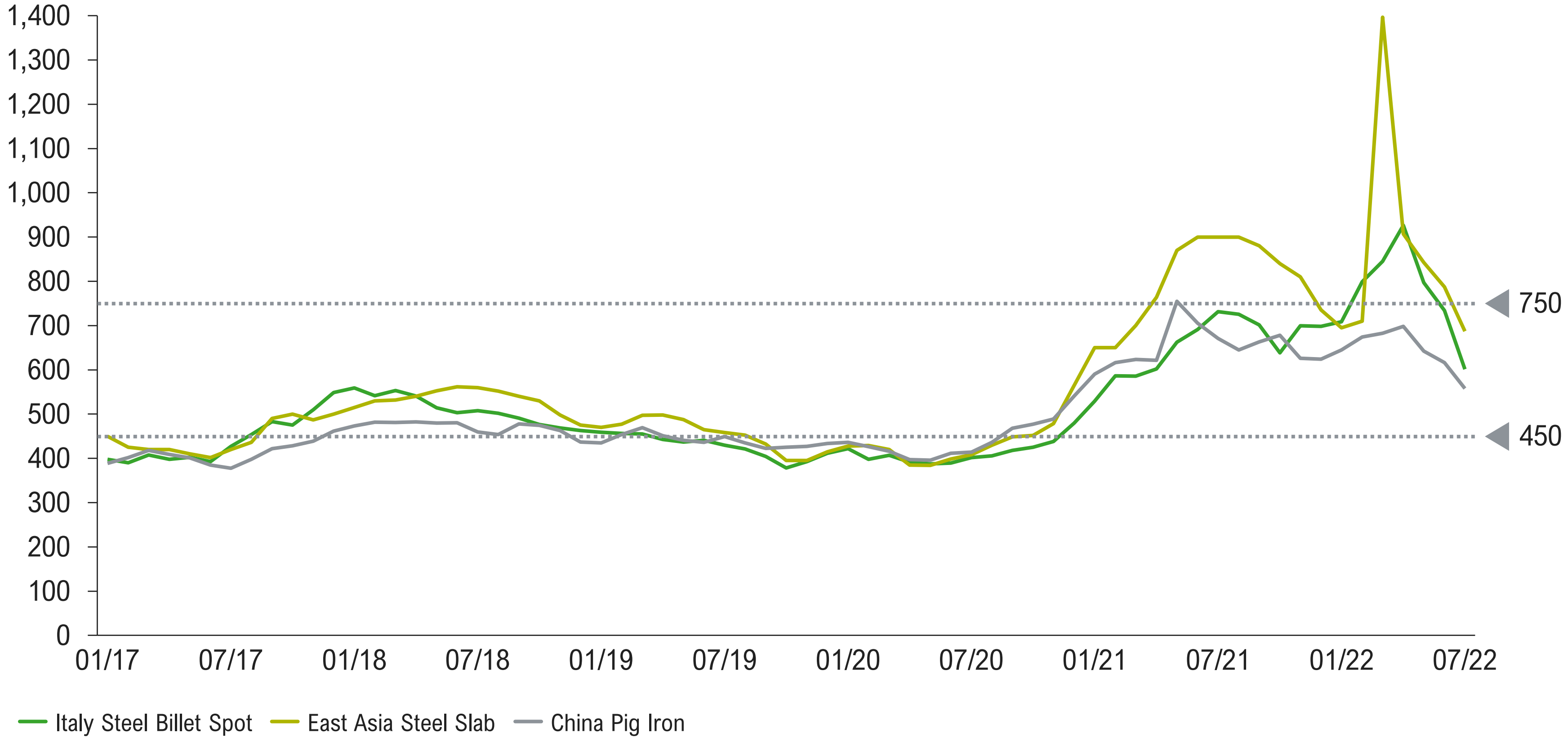
Recommended initial steps for ProRail

- **Contact rail steel suppliers together with other railway infrastructure managers to achieve higher content of scrap recylcing**
  - Contact other national railway infrastructure managers (e.g. DB Netze) to together determine the desired increase in scrap content in procured rail steel
  - Approach rail steel suppliers (e.g. voestalpine, ArcelorMittal etc.) together with other infrastructure managers to discuss increasing scrap content
- **Continue efforts to extend lifetime of rail assets**
  - Work closer with contractors to ensure suitable rail track is re-used instead of brought to scrap
  - Identify further possibilities to extend asset lifetime
- **Create short term and long term planning**
  - Define a short term planning with existing and above initiatives to reduce emissions in coming 1-3 years
  - Create a roadmap for the long term to be ready for when the steel industry is ready to supply sufficient quantities of green steel

I. Information on steel and decarbonization

Market steel prices, especially billet and slab steel, traded at a significantly higher level in 2021-2022 than years before

Steel prices per metric tonne, 2017-2022 [USD]



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Comments

- In recent years commodity prices, including steel prices, have increased and shown high volatility

Source: Bloomberg

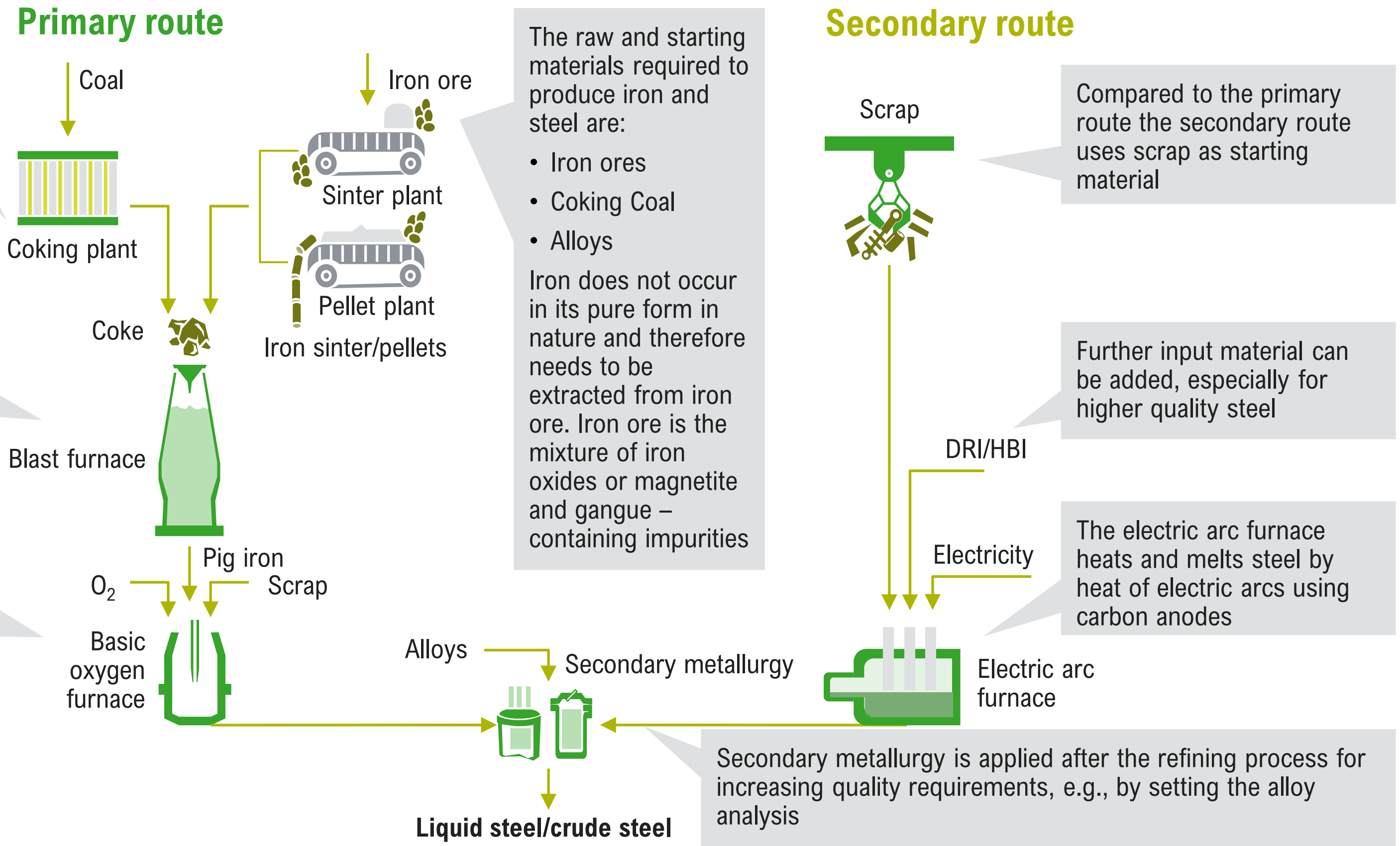
The traditional steel production can follow two distinct production routes, namely the primary and secondary route which uses scrap steel

Steel production routes (simplified)

Metallurgical coal provides the coke that serves as reductant in the blast furnaces in which the ore is smelted

The blast furnace is used to reduce iron ore with a chemical reaction. The furnaces reaches temperatures above 2000 °C

Basic oxygen furnaces convert iron into crude steel by adding O_2 to remove carbon. Scrap is primarily used for cooling the reaction



The raw and starting materials required to produce iron and steel are:

- Iron ores
- Coking Coal
- Alloys

Iron does not occur in its pure form in nature and therefore needs to be extracted from iron ore. Iron ore is the mixture of iron oxides or magnetite and gangue – containing impurities

Compared to the primary route the secondary route uses scrap as starting material

Further input material can be added, especially for higher quality steel

The electric arc furnace heats and melts steel by heat of electric arcs using carbon anodes

Secondary metallurgy is applied after the refining process for increasing quality requirements, e.g., by setting the alloy analysis

Considerations

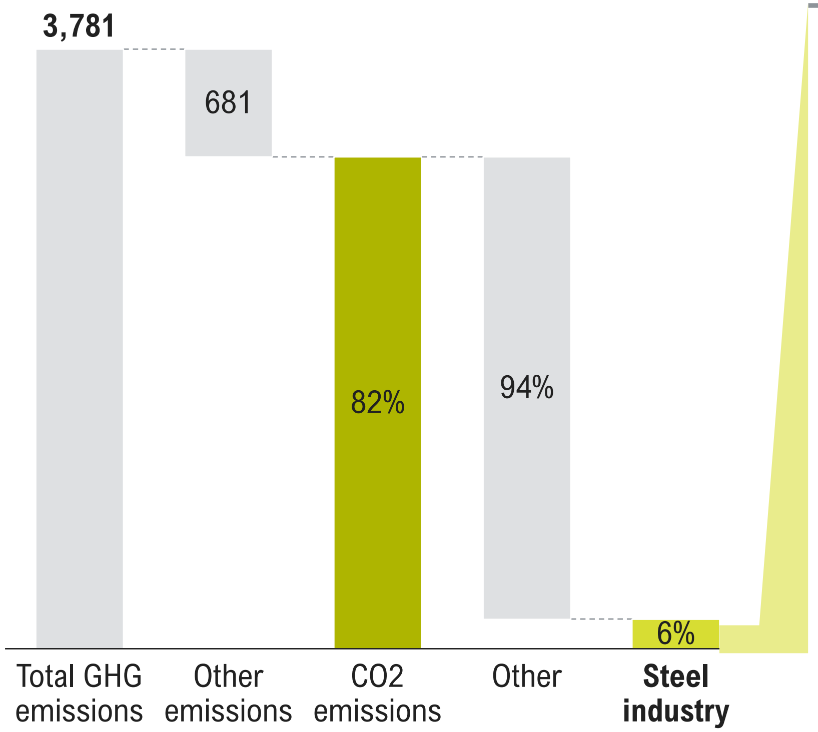
- **Flat products** were traditionally primarily produced via the **BOF route** (primary route) due to higher quality/purity requirements
- Currently, the **primary route** is often operated by **large steel producers (integrated steel mills)**, while the **secondary route is also operated by mid-sized** and smaller steelmakers
- Due to the transition to **green steel** and the lower CO_2 emissions, **large manufacturers** are shifting **towards the secondary route** as well

Source: Company information, desk research, Eurofer, interviews with market participants, World Steel Association, Roland Berger

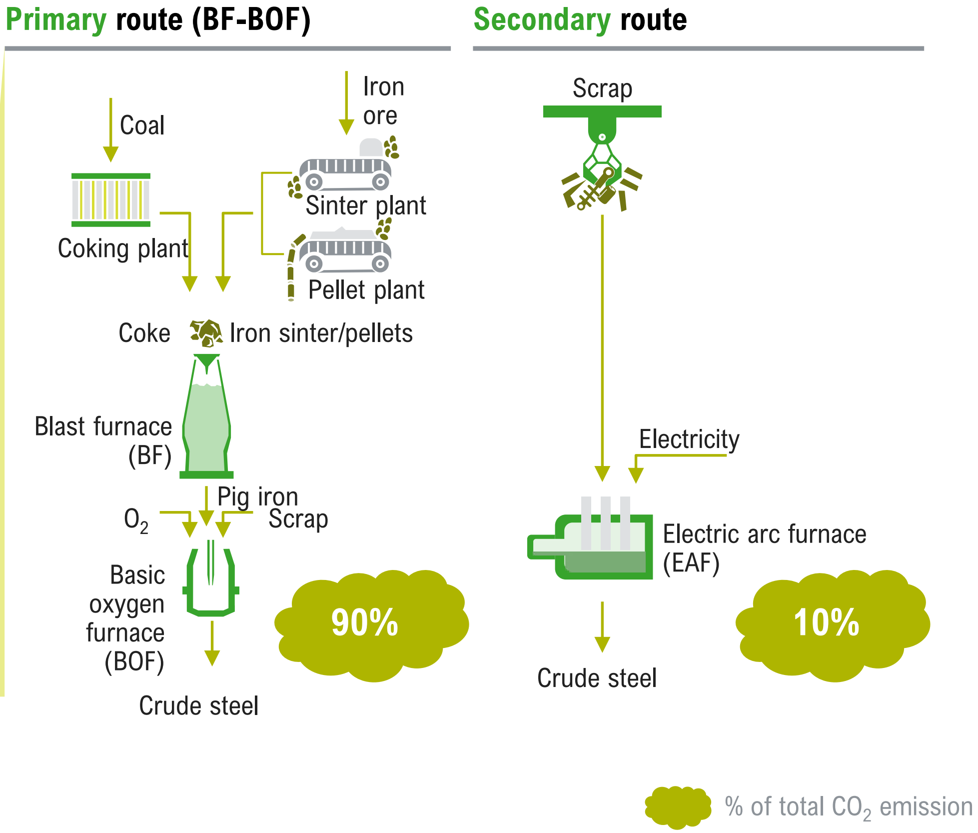
The steel industry is responsible for 6% of total European CO_2 emissions, with 90% coming from the primary route – Blast furnace as major emitter

EU-27 steel production – CO_2 emissions 2021 [m tons]

Steel industry's contribution to CO_2 emissions[1)]



EU-27 steel production routes (simplified)



Considerations

- **European steel industry accounts for c.6% of total EU-27 CO_2** and c.22% of industrial CO_2 emissions excluding combustion
- With almost **90%, most European steel industry's CO_2 emissions originates from the primary route**, given higher emissions but also higher market share of the primary rout (i.e., primary route emits c.4 times more CO_2 as the secondary route)
- The **secondary route requires c.80% less energy per ton crude steel** than the primary route and mostly emits indirect CO_2 depending on the energy mix of its consumed electricity and share of pig iron feed stock

1) Without LULUCF and indirect CO_2

Source: Carbon Trust, EEA, EU Commission, Fraunhofer, Hasanbeigi, Kollmann, Vögele, World Steel Association, Roland Berger

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In the DRI-SAF scenario using hydrogen, the SAF requires the largest amount of electricity with c.580 kWh/t steel – In total, c.130 kg CO_2/t green steel emitted

Mass balance per ton of steel: DRI-SAF – Hydrogen (1/2)[1, 2)]

	Iron ore mine	Beneficiation plant	Pellet plant	Shaft furnace	Submerged arc furnace	Basic oxygen furnace	Downstream aggregates
Input	c.20 kWh diesel; c.1 kWh electricity	c.5 kWh electricity	c.220 kWh coal; c.30 kWh natural gas; c.30 kWh electricity	c.2,000 kWh hydrogen; c.80 kWh electricity	c.580 kWh electricity	c.30 Nm^3 oxygen; c.150 kg scrap	∑ c.: Elec. 700 kWh; NG 30 kWh; Coal 220 kWh; H_2 2,000 kWh; Diesel 20 kWh; O_2 30 Nm^3; scrap 150 kg
Production	Raw iron ore c.1.6 tons →	Iron ore fines c.1.4 tons →	Iron ore pellets (DR or BF) c.1.3 tons →	Sponge iron (DRI/HBI) c.1.0 tons →	Pig iron (similar) c.0.9 tons →	Liquid steel 1 ton →	
By-products	c.10 kg CO_2 Scope 1; c.1 kg CO_2 Scope 2	c.1 kg CO_2 Scope 2	c.80 kg CO_2 Scope 1; c.2 kg CO_2 Scope 2	No CO_2 Scope 1; c.4 kg CO_2 Scope 2	c.30 kg CO_2 Scope 2	c.170 kg slag; c.20 kg BOF gas	∑ c.: CO_2 130 kg; Slag 170 kg; BOF gas 20 kg
Comments	Diesel for drilling, loading, hauling and transportation and electricity for transportation	Electricity mainly used for crushing, screening, stacking and reclaiming	The induration of pellets which requires great amounts of heat is based on the use of coal – Limited amounts of electr. and natural gas required	Almost no CO_2 emissions as green hydrogen and electricity are used	Large amounts of electricity are required for the liquefaction of the solid sponge iron coming from the shaft furnace	Neither natural gas nor electricity is needed, thus limited to no emissions from the BOF	

1) This calculation only considers Scope 1 (e.g., emitted by natural gas or diesel consumption) and Scope 2 (e.g., produced by electricity use), however no Scope 3 emissions coming from used chemicals in the steel making process as well as major emissions resulting from Scope 3 activities such as transportation and use of products are considered. The input of fluxes (e.g., lime or dolomite) or other chemicals are not taken into account as well as minor outputs like dust; 2) CO_2 emission data for low-carbon electricity (e.g., generated from solar, hydro, wind, geothermal and nuclear power) was considered

Source: Midrex, Energiron, desk research, Roland Berger

New ETS aims for a GHG emission reduction of 61% for EU ETS covered sectors by 2030 – Free allowances for steelmakers to be phased out from 2026 to 2035

Deep dive – EU Emission Trading System (ETS)

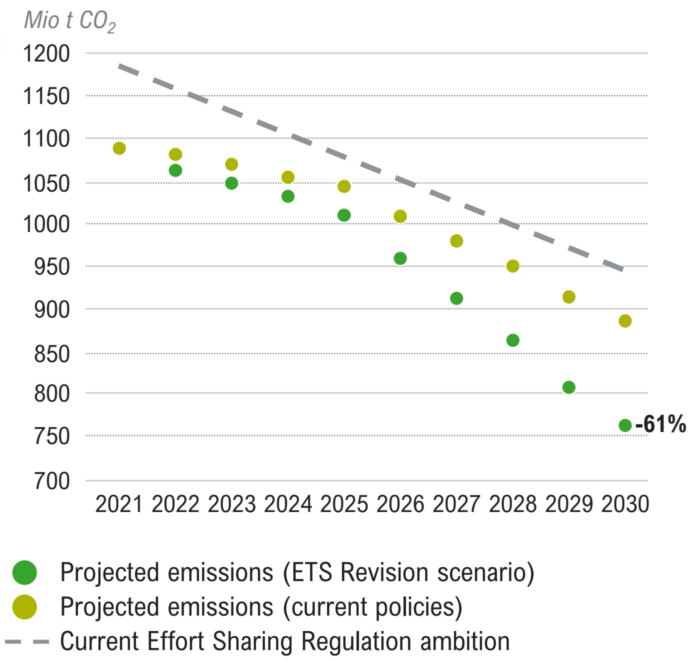
Scope and mechanism

- Emission Trading System puts a **price on carbon** and **lowers the cap on emissions** from certain economic sectors every year
- Works on the principle of **"cap-and-trade".** It sets an absolute limit ("cap") on the total amount of certain GHG that can be emitted each year
- Reducing emissions from **power generation** and **energy-intensive** industries by 42.8% since 2005
- Sectors covered by the existing EU ETS: **Power and heat generation**, **energy-intensive sectors** (e.g., oil refineries, steelworks, and producers of iron, aluminum, cement, paper, and glass) and **aviation** within Europe

New in "Fit for 55"-package

- Emissions from EU ETS sectors to be **reduced by 61%** by 2030 instead of 43% reduction target under current legislation
- To reach this target, a steeper annual emissions/allowances **reduction of 4.2% until 2030** (instead of 2.2% per year under the current system) is set in place
- One-off reduction of overall emissions by **117 m allowances**[2] to bring the cap in line with the new 4.2% reduction pathway
- By 2026, when **CBAM** comes into action, **free allocation** will be gradually reduced by **10% per year**
- Additional **2.5% ETS allowances** for **Modernization Fund auctions** (funding program to support 10 lower-income EU Member States in their transition to climate neutrality)

Cap setting EU ETS Revision



Implications

- Reduction of free allocation expected to **significantly increase carbon prices** and hence, industry exposure to EU ETS costs
- Free ETS allowances for EU steelmakers **phased out from 2026 to 2035** (10% reduction per year, reduced to zero by 2035)
- **Failure to comply with the recommendations** will lead to a **25% reduction in free allowances** for the relevant EU steelmaker

1) Each allowance gives the holder the right to emit: one ton of carbon dioxide (CO_2), or the equivalent amount of other powerful greenhouse gases, nitrous oxide (N2O) and perfluorocarbons (PFCs). Companies can buy allowances or receive them for free when belonging to certain industries; 2) So called "re-basing"

Source: European Commission, Impact Assessment report 2/4 of the legislative proposal (option EXT1), Figure 23, Roland Berger

"Green steel" has a low CO_2 footprint compared to traditional steel due to the use of hydrogen and renewable energy

Traditional steel vs. green steel

Traditional steel

Blast furnace

- Coking coal used in blast furnace
- Produces 2x more greenhouse gases than other process steps
- Carbon capture and storage can reduce emissions but is costly
- Using natural gas reduces emissions by 50%

Recycled steel

Electric arc furnace

- Uses electric arc to melt scrap steel
- Emissions reduced by 50%, even with coal power
- Using renewable energy cuts emissions further
- Limitations are scrap supply and product quality

Combines the best of both worlds, with a low CO_2 emission steel manufacturing technology

Green steel

greensteel

DRI with electric arc furnace (EAF) or submerged arc furnace (SAF)

- Combines **advantages of traditional steel** (high quality and availability of raw materials) and **recycled steel** production (low emission through circular economy)
- Low emission manufacturing technology with **green hydrogen and electricity** instead of coal
- **Clean by-products:** Water, hydrogen and oxygen

The term “green steel” has existed in the steel industry for a while, but there is no universal definition for it

Overview of different "green steel" concepts

- The term "green steel" is used to describe **steel that has been manufactured in a carbon-reduced manner**
- Steel producers have started to have their **steel certified as “green.”** However, these **certificates vary**, which makes it difficult for customers to compare
- Green steel is being **used and interpreted by many different stakeholders to mean different things**, often in the context of marketing new, more environmentally conscious products; It has been used to refer to steel manufactured using breakthrough technology, steel produced from scrap, reused and remanufactured steel, and conventional steel with emissions offset through the retirement of carbon units or allowances
- There are multiple representations on transition towards green steel manufacturing and **multiple definitions/concepts of green steel**

Low carbon steel
Low carbon steel is manufactured using technologies and practices that result in the emission of significantly lower emissions than conventional production

Net-zero, or carbon-neutral steel
Net-zero steel is manufactured by achieving a balance between the greenhouse gases put into the atmosphere when producing steel and emissions taken out of the atmosphere by sinks (e.g., CCUS[1])

Decarbonized steel
It refers to steel production that needs to be free of GHGs/CO_2, not the process itself

Fossil-free steel[2]
Fossil-free steel is steel manufactured without using any fossil fuels such as coal or natural gas, nor any fossil fuel-derived energy (e.g., via pink, turquoise or blue hydrogen)

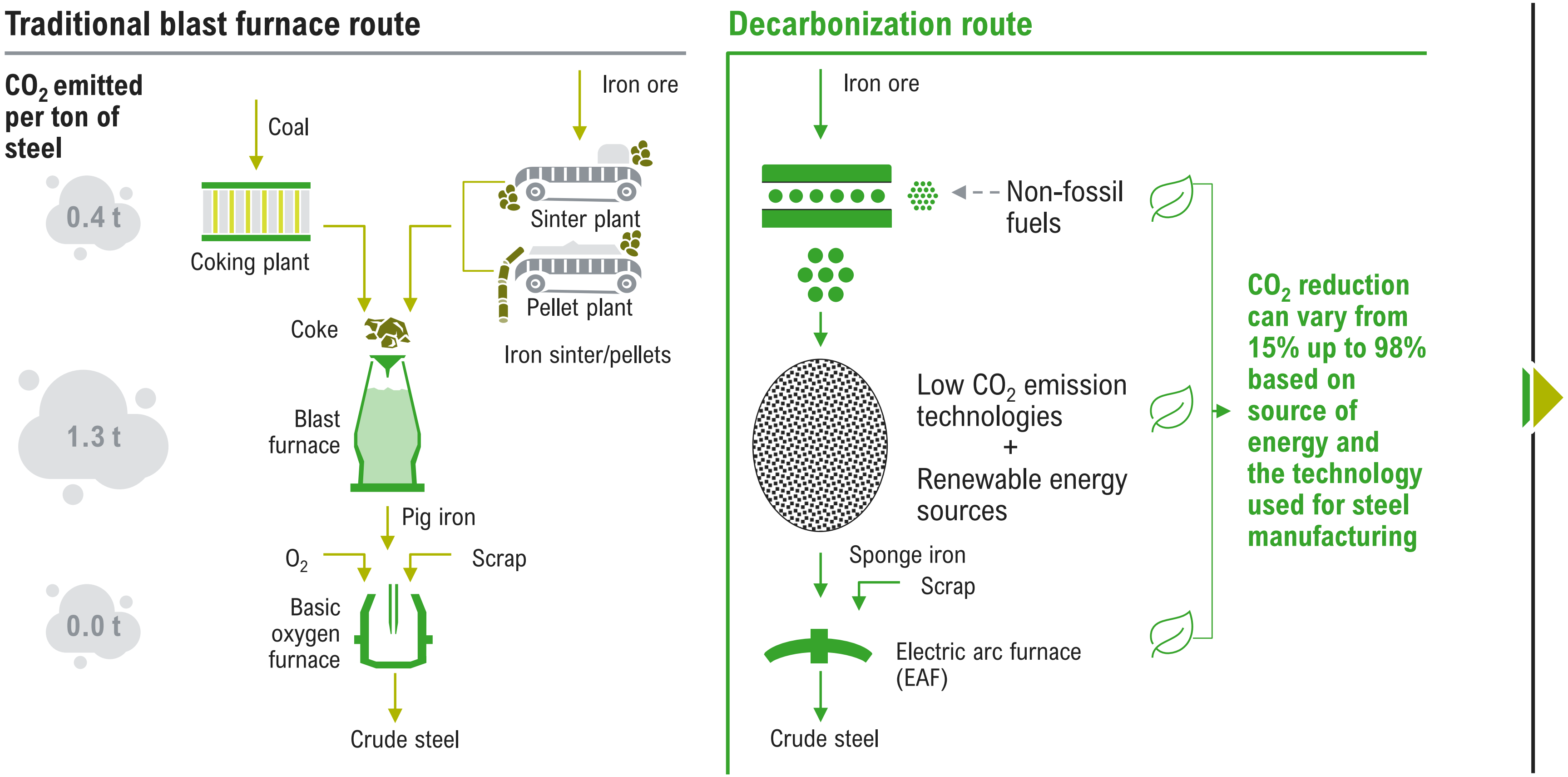
Green steel
This steel manufactured using hydrogen based DRIs. Hydrogen used in this process is green hydrogen and is manufactured using renewable energy sources

1) Carbon Capture, Utilization, and Storage; 2) Fossil-free steel is also expected to be accepted as green steel by regulators and is sometimes labelled as such by producers

Source: World Steel Association, Roland Berger

Green steel manufacturing focuses on altering traditional blast furnaces with low-CO_2-emission technologies powered by renewable energy

Traditional steel production vs. green steel production



Considerations

- **Blast furnace is the main source of CO_2 emissions** in traditional steel manufacturing, accounting to almost c.90% of the total CO_2 emission
- **Traditional steel manufacturing involves high use of coal** and is a very energy intensive process
- **Green steel manufacturing aims to reduce CO_2 emissions** by using low CO_2 emission technologies and renewable energy
- **Blast furnaces are being replaced by direct reduced iron (DRI) plants with electric arc furnaces (EAFs) or submerged arc furnaces (SAFs) and use of natural gas or hydrogen instead of coal**
- Energy and hydrogen required for this process is generated **using renewable sources such as wind or solar energy**

Steel manufacturers are focusing on 2 main technologies to transition to CO_2-reduced steel, CCUS and DRI – DRI can be natural gas-based or hydrogen-based

Low carbon steel manufacturing process overview

1 CCUS

- Carbon Capture, Utilization, and Storage (CCUS) encompasses methods and technologies to **remove CO_2 from the flue gas and from the steel production process**, followed by recycling the CO_2 for utilization or permanent storage options
- **CCUS is one of the least expensive approaches** which can be used in the steel industry and can deliver **up to 80% CO_2 reduction**

2 DRI

- Direct reduction refers to solid-state processes that **reduce iron oxides to metallic iron** at temperatures significantly below the melting point of iron by a reducing gas or elemental carbon produced from natural gas or coal
- The direct reduction process is **comparatively energy efficient,** and does not need a traditional blast furnace

	Technology route	CO_2 emission (scope 1) [t/t crude steel]
0 Baseline	BF-BOF	1.8
1 CCUS	CCUS in conventional BF-BOF route	0.4
2 DRI	**Natural gas-based DRI** (w/wo CCUS)	0.3[1)] / 0.6 (Excl. CCUS)
	H_2-based DRI[2)]	0.04[3)]

+ Alternative technologies

- Alternative technologies include producing iron directly from fine iron ore concentrates by a gas-solid suspension reduction that bypasses energy intensive and environmentally problematic coke making, pelletization and sintering steps

1) Assuming CO_2 is captured in reduction furnace; 2) DRI technology using 100% H_2; 3) Assuming the entire process uses green energy and bio-based carbon sources

Source: European Parliamentary Research Service, IEA, interviews with market participants, Roland Berger

Non-Exhaustive

Europe has roughly a dozen steel players, some are pan-European, voestalpine is a mid-size regional player and there are small smaller local players and importers

Segmentation of competitors in the European carbon steel market

	Pan-European players	Mid-sized regional players	Small local players	(Premium) importers
Description	Pan-European players have **large production capacities** across the globe and typically offer a broad product portfolio from flat to long steel products; they rather act as generalists covering a broad spectrum of end markets	Mid-sized regional players are geographically **more focused within Europe** and smaller in terms of production capacity compared to pan-European players	Small local players have only limited production capacity and typically have a narrow local focus (e.g., customers in geographical proximity), including a dedicated focus on specific end markets	Steel producers with no production capacities within Europe are also part of the European competitive landscape as they import finished steel to Europe; other importers (of more basic steel) are based in Turkey, India, etc.
Market players (exemplary) – Flat and long products	Tata Steel, ArcelorMittal, Liberty	Salzgitter AG, Acciaierie d'Italia	Marcegaglia	Metinvest, Posco
Focus: Flat steel	thyssenkrupp	voestalpine, Arvedi, SSAB, U. S. Steel Košice	Dillinger[1]	Severstal, NLMK Europe
Focus: Long steel		Feralpi Group, IVA	BSW, saarstahl[1], GMH Gruppe	Evraz
# of players	4	10-20	>30	>100

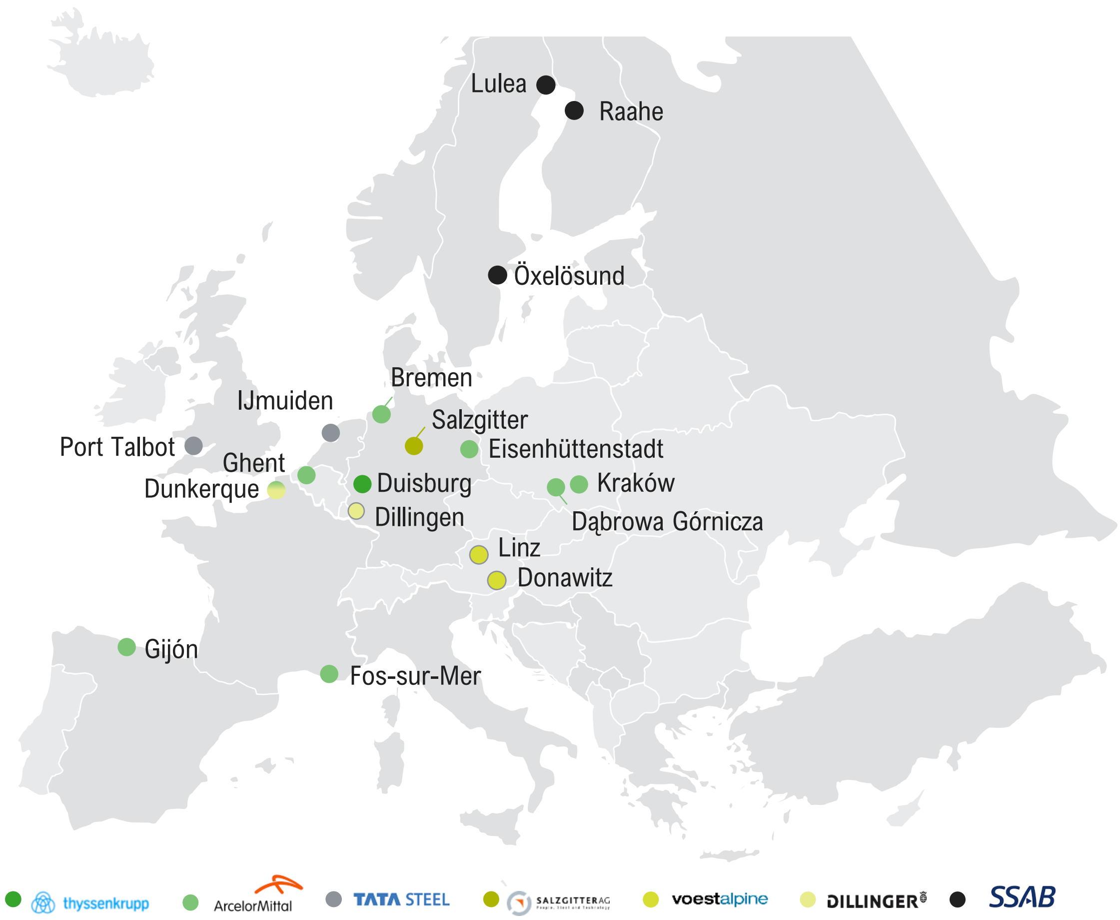
1) Part of the Stahl-Holding-Saar GmbH & Co. KGaA

Source: Annual reports, company information, interviews with market participants, Roland Berger

Draft

Of the 38 blast furnaces in Europe, 18 need to be relined in the next 10 years, they are therefore likely to be replaced by technologies with lower or zero emissions

Overview of blast furnaces (BF) of selected key companies in Europe



Location	Hot metal capacity ['000 tons/year]	Number of furnaces	Relining schedule[3]			Company
Ghent	4,430	2	2023	2041		ArcelorMittal
Dunkerque	6,800	3	2026	2035	2042	
Fos-sur-Mer	5,160	2	2028	2031		
Bremen	3,960	2	2029	2037		
Eisenhüttenstadt	2,340	2	2036	2036		
Dabrowa Gornicza	4,500	2	2026	2029		
Krakow	1,310	1	2026			
Gijon	4,480	2	2032	2032		
IJmuiden	6,310	2	2041	2041		TATA STEEL
Port Talbot	4,770	2	2035	2041		
Duisburg	11,600	4+2[1]	2032	2034	2041[4]	thyssenkrupp
Donawitz	1,370	2	2032	2035		voestalpine
Linz	4,340	3	2024	2036	2036	
Salzgitter	4,800	3	2028	2033	2035	SALZGITTER AG[2]
Raahe	2,400	2	2030	2031		SSAB
Lulea	2,200	1	2035			
Öxelösund	1,800	1	2031			
Dillingen a. d. Saar	4,790	2	2030	2036		DILLINGER[2]
	∑ 72,570	∑ 38				

Relining until 2030 | Relining post 2030

1) Two blast furnaces from HKM joint-venture; 2) Part of the Stahl-Holding-Saar GmbH & Co. KGaA; 3) Taking 20 years into account as relining interval; 4) BF 2, 9 and 8, underwent relines within the past eight years

Source: Company information, Eurofer, interviews with market participants, sell-side documentation, Roland Berger

Steelmakers' "certified" green steel realizes CO_2 reductions through production improvements and statistically allocating the savings to part of the production

Overview of current green steel products by selected key players

Company	Green steel brand	Certification by	Green steel product	Current green steel production	Base year for CO2 reduction	Shipments of green steel
ArcelorMittal	XCarb®	DNV	XCarb products are either green steel certificates or recycled and renewably-prod. products via EAF	Certificates are offered with BOF steel, and CO_2 savings from investments in decarbonization activate across European sites or products produced via EAF, scrap and renewable energy	2018	2021: 100 k t 2022: 600 k t
thyssenkrupp	bluemint®	DNV (bluemint® pure)/TÜV SÜD (bluemint® recycled)	**Pure**: carbon-free steel production by use of HBI; **70%** CO_2 reduction **Recycled**: use of scrap steel; **64% CO_2 reduction**	Bluemint is currently produced by **CO_2 savings** achieved by improvements and changes in the production processes, energy supplies and energy recovery **– Statistical approach**	2018	2021: First shipment quantity n/a 2022: 50 k t
voestalpine	greentec steel	Lloyd's Register	Greentec steel is certified as steel with a reduced CO_2 footprint	**A statistical model** is applied to distribute the actual CO_2 savings across a specific quantity of product. CO_2 is reduced through adjustments to the manufacturing process, such as replacing coke with a hydrogen-based reductant	2018	2022: First coils
TATA STEEL	Zeremis ™ Carbon lite	DNV	Zeremis™ Carbon Lite is a certificate-based, low carbon emission steel solution, offering a 30% reduction in CO_2 intensity against the EU average	Green steel solutions for sustainable steel making at Tata steel include direct reduced iron (DRI), electric arc furnace (EAF) and hydrogen production technology	2018	Before 2030

?!

Explanation "statistical green steel": Steelmakers take action to reduce CO2 emissions in their production process. Reduced CO2 emissions are audited and verified by external auditors. Steelmakers can allocate savings to certain products or sell them as certificates. Customers benefit from improved Scope 3 emissions.

Source: Company information; desk research; Roland Berger

Non-exhaustive

Several of the European steelmakers have launched projects to invest in DRI shaft furnace projects to produce less CO_2 intensive steel

Selected low carbon steel transformation projects in Europe (DR plants and/or EAF/SAF plants)

	ArcelorMittal	TATA STEEL	thyssenkrupp	voestalpine	SALZGITTER AG	SSAB	DILLINGER	H2 green steel
Climate targets	35% CO_2 reduction by 2030; Carbon-neutral by 2050	Carbon-neutral by 2045 in NL & carbon-neutral steel by 2050 in UK	30% CO_2 reduction by 2030; Carbon-neutral by 2045	CO_2 reduction of 30% in 2027; Carbon-neutral by 2050	No coking coal by 2033; Carbon-neutral steel by 2050	Entirely fossil-free by 2030	65% CO_2 reduction by 2030, 80% until 2045	Entirely fossil-free
Projects	• **H2H** – Setup of H_2-based plant in Hamburg with production capacity of 0.1 m t/a • **Bremen and Eisenhüttenstadt** – DRI-EAF plants will be setup until 2030 • **Dunkerque and Fos-sur-mer** – Setup of **2.5 m tons DRI** and **two EAFs** on the Dunkerque site and **a EAF** in Fos until 2027 • **Gent**[1] – Plan to set up a 2.5 m t/a **DRI plant and two EAFs** • **Gijón** – Plan to set up a 2.3 m t/a **DRI and 1.1 m tons EAF plant before 2026**	• **IJmuiden** – Plan to replace two blast furnace by **DRI-EAF** using Energiron technology • **Port Talbot** – Discussion about replacing existing furnaces with EAF	• **Duisburg** – Setup of H_2-DRI plant with an annual production of 2.5 m tons DRI per year	• **Greentec** – Plan to shift gradually to H_2-based DRI route with **two EAF units (2.5 m tons)** at the sites Linz and Donawitz by 2027 and an operational **2 m t/a DR plant** in Texas[2] • **H2FUTURE** – Pilot electrolysis plant at 6 MW in operation since 2019	• **Wilhelmshaven** – Feasibility study of DRI-EAF route with capacity up to 2 m t/a • **SALCOS** – EUR 723 m investment approved for first stage of transformation of existing plant to DRI-EAF with 2.1 m t/a capacity	• **HYBRIT** – Plan to create an entirely fossil-free value chain with fossil-free pellets, fossil-free electricity and hydrogen with a **DRI-EAF** route	• **Dillingen** – By 2030 launch of DRI plant with 2.5 m t/a • **Dillingen/Völklingen** – 2 EAFs with ~3.5 m tons of crude steel p. a. by 2030 • By 2045 third EAF with 1.2 m t/a • **Dunkerque – H_2-based steelmaking plant** (1 GW electrolyzer and 2 m tons DRI) with LIBERTY Steel & Paul Wurth • Rio Tinto, Paul Wurth partnership on study on **low-carbon HBI** with possible investment in a H_2-DRP	• Aiming to setup a fully-integrated, **DRI-EAF** greenfield steel plant in Boden with a capacity of 5 m t/a

1) Both EAF and SAF in consideration; 2) voestalpine Texas: sale of majority stake to ArcelorMittal

Deep dive for furthest advanced projects on following slide

Source: Company information, desk research, interviews with market participants, Roland Berger

Draft

Non-exhaustive

In particular, some companies in Europe have invested in DRI techniques using hydrogen to lower their CO_2 emissions but still for small annual production

Deep dive: Selection of advanced hydrogen DRI/EAF projects in Europe

Companies	ArcelorMittal	thyssenkrupp	voestalpine	Salzgitter AG	SSAB, LKAB, Vattenfall
Project name	**Hamburg H2**	**tkH2Steel®**	**H2FUTURE/SuSteel**	**Salcos**	**Hybrit**
Country of company					
Description	• On site in Hamburg, **DRI-EAF facility made with 100% hydrogen** • Process of reducing iron ore with hydrogen will first be tested using grey hydrogen, then switch to blue and green H_2	• Plan to build a **first DRI plant** in mid 20's in Duisburg • Launched transformation project tkH2Steel® leading to **3.5 m tons CO_2 reduction**	• **Hydrogen** producing **electrolysis** plant built on **premises** for energy storage • **Electric arc** furnaces powered with **green electricity**	• **Onsite** production and local supply of green electricity and **green hydrogen** • Hybrid usage of **DRI** and **electric arc furnace** (2.1 m tons) routes	• **Fossil-free steel** value chain with **renewable energy** sources issued H_2 • **Feasibility** study on pilot plant **completed** • Fossil-free pellets trial by **2021**
Capacity	0.1 m tons DRI per year	2.5 m tons DRI per year	6 MW PEM electrolysis system	7 wind turbines with 30 MW wind power ($WindH_2$) 2.2 MW electrolysis plant	1.3 m tons/year until 2026 and 2.7 m tons/year iron sponge until 2030
Commercial start date	2025	Contract award fall 2022 – production start in 2026	Commissioned 2019	Production start end 2025	2025
Selected Investments	**EUR 110 m** (EUR 55 m from German government for DRP)	**EUR 2 bn** by tk SE + public financial support	**EUR 18 m** EU-funding for hydrogen production pilot plant	**EUR 1.3 bn** for first project stage (power, electrolysis, DRI)	**EUR 143 m** funding from EU IF[2)] for demonstration project

1) Dedicated electrolysis set up in RWE Linde plant for 70% of required volumes; 2) Innovation Fund

Source: Press review, Roland Berger

II. Team and contact details

Your team for this project

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III. Interview list and data requests

In total nine interviews have been performed, three internally at ProRail and six with suppliers

Interview list

Expert	Company	Topic	Date	Status
Bart Schotsman	ProRail	Technical specifications	29-9-2022	Performed
Liselotte Gijsbers	ProRail	Contact rail suppliers	30-9-2022	Performed
Joost Scheepens	ProRail	Procurement materials	3-10-2022	Performed
Friso Copier	Van Roon	Procurement contractors	5-10-2022	Performed
Joris Jan Gerritse	Vossloh	Recycling	7-10-2022	Performed
Eduard Coomans Janthijs de Haan	BAM	Contractor	10-10-2022	Performed
Joost de Bonte	VolkerRail	Contractor	11-10-2022	Performed
Fred Prinsen	F. Prinsen B.V.	Recycling	13-10-2022	Performed
Sander Brinkhuis	voestalpine	Rail supplier	13-10-2022	Performed

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Comments

- Discussions with different people at ProRail and its suppliers have been performed

We based our findings on the information we have been able to collect in a short time

Data used for project

Data item	Status	Comment
Life cycle analysis rails report	Received	
ProRail scope-3 emissions report	Received	
Rail network size	Received	• Only published ProRail figure • Other countries obtained from UNECE
Expected km of new build and replacement of rail in next 10 years	Not received	
Green steel plans voestalpine	Received	
Techniek Strategie 2023	Received	• Carbon reduction plans across wider ProRail organization are described
Rail procurement by contractor	Not available	• ProRail has a very limited view on material use by its contactors • Information needs to be obtained in interviews with contractors

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