CORROSION SCIENCE AND TECHNOLOGY, Vol.23, No.6(2024), pp.482~494 pISSN 1598-6462 / eISSN 2288-6524
[Research Paper] DOI: https://doi.org/10.14773/cst.2024.23.6.482

Europe: Towards Clean and Green Steel Production in Challenging Times

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(Received March 21, 2024; Revised June 01, 2024; Accepted June 01, 2024)

Europe is on the verge of a new Industrial Revolution. Steel production faces major challenges, not only to decarbonise the steel production to meet climate goals, but also to become an essential part of a closed-loop economy with minimal environmental footprint. Numerous projects are running to decarbonise the steel industry and to promote the transition to hydrogen-based steel making. This requires large investments and a carbon border mechanism legislation is necessary to keep a level playing field with other global regions with leaner legislation. The green energy transition will also have implications for 1) the future furnace layout of galvanising lines, 2) on the processability of steels during galvanising in the line and 3) on processability during manufacturing at the customer due to higher recycled content. For galvanised markets, automotive is expected to remain stable, while growth is expected in construction and engineering, especially in relation to green transition and in-door climate control. The excellent corrosion protection of zinc will be an enabler for a durable society.

Keywords : *Decarbonisation, Environmental footprint, Markets, Production, Galvanising*

1. Introduction

The history of modern steel production started in the second half of the 19th century when Henry Bessemer engineered the Bessemer converter (Fig. 1) which increased the steel production to an impressive five tons per hour. When Sidney Thomas adjusted this design to cope with acidic ores around 1880, it kick-started the basic Bessemer steel production at multiple locations in Europe and America [1].

This Bessemer-Thomas process propelled the world into the second industrial revolution, as steel was not only needed for new products but also for the machinery that produced these products. Since that time, steel production has been the cornerstone of the economic growth. As such, the focus of the steel industry over the last two centuries has been one of increasing quality and productivity.

One of the major improvements was the change from a manufacturing chain of geographically separated production facilities towards an integrated steel site where everything from ore preparation to coating is in an efficiently aligned production chain in one geographical location. This had of course a massive beneficial impact on production cost and time and allowed the integration of sourcing raw materials to an optimum ore mixture.

Furthermore, steel producers have been actively working together with their customers to optimize the use of materials, material properties and component design criteria. This accelerated the advancement of new steel grades and has led to an increasingly versatile range of steels and related products to address technological challenges.

Hence, steel has remained the corner stone of economic growth and because of cheap, high quality, and readily available steel, we have seen an enormous increase in

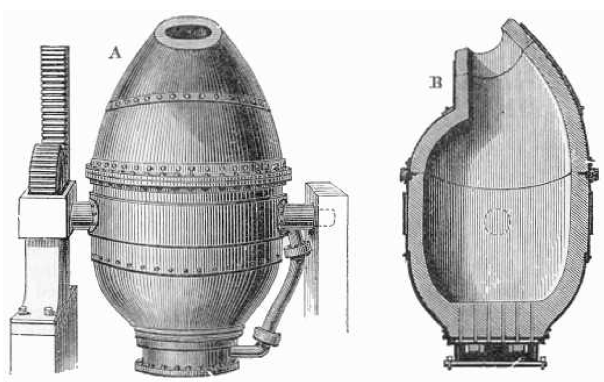

Fig. 1. Bessemer converter [1]

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wealth and living standard. Adding to this the increase of the global population and its desire to have a high living standard has resulted in a consumption society with an even bigger appetite for steel. However, there are consequences associated with this. First of all, the fact that classical steel production is a massive contributor to greenhouse gas emissions. Secondly, the production of steel has an environmental impact on its surroundings and especially in areas with a high living standard this is commonly seen as unacceptable nowadays. The associated cost of these consequences will be passed back onto the steel industry and as such represents an enormous challenge and major threat for the steel industry. So, it is obvious that the major developments in the steel and galvanising industry are associated with these challenges.

2. Sustainable Steel

The only way the steel industry can survive is if the afore mentioned issues are faced and addressed: the need for decarbonisation and increased circularity to reduce our CO_2 and environmental footprint and that of our customers downstream the need to listen to and act on an increased environmental awareness from empowered social (neighbouring) communities and environmental organisations.

2.1 Decarbonisation

Almost two tons of CO_2 are emitted per ton of crude steel produced, making steelmaking one of the most carbon-intensive industrial processes in the world. At present, the European steel industry is responsible for 5.7% of CO_2 emissions compared to roughly 7% worldwide [2,3]. Since 1960, the steel industry in Europe has made massive undertakings to reduce CO_2 emissions, resulting in halving its CO_2 emissions. To reduce the greenhouse gas emissions further by at least 55% by 2030 compared to 1990 levels, and even to near-zero emissions by 2050 a revolutionary approach is required. The main strategy for the European steel industry is the transition from coke-reduced iron and blast furnaces towards Hydrogen-based Direct-Reduced Iron (DRI) facilities and Electric Furnaces (EAF/ REF) – see Fig. 2 [4]. Many companies anticipate an initial phase with natural gas as reducing agent, followed by a transition towards hydrogen at a later stage [5], when the required Hydrogen infrastructure is further established and the technological readiness level of hydrogen-based DRI is demonstrated by successful pilot trials. Carbon Capture and Storage (CCS) or Carbon Capture and Utilization (CCU) technologies have been investigated and piloted, but for now these technologies are foreseen to play only a small role in the decarbonisation of the steel industry.

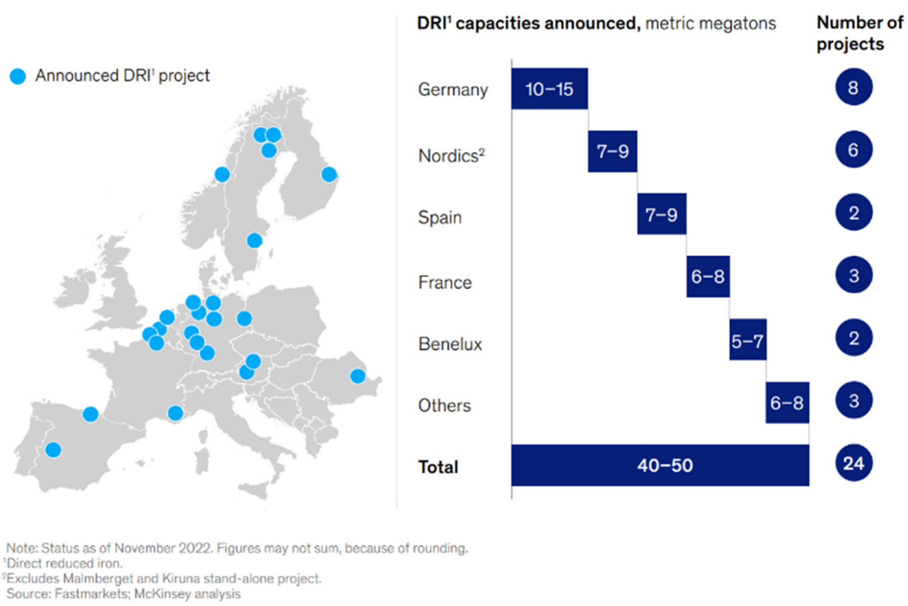


Fig. 2. Announced DRI projects in Europe (status November 2022) [4]

The decarbonisation in the steel industry was partly enforced by the EU with the introduction of the Emissions Trading System (ETS) in 2005. This ETS is the largest multi-country, multi-sector greenhouse gas emissions trading system in the world and is a key instrument for the EU to reduce greenhouse gas emissions for a number of sectors, including the steel industry [7]. This trade in emission provides an incentive to invest in low-carbon technologies, whilst this trading also ensures that emissions are cut where it costs least to do so. A drawback of the EU ETS is that it fuels cheap steel imports to the EU from other places in the world where no or lower penalties on CO_2 emissions are levied. To mitigate this, the Carbon Border Adjustment Mechanism (CBAM) has been proposed [8] to level the playing field for European steel producers and other industries. At present, it is foreseen that the CBAM measures will start in 2026 and will be gradually phased in over a nine-year period.

2.2 Circularity and sustainability

The steel sector is of vital importance to economy of Europe, due to its role in the green energy transition, the large number of jobs involved, and the ambition to be self-supporting in steel as Europe. The European Union (EU) is dedicated to the transition to a green and clean production, and is therefore committed to support R&D programs that look into the commercial feasibility of innovative low-carbon technologies, such as the Clean Steel Partnership [9]. This program, launched in June 2021, aims to push a number of breakthrough technologies for clean steel production to large-scale demonstration plants by 2030. Furthermore, there is a trend in Europe to move from a disposable society, towards a society that focuses on increased lifetime and re-use. In this context, life-cycle analyses are used to evaluate the environmental impact of the entire chain from cradle to cradle. The sustainability performance is then optimized by - for example - improved corrosion resistance, materials-efficient manufacturing, improved product-to-product recycling, automated post-consumer scrap sorting, recycling-oriented alloy design, and the development of multi-purpose cross-over alloys [10].

2.3 Environmental awareness

Like the major reductions in CO_2 made since 1960, also air pollution and other emissions from steelmaking have been strongly reduced in Europe since the beginning of industrial steelmaking – see Fig. 3a. However, the steel production in Europe is still causing pollution, see for example the emission intensity of one of the major sources of air pollution – Particulate Matter - in steel production in Fig. 3b [13]. The differences in emissions between the four global regions in Fig. 3b are related to differences in the share of EAF steelmaking (USA has a high percentage of EAF), fuel mix used by the industry, and implementation of pollution control technologies (strong in Europe enforced by legislation).

In Europe, with its high standard of living, social communities do not accept the burden that a steel company places on the local surroundings and the

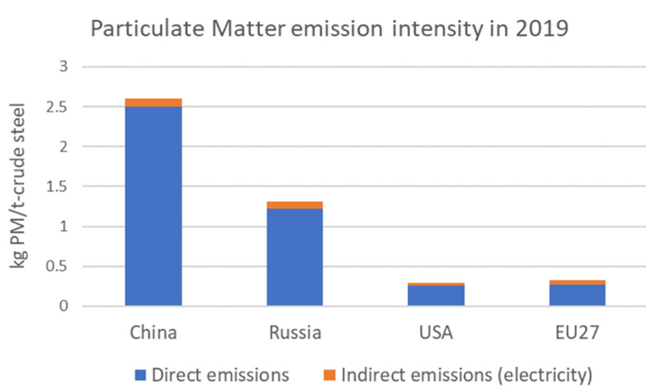


Fig. 3. (a) Left: Polluting coal-burning factories in 19th-century UK [12]. (b) Right: Air pollution by Particulate Matter (PM) emission intensity in 2019. Direct emissions from the on-site steel production and fuel combustion; indirect emissions are off-site emissions associated with electricity use by steel plants [13]

environment. Steel sites that are in urban areas – like many in Western Europe – need to react socially responsible to the increased environmental awareness and criticism from empowered neighbouring social communities. Steel companies not only have to reduce CO_2 and ensure that production complies with emission legislation limits, but also must reduce nuisance caused by dust, noise, and odour. Just as with CO_2 emissions, this is a serious threat towards the viability of the steel industry, in particular in densely populated areas, and may require large investments to reach technical solutions to reduce this type of nuisance of pollution, on top of the already enormous investments required for decarbonisation.

3. Galvanised Steel and Production Line

Like the heavy end, the hot-dip galvanising lines are facing major challenges with the transition to become CO_2 neutral. Especially when this comes next to the challenges of today, i.e., the focus on furnace improvements and new lines to allow the production of 3rd Generation steel grades.

3.1 Production AHSS grades

Over recent years, new hot-dip galvanising lines [14,15] dedicated to the production of these AHSS grades have been commissioned by ArcelorMittal in Belgium (2018), and Salzgitter (2022) and TKS (2022) in Germany. However, many hot-dip galvanising lines have a comprehensive product mix. These lines must cope with variations in strip dimensions and steel grades with different process recipes. Next to this, the process window is often tight and the surface condition along the coil can be inhomogeneous. Variations in roughness or the amount of surface cavities can occur over the length and width of the cold-rolled strip [16]. This can lead to inhomogeneous emissivity and via subsequent variations in heat absorption to undesirable temperature fluctuations. Furthermore, the variations in emissivity can lead to significant errors in temperature readings when using pyrometry. These emissivity related issues can be addressed in two ways. Firstly, thermal imaging using a camera in the wedge of a deflection roll [17] can give an accurate temperature reading across the strip width that is no longer sensitive to emissivity variations of the strip. Secondly, by using digitalisation and Industry 4.0 to improve control systems in the line with predictive models and digital twins. Model predictive temperature control [18,19] is widely applied to ensure a stable production for steel grades in general and challenging automotive grades in particular.

Digitalisation and improved measuring systems are also used in other areas in the galvanising line where the use of modelling will increase. For example, Tata Steel has been working on an improved oxidation model, which was initially developed by Delft University (TUD), and which will be used for predictive control in the future. Another example is the control of mechanical properties, for which an in-line XRD measurement system – see fig. 4 [20] – has been installed that measures the austenite and ferrite fractions in the slow cool section. With closed-loop feedback the top temperature can be adjusted in case the phase fractions are not correct to reach the mechanical properties. This fast feedback-loop will increase production stability and yields improved consistency in

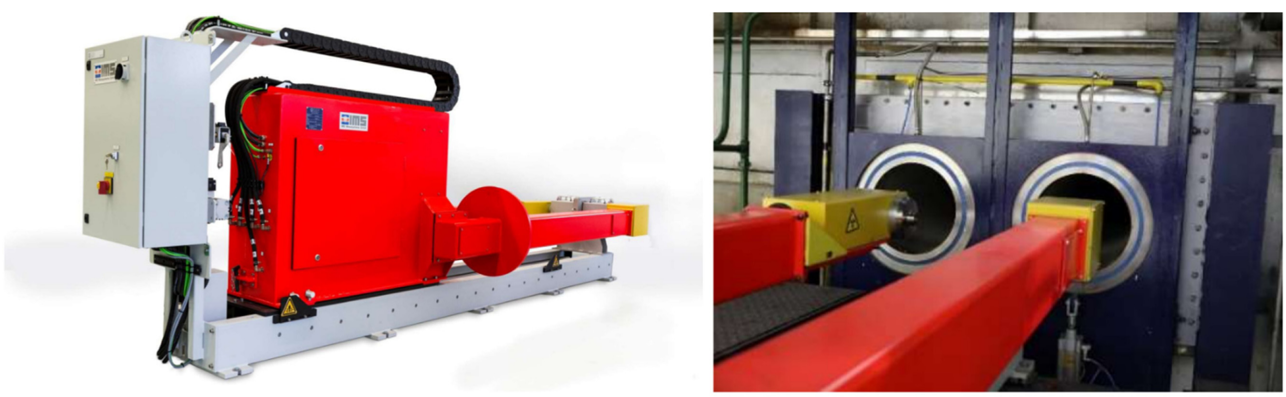


Fig. 4. X-CAP gauge and protective housing in the annealing furnace [20]

mechanical properties. Furthermore, in the context of sustainability, improving the product yield is an important tool to reduce the environmental footprint of the galvanising line.

3.2 Increased scrap content

Being able to deal with a larger variety of incoming material will also be essential in relation to future circularity. The galvanising lines will be forced to process incoming substrates that are produced with higher scrap contents and associated increase in tramp elements like Cu, Ni and Sn. These elements may influence production, processability, and properties of the galvanised steel. They can for instance affect galvanizability, mechanical properties, yield increased contamination of the zinc bath, or potentially affect the interaction between coating and substrate, which in turn can alter the conditions for liquid-metal embrittlement (LME). Beyond these considerations, there may be other effects that are not yet foreseen.

3.3 Zinc recycling

The increased focus on circularity and reducing emissions is also relevant for galvanising. It is expected that the yearly zinc demand will grow from 20 Mt in 2019 to 32 Mt in 2050 [21]. At present, most of the global zinc supply comes from mining. From Fig. 5a it follows that at the current mining rate, the 250 Mt of proven and probable zinc reserves may all have been mined within 20 years. And although the extractable global zinc resources are large, it is essential to increase the zinc recycling rate. Zinc recycling has already doubled between 2010 and 2019 due to more stringent legislation against landfill of zinc-containing dust, but further improvements in zinc recycling are required.

Currently, most galvanised steel scrap is preferentially routed towards the EAF production route [22], with zinc ending up in EAF dust (10-40% zinc). The current Best Available Technique to recover zinc from the zinc dust is by the Waelz Kiln process [22], in which zinc oxide in the dust is reduced in a rotary kiln at 1000 to 1500 ºC with a carbon containing reductant/fuel. As such this process is – like the blast furnace iron making process – a major greenhouse gas emitter [23]. The new smelting-reduction iron making process of HIsarna [24,25] has the potential to play an important role in zinc recycling. The HIsarna process is - apart from being a low CO_2 steelmaking process (potentially 50% reduction in CO_2 emissions compared to blast furnace route) - also capable of reclaiming zinc from zinc dust or from galvanised steel scrap. Continuous development for zinc recovery by HIsarna is focussed on increasing the enrichment level for Zn in recovered dust so that it is suitable for direct

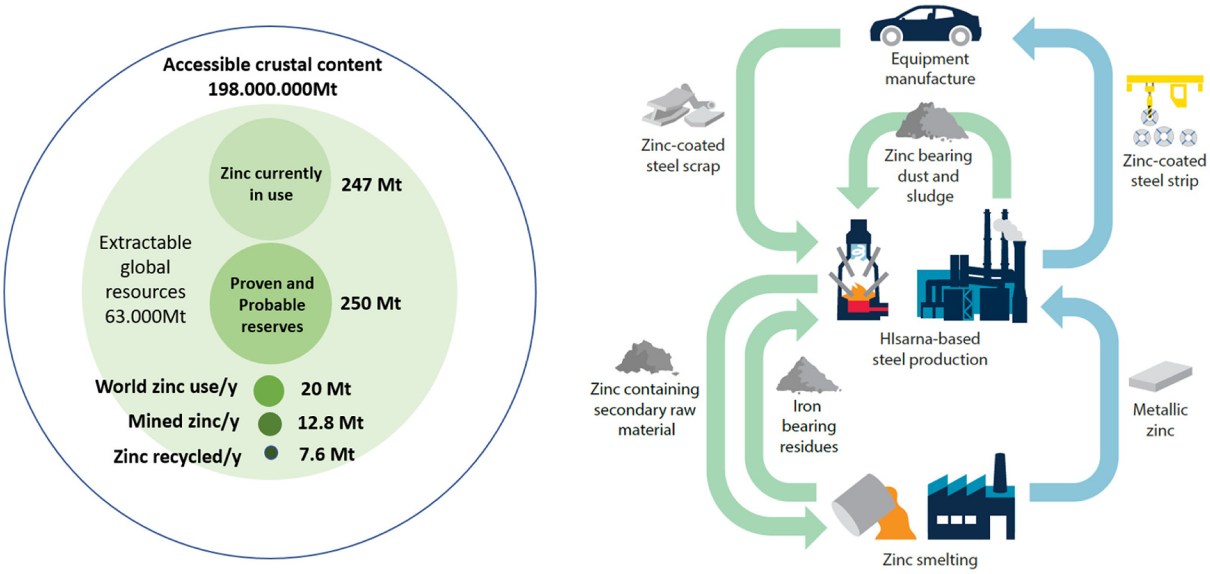


Fig. 5. (a) Left: Global estimates in million tons (Mt) of zinc resources, reserves, production and use in 2019. [21]; (b) Right: Schematic for the recycling of zinc-coated steel scrap and zinc bearing dust and sludge via the HIsarna process [24]

use in Zn smelting – see Fig. 5b. For this a dedicated facility has been installed next to the HIsarna pilot plant in IJmuiden in the Netherlands to turn a mix of wet sludges and dry dusts into micro-granules and briquettes, which are suitable for direct charging into the HIsarna process. The HIsarna iron making process is close to upscaling to a first industrial scale application in India.

3.4 Energy transition for galvanising lines

In addition to a focus on yield and circularity, the galvanising lines will also have to face the required transition from fossil-fuel to hydrogen and/or renewable-energy sources. Furnace suppliers are working on options that include induction units, electrical radiant tubes – see Fig. 6, hydrogen-fuelled combustion [26-28]. The question if hydrogen or electrical prevails is at present difficult to answer and will to a large extend depend on the location, present configuration, and the product mix that is produced on a line. Looking at the technological development required, electrification of the lines seems to be the easiest solution. This does however require large investments for implementation and comes with large fluctuations in operational costs. Alternatively, modern gas-fuelled burners can already deal with a certain level of hydrogen. The partial replacement of natural gas generates as such a certain flexibility. However, hydrogen causes a modification in the composition of the furnace atmosphere, with lower or no CO_2 and an increased concentration of H_2O. This different atmosphere may interact with both the steel surface (different scale formation and or decarburization) and the ceramic walls of the furnace [26,27]. Furthermore, the higher flame temperature of hydrogen combustion will increase the emissions of NOx in conventional burners. Therefore, for hydrogen-rich fuels, new burner concepts are required to keep NOx emissions low to near zero, for instance by using oxygen enriched air or 100% O_2 [28].

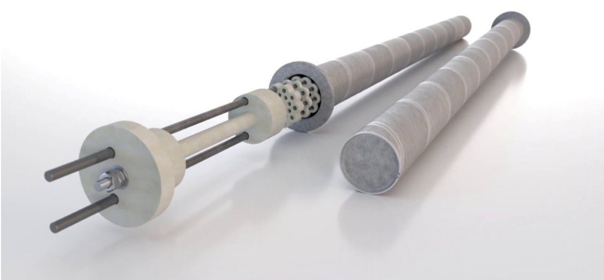


Fig. 6. Electrical radiant tube [29]

3.5 Choice of coatings

Hot-dip galvanised is the dominant coating nowadays for many applications. With the growing interest in reducing raw material usage, it is expected that there is a market in tailored galvanised coatings. The corrosion performance requirements can be different for prime and non-prime side and thus differences in coating thickness can be interesting ArcelorMittal implemented a new coating technology Jet Vapor Deposition (JVD) that is capable of making such tailored coatings. This process was added to their existing Kessales continuous annealing line in Belgium in 2017 [30] for automotive, construction, packaging and household appliances and has shown a steady increase in production [31].

While Electro-galvanising (EZ) in automotive has been largely replaced by hot-dip equivalents, the scale may turn back in favour of EZ when electricity prices drop. Furthermore, martensitic grades are upcoming in the car-body – for instance for protection of the battery pack -, and these are invariably coated via EZ to uphold their mechanical properties. For automotive it is also expected that the Hot-Press Forming (PHS) share in the car-body will grow, and hence that the market for AlSi-coatings will grow at the expense of galvanised.

4. Galvanised Steel and Market

The steel industry in Europe is recovering after the Covid years with the associated issues in the downstream supply chain. This holds in particular for the availability of chip components, which was a major issue at – foremost – automotive customers of the steel industry. At present, only a small growth in the steel industry is forecasted, and this growth is believed to be driven by markets in the Energy, Construction and Heavy Machinery sectors. However, uncertainty in Europe regarding the high energy costs and price volatility as well as the war-related disruptions cast a profound shadow on this economic forecast.

For all galvanised markets, decarbonisation and reducing its environmental footprint throughout the product life cycle is at the core of their development. Automotive and construction sectors are willing to pay a premium for green steel, which is more expensive to produce. For the automotive sector, the use of green and circular steels is an important step towards carbon-neutrality in addition to electrification of their car fleet. Important topics in automotive are the electrification of the car fleet and the increase of the recycled content. For construction and engineering enabling the green energy transition, durability and Heating, Venting and Air Conditioning play a key role.

With the transition to carbon-neutrality in Europe and associated costs involved, there is the risk that Europe is being flooded by cheap carbon-intensive imports from other parts of the world. In this context, it is essential for the European steel industry that the CBAM is put into place, not only for the steel sector, but also for manufactured goods made with steel. The fear is that otherwise the production lines of e.g., automotive OEMs will be moved to regions outside Europe where the CO_2 legislation is less strict and hence the production costs are lower.

4.1 Automotive Sector

4.1.1 Growth in electric vehicles at expense of combustion vehicles

During the last decades, the reduction of the carbon footprint was primarily focused on the in-use phase and reduction of tail-pipe emission. This was to a large extend driven by EU legislation. However, now that the EU has set ambitious goals to bring their environmental footprint to zero, the automotive sector has to step-up and decarbonize its product portfolio over the full product lifecycle. Automotive OEMs want to achieve this by having a sustainable supply chain, using raw materials more efficiently and using technologies that reduce their CO_2 emissions. And finally, by choosing materials and designs that enable the recyclability at the vehicle's end-of-life, automotive OEMs hope to reduce even further their environmental footprint.

The EU has also set an ambitious target for the production of new car to be 100% electric (EV) by 2030. Although this ambition is being questioned, the majority of the new car models presently introduced are now electrical vehicles with new car sales in the EV segment in Europe in 2022 being already 20% [32].

For EVs the emissions during the in-use phase are much less dependent on the vehicle weight compared to internal combustion engine (ICE). So, the trade-off between in-use emissions and emissions during production and end-of-life phase will change from ICE to EV. Intelligent light-weighting should therefore consider the full life cycle to define the lowest overall footprint [33].

With the change from ICE to EV, the weight distribution of the Body-in-White (BIW) is changing. The heavy engine in the front end of the ICE is no longer needed, and this has an impact on the crash performance and this needs to be compensated by redesigning the front crash structure. Cross members need to be added to the body structure to maintain stiffness and to effectively dissipate crash loads in case of a front collision. Furthermore, for electric vehicles, a good protection of the battery pack is essential to ensure integrity of the battery pack in case of collision and to prevent the battery from catching fire. These battery cases are often made from aluminium, with a steel cover plate. However, recently also the first battery casings completely made from steel have emerged (e.g., Honda e, Toyota BZ4X, GMC Hummer EV).

4.1.2 Autonomous driving and car sharing

The development of the automotive market will also depend on trends for car sharing and the development of autonomous driving from the tentative experimental phase at present to the commercial phase. Private owners of a car are more likely to value a pristine surface and design of their vehicle, while people who share a car may have a more pragmatic and price-based approach. This may have an influence on requirements for surface finish and choice of materials. As for autonomous driving, with the possibility to sense the environment and anticipate on what is coming ahead, it is expected that this will largely eliminate road accidents by human errors and so boost road safety [34]. One might say that this makes the use of crash resistant steels less important. However, autonomous driving requires a variety of sensors, including GPS, ultrasonic sensors, light detection and ranging (LiDAR), and millimetre-wave (MMW) radar. These detection systems may be blinded, or intentionally managed/hacked, which could result in lethal disasters [35]. This in turn raises the question of liability. All the

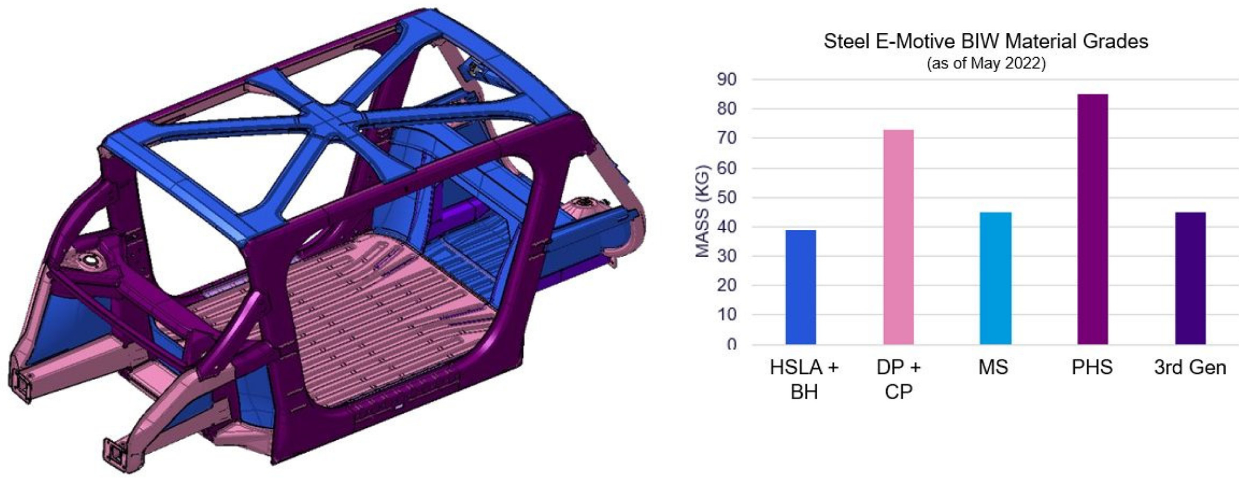


Fig. 7. BIW design of autonomous Battery EV car from the E-Motive project [36]

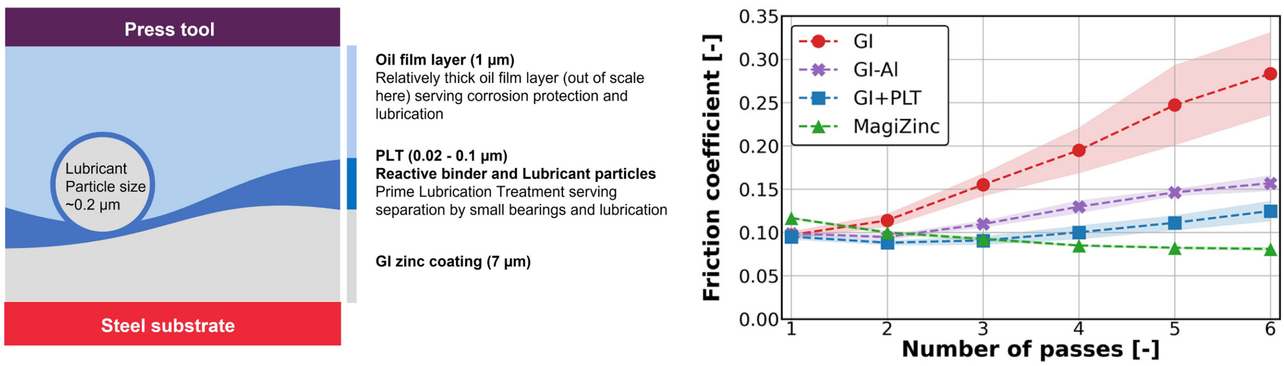


Fig. 8. (a) Left: Booster Lube on zinc coating reduces galling in the press shop by use of lubricant particles in a reactive binder; (b) Right: Evolution of friction coefficient during the galling test for GI, GI-Al, GI with PLT and MagiZinc®. The band width denotes the spread in test results [37]

technological and legislative challenges associated with autonomous driving at present mean that the commercial developments in autonomous driving are progressing much slower than anticipated. Therefore, U/AHHS steels for crash and passenger safety will remain essential and most likely also in the future with autonomous driving. This is also reflected in the optimized design for a fully autonomous body structure, as designed within the E-Motive steel industry program from WorldAutoSteel (Fig. 7, [36]).

4.1.3 Processing at OEMs

Apart from design changes to the automotive BIW structure to optimize crash performance and to accommodate safety for a battery pack, there are also changes regarding the hang-on parts of the car structure. For these outer panels, the electro-zinc coatings (EZ) have been replaced nowadays by hot-dip galvanised coatings (GI). In the past, press behaviour and pristine surface quality made EZ the preferred coating for outer panels. However, over recent years the GI coating surface quality has significantly improved and so has the press behaviour of GI in terms of press pollution and galling. Harder coatings like zinc aluminium magnesium coatings (ZMA) give even further reduced galling and tool pollution compared to GI. However, an alternative way to reduce the galling for normal GI coatings is the use of recently developed booster lubes. A booster lube is a thin film applied in the galvanising line on top of the zinc coating. This thin film consists of a reactive binder with lubricant particles – see Fig. 8a.

The lubricant particles in the booster lube act as a barrier between the press tool and the steel strip, while the reactive binder improves lubrication and reduces galling and tool pollution in the production line at the customer. The booster lube offers better performance than the pre-lube which is normally applied at the OEMs, and which give - at best – only give a marginal improvement over normal GI without a booster lube [37]. Fig. 8b confirms the excellent friction behaviour seen for GI with a booster lube (GI-PLT), equalling almost MagiZinc® in performance and showing clearly much better results than GI with no treatment, and even significantly reduced friction behaviour compared to GI with higher Al% (GI-Al).

4.1.4 LME and european collaboration

Steel companies have been developing a range of advanced and ultra-high strength steel grades over the last few decades. A serious threat to the use of these steel grades in relation to weldability can be the higher sensitivity to liquid metal embrittlement (LME) for zinc coated steels. Zinc-coated steel grades that are sensitive for LME will display poor tensile behaviour and early fracture at elevated temperatures. Over the recent years a number of measures have been identified in the welding process to mitigate the risk on LME. However, these measures often require adjustments to the processing at the OEMs or Tiers and comes with extra costs and production time. Therefore, research continues to find process conditions and steel substrates that are intrinsically less sensitive to LME.

This research is challenging as the sensitivity to LME is not easy to assess. It can take a large number of welding tests and extensive analyses of the welds to encounter the effects of LME and its severity. Therefore, it is crucial to have a standardized test that can mimic LME sensitivity. To this end, a VDA work group consisting of experts from European steel companies and OEMs have worked together to develop a test procedure to assess LME sensitivity [38]. The test procedure comprises tensile testing at temperatures between 450 and 900 ºC on steel substrates, with and without a zinc coating. As part of this VDA group effort, Round Robin tests have been conducted in four labs at different steel companies in Europe. The tests focused on an LME-sensitive and a non-LME-sensitive zinc coated AHSS grade. The results showed that the test has potential to be a representative test to assess LME for welding applications and highlights the strong collaborative spirit between the European steel industry and the automotive sector.

4.1.5 Threats and choice of material

For the Body in White (BIW) and the hang-on parts (doors, hood, etc), the strategy and material of choice remains diverse between the different OEMs, although the majority of OEMs uses more than 70% steel in the car body. In case aluminium is used, this is mostly used as sheets in hang-on parts, but also as a combination of aluminium sheet, extrusion, and casting in the Body-In-White and battery-case structure. However, this could change with the introduction of aluminium mega-castings.

Aluminium high pressure die casting or so-called mega-castings are upcoming for car body parts [39]. It allows making large parts of the car body as one single cast. These mega-castings first appeared in the rear of the car body of Tesla Model Y' (see Fig. 9a). The use of a mega-cast platform is very attractive for greenfield (start-up) OEMs, because - although it has an increased unit manufacturing cost -, it also requires a much lower initial investment to bring a plant online. This advantage allows Tesla to quickly build factories and to scale up their production per factory to around 2 million vehicles per year. The use of mega-castings is also an efficient method to produce less waste, as any failed parts can be recycled in-house. A disadvantage of the mega castings is that they cannot be repaired when damaged in a crash. The mega-castings have been called a game changer in the industry. Volvo will introduce a new EV platform in 2025 with an aluminium mega-casting for the rear floor section [40], and OEMs like Toyota, GM, VW and Hyundai are also considering using high-pressure aluminium die casting machines to build cars faster and more efficiently. However, the WorldAutoSteel organisation expects that high volume OEMs operating in versatile and cost sensitive markets will continue to use a multi-part sheet metal car-body.

Apart from the switch to mega casting in the car body, Tesla has also made a revolutionary choice to use cold-rolled 30X stainless steel in the exoskeleton of their announced Cybertruck [41] – see Fig. 9b, although it is not expected that this choice will be followed by other steel makers.

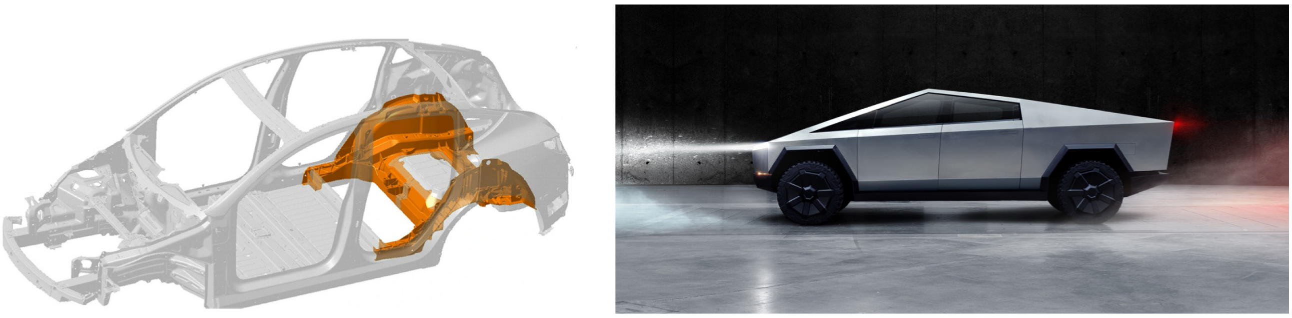


Fig. 9. (a) Left: Single cast component (Aluminium mega casting) in the rear of Tesla model Y's body structure; (b) Right: Announced Tesla Cybertruck with an exoskeleton from Ultra-Hard 30X Cold-Rolled stainless-steel structural skin and armour glass [41]

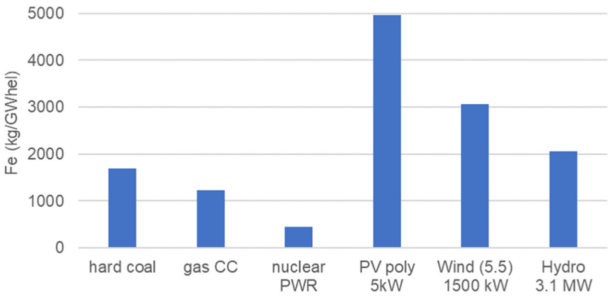


Fig. 10. Steel intensity of electricity generation from fossil fuels and renewable energy [43]

4.2 Engineering and construction markets

To accommodate the decarbonisation of steel, the transition has to be made from the use of oil and gas to zero-carbon electricity and /or green and affordable hydrogen. If fossil fuels like coal or gas are replaced by reduced-CO_2 or CO_2-free energy sources, then only nuclear power will reduce the amount of steel that is required per GWh (see Fig. 10). However, since wind, sun and hydro are inexhaustible natural energy sources that do not come with the typical drawbacks of nuclear power it is expected that the required steel consumption in this area will grow. A good example for this is the major projects to build windmill farms in the North Sea. These projects require large volumes of steel, which is mostly thick plate material with thick thermal spray zinc coatings.

In the solar market, especially for large-scale solar parks a significant growth in the utilisation of zinc-coated steels for solar frames (see Fig. 11a) is predicted. For this specific application, Zink Aluminium Magnesium (ZMA) coated products such as MagiZinc® may be the preferred solution. For instance, MagiZinc®310 from Tata Steel offers superior corrosion protection in harsh environments, providing the commercial opportunity to deliver this material with a corrosion guarantee of 25 years for solar structures in corrosion class C3 environments [42]. This type of coated steel can also be used for wind-deflection systems or supporting systems for solar panels on buildings. The extended lifetime means less use of valuable resources and a reduced environmental impact.

An adjacent market in which growth is expected, is the Heating Ventilation Air Conditioning (HVAC) market. Increasing global warming will make indoor climate control increasingly important. Hence, the future demand for cooling and ventilation systems is expected to increase. Most components in HVAC systems are made of metals, like copper, aluminium or steel, most ducts are made from galvanised steel. Corrosion protection is of the outmost importance for these components for prolonged lifetime, especially when these HVAC systems are used in industrial and agricultural facilities with potentially aggressive atmospheres. Furthermore, for air and ventilation systems oxidation in air shafts could affect the air cleanliness, which must be avoided at all times.

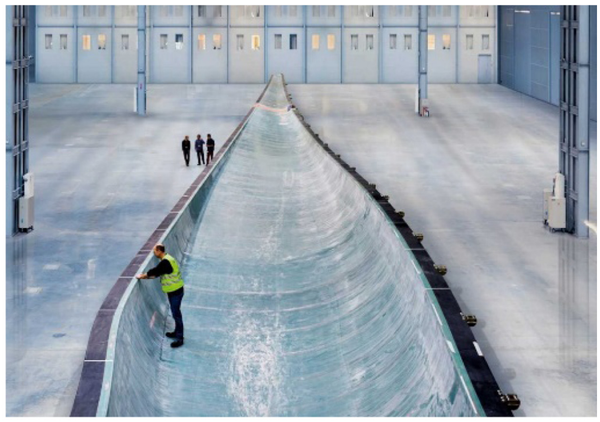
The development of 310 g/m^2 ZMA[1] coated steels for construction also enables the access to other, new markets. Due to the increased corrosion resistance of ZMA coatings in comparison with GI and GA, and their excellent formability and weldability, ZMA coatings have become an attractive alternative for the brittle batch galvanised coatings. Hot-dip coated steel can be used to produce complex-shaped components with ease, which saves assembly time, while offering excellent corrosion protection with thin durable coatings compared to batch galvanised. The significant potential in reducing coating weight in

a)

b)

Fig. 11. a) Galvanised steel in solar frame with prolonged anti-corrosion guarantee for ZMA310 (MagiZinc®) for solar frames (25 years in C3 corrosion environment); b) Continuous galvanised steel with Magizinc® coating as alternative for batch galvanised on guard rail (right)

a)



b)

Fig. 12. Examples of galvanised steel in construction a) Sandwich panels made from pre-painted galvanised steel strip with a thick PIR foam core; b) Tata Steel, the UK's largest steelmaker, has supplied Celsius® high-strength structural hollow sections to help create a vast new extension to the off-shore wind turbine blade factory in Hull for Siemens Gamesa

combination with an improvement in surface homogeneity have hence tipped the scale in favour of continuous galvanising for a number of applications previously made via batch galvanizing. Examples are guardrails along highways, see Fig. 11b.

Reducing the coating weight is also a trend that is seen in the construction and building envelope markets. As an example, the improved corrosion protection of ZMA coatings allows replacing GI275 by ZMA120 coatings. On large building surfaces this coating weight reduction is very rewarding. Zinc coated steel can also help to improve the isolation value of buildings. Sandwich panels for facades and roofs can be used to support good climate control in buildings. These zinc-coated systems are made from galvanised sheet with a thick PIR foam core that offer excellent isolation and are fire resistant, durable, and furthermore allow fast assembly (see Fig. 12a).

It is important to realise that decreasing the coating weight by adding magnesium and aluminium - elements that increase the corrosion performance - is only sustainable when this is done in moderate quantities, because the global warming potential of Al and Mg are respectively 3 and 12 times higher than that of Zn.

Finally, similar to the second industrial revolution when steel was needed to build factories, at present steel is needed to enable the transition to a society that is driven by green energy. Zinc coated steel constructions are used for factories that are required to enable the green energy transition. An example is given in Fig. 12b showing part of a hall for the production of the carbon-fibre reinforced blades for wind turbines where steel is indirectly supporting the transition to a green future.

Conclusions

The EU is keen to be at the forefront of decarbonisation of the steel industry and making the transition to a sustainable and circular economy fuelled by green and renewable energy. However, to enable this in an economical sound way and to protect its industry from cheap imports with a high CO_2 footprint, EU legislation to level the playing field for the European steelmakers and manufacturers is essential. Furthermore, located in one of the most densely populated continents of the world, the European steel industry will need to react socially responsible to the increased environmental awareness and criticism from empowered neighbouring social communities. Only in this way, the steel industry in Europe can keep its economic and societal relevance and focus on: (1) developing new advanced steel grades with added value for our society, (2) solving the technological challenges related to the green transition in our society, (3) exploring new market opportunities to support an economy that is increasingly driven by circularity, durability, and the use of renewable energy, and finally (4) joining forces with suppliers and customers across the full product chain to enable a carbon-neutral society based on reduce, repair, re-use, and recycle.

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