On the Cover

Towards the Circular Economy: What It Means to the Steel Industry

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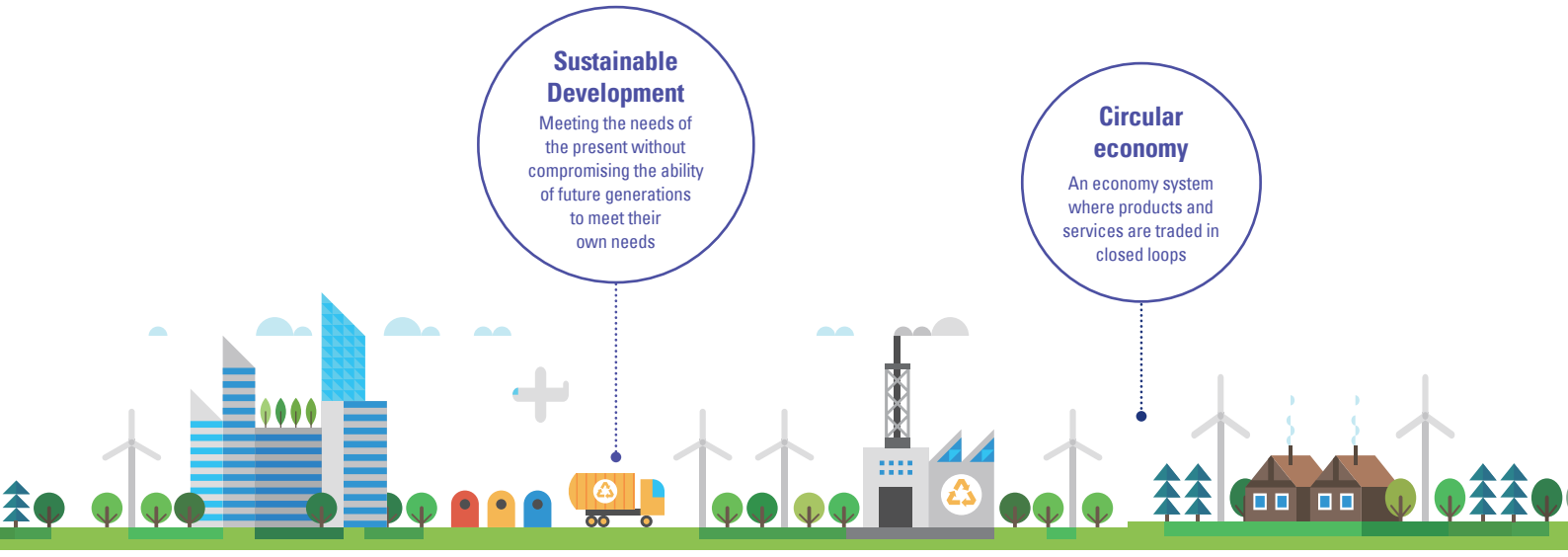
How Steel is Helping to Achieve a Global Circular Economy

Summary

Environmental considerations are increasingly being included in every day decisions on a global level, by consumers, policy makers and product designers.

This can be for anything from the energy consumption of a washing machine, the CO_2 emissions from driving a vehicle, the resource consumption in product design or the focus on zero waste from different products. However, these issues do not address the overall environmental impact from products, for different environmental impact categories (air pollution, resource consumption, water pollution, etc.) nor for the full life cycle of a product (from raw material extraction to



the end of life of a product). This also means that it is quite possible that the environmental "burden" is shifted from one life cycle phase to another.

In addition, there is an increasing focus on making products last longer, reusing or mending them, or even remanufacturing them. This is by no means anything new; we are coming back to practices we used to employ decades ago, but unfortunately in the meantime we have become a "make, take, and throw away" society.

This new concept has been branded a circular economy where the focus is on reduce, reuse, remanufacture and recycle. The steel industry is well placed to contribute to a circular economy and is part of the solution in addressing environmental concerns for many products and services. Key properties of steel (strength, durability, magnetic properties) make steel a key enabler of a circular economy.

This article outlines how the steel industry is addressing current environmental issues as well as how regulations can be utilized to generate an overall environmental improvement of products and services. Developing higher strength and value-added steel products will have an ultimate benefit to the environment despite the higher energy demand and environmental impact for their production. This is because these higher value products will be more resistant to corrosion, need less maintenance, and have a greater length of life.

Undertaking a full life cycle assessment of a product will clearly show the overall benefits of a product's design throughout its life cycle as well as where the greatest potential for environmental improvements can be made. Examples of steel use in society will be given, particularly from the automotive and construction sectors.

The concept of sustainability is understood to include current economic activity and the changes in such activity to ensure that the activity can continue into the future. This implies that economic activity must continually strive to become environmentally neutral, that is to not deplete natural and other resources as a result of the activity and reduce the ability of future generations to continue with such economic activity.

Introduction

The climate change debate in recent years has evolved into a discussion on sustainable development and the circular economy and encompasses much more than just CO_2 emissions. This debate will continue for the foreseeable future. What is certain is that our environment will undergo changes in the future and the objective is to aim for future sustainability. Based on the United Nations definition of sustainable development[1], worldsteel describes the Green Economy[2] in the following way: The steel industry believes that sustainable development must meet the needs of the present without compromising the ability of future generations to meet their own needs.

Within this, a green economy delivers prosperity for all nations, wealthy and poor alike, while preserving and enhancing the planet's resources.

1 Brundtland Commission (1987), Report of the World Commission on Environment and Development, United Nations

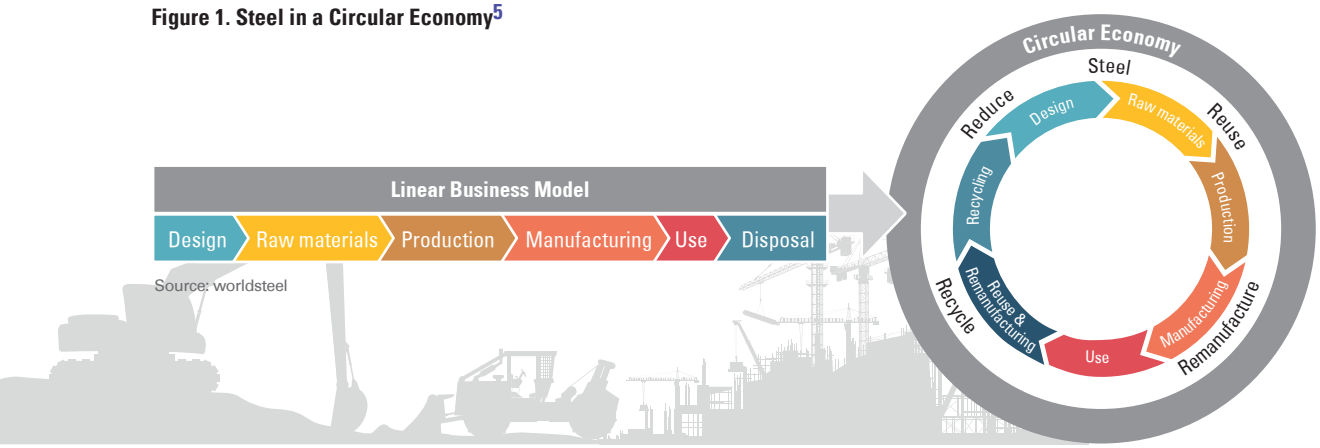
2 "Sustainable Steel: at the core of a green economy", worldsteel (2012)

Sustainability

The concept of sustainability is understood to include current economic activity and the changes in such activity to ensure that the activity can continue into the future. This implies that economic activity must continually strive to become environmentally neutral, that is to not deplete natural and other resources as a result of the activity and in doing so reduce the ability of future generations to continue with such economic activity. For the steel industry, this implies different challenges that will be addressed in this article.

The concept of the Triple Bottom Line expands the traditional accounting techniques to also include performance on social and environmental impacts and is today widely used as a measure of sustainability of an enterprise. This approach measures the impact of an enterprise on three levels—economic (or financial), environmental, and social. The aim is to show that posi-

Figure 1. Steel in a Circular Economy[5]



tive financial results can be achieved, while at the same time realizing no negative impact on the environment or society around the enterprise.[3]

The circular economy

The circular economy refers to a move from linear business models, in which products are manufactured from raw materials and then discarded, to circular business models where products or parts are repaired or remanufactured, reused, returned and recycled.[4] This concept is nothing new, but is something that has been forgotten as people become more affluent and businesses want to make money out of people having to buy new updated products.

In economic theory, the concept of the circular economy equates to optimal resource efficiency, which implies the most efficient allocation of resources to the areas of use that will maximize economic well-being. In economic terms, it assumes that all resources are correctly priced and therefore supports the reuse and recycling of resources as far as is possible.

A circular economy ensures that value is maintained within products while reducing or eliminating waste.

This concept is fundamental to the triple bottom line concept of sustainability, which focuses on the interplay between environmental, social, and economic factors as a result of enterprise activity. This should all be based on a life cycle approach.

In a well-structured circular economy, the steel industry has significant competitive advantages over competing materials. Four keywords

3
Since 2004, worldsteel has been publishing its Sustainability Report and in 2012, published the "Sustainable Steel: At the Core of a Green Economy Report", both of which provide a sustainability overview of the steel industry that mirrors the concept of the triple bottom line.

4
"Scoping paper: Mining and Metals in a Sustainable World", World Economic Forum (2014)

5
"Steel in the Circular Economy: A Life Cycle Perspective", worldsteel (2015)

define these advantages:

• **REDUCE:** Reducing the weight of products, and therefore the amount of material used, is key to the circular economy. Through investments in research, technology and good planning, steelmakers have over the past 50 years drastically reduced the amount of raw materials and energy required to make steel. In addition, the steel industry is actively promoting and developing the use of high-strength and advanced high-strength steel grades in many applications. These grades contribute to the light-weighting of applications, from wind turbines to construction panels and automobiles, as less steel is needed to provide the same strength and functionality.

• **REUSE:** Because of its durability, steel can be reused or repurposed in many ways, with or without remanufacturing. This already occurs with automotive components, buildings, train rails, and many other applications. Reuse of steel is not limited to its original application; repurposing dates back to ancient times (turning swords into ploughshares). Reuse occurs in sectors where it is technically possible without reducing safety, mechanical properties and warranties. Rates of reuse will increase as eco-design, design for reuse and recycling, and resource efficiency become more commonplace.

• **REMANUFACTURE:** Many steel products, such as automotive engines and wind turbines, can be remanufactured for reuse to take advantage of the durability of steel components. Remanufacturing restores durable used products to like-new condition.[6] It differs from repair, which

6 Lund, R. 1984. Remanufacturing: The experience of the United States and implications for developing countries. World Bank technical paper, ISSN 0253- 7494, no. 31. Integrated resource recovery series 2. Washington, DC: World Bank and United Nations Development Program, The International Bank for Reconstruction and Development.

is a process limited to making the product operational, as opposed to thorough disassembly and restoration with the possible inclusion of new parts[7].

• **RECYCLE:** Recycling has been carried out in the steel industry since steel was first made. Steel is 100% recyclable and can be recycled over and over again to create new steel products in a closed material loop. Recycled steel maintains the inherent properties of the original steel. The magnetic property of steel ensures easy and affordable recovery for recycling from almost any waste stream while the high value of steel scrap guarantees the economic viability of recycling. Today, steel is the most recycled material in the world. Over 630 Mt of steel are recycled annually[8], including pre- and post-consumer scrap.

Steel has significant competitive advantages over material competitors in the circular economy and will need to focus on these benefits as part of enhancing the attractiveness of steel in inter-material choices. It is an area that is as yet under-developed and under-utilized in the steel industry. In the future, manufacturers of steel products may also have an important role to play as certifiers of used steel products before they go to market, ensuring the integrity and safety of the product.[9]

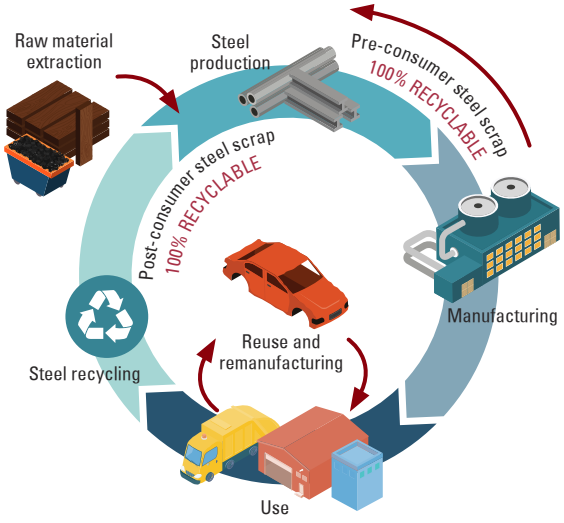
Life cycle thinking

Life Cycle Assessment (LCA) is a tool that can be used to measure the 'circularity' of products, by measuring the costs and discounts to society of using specific materials and products throughout their full life cycle. Assessing the true benefits of conserving resources demonstrates the real savings due to the recycling and recyclability of steel and encourages the reuse and recycling of these products.

LCA becomes a tool to measure the impact of decisions taken in an enterprise with respect to production techniques, raw material and energy use and product allocation design on the environment. To this effect, LCA is presently the only tool by which an enterprise can truly measure the extent to which its actions are resource neutral. Without LCA, a true triple bottom line reflection is not possible.

A life cycle approach should be con-

Figure 2. The Life Cycle of Steel



Source: worldsteel

7 Lund, R. 1993. Remanufacturing. In The American edge: Leveraging manufacturing's hidden assets, edited by J. Klein and J. Miller. New York: McGraw-Hill.

8 worldsteel estimations

9 Allwood J.M., Cullen J.M., et al., 2012. Sustainable Materials: with both eyes open, UIT Cambridge, England.

As steel is everywhere in our lives and is at the heart of our sustainable future, the steel industry is an integral part of the global circular economy. The circular economy promotes zero waste, reduces the amount of materials used, and encourages the reuse and recycling of materials, all fundamental advantages of using steel. A life cycle approach is very important in delivering true sustainability.

sidered within the concept of the circular economy to create a more resource-efficient world, focusing on waste minimization. The steel industry has been doing this for hundreds of years.

In order to further contribute to the circular economy, a number of key areas that the steel industry should focus on include the following:

• Water used in the production process must be handed back to society in the same or better condition as it was received, and that emissions to atmosphere will be minimized as much as possible.

• Regarding the raw materials consumed, such as coking coal and iron ore, strict adherence to sustainability is impossible as raw materials, once consumed, can clearly not be replaced and as such would reduce the ability of future generations to produce steel in the same way as today. This challenge can be bridged by the construct of reuse, remanufacture and recycling, to design products for easy reuse and to recycle as much steel from products at the end of their life as possible to make new steel products. Clearly this requires that in time, sufficient quantities of reusable and recyclable steel are available to satisfy market demand for steel. In addition, the concept of responsible sourcing needs to be addressed further, taking consideration for the sourcing of materials in the supply chain.

• Emissions into the atmosphere (e.g. CO_2 and other GHGs) can be reduced by ensuring that the application of steel leads to reduced emissions during the product use phase. This can be done through the use of, for example, high-strength steels or more efficient steels used in motors.

• Many competing materials have 'light-weight' properties (more specifically lower density materials) and can help reduce the emissions of energy intensive products in the use phase. However,

these materials are often so much more energy and CO_2 intensive to produce than steel products, negating the use phase benefits that these alternative materials offer.

Conclusion

As steel is everywhere in our lives and is at the heart of our sustainable future, the steel industry is an integral part of the global circular economy.

The circular economy promotes zero waste, reduces the amount of materials used, and encourages the reuse and recycling of materials, all fundamental advantages of using steel. A life cycle approach is very important in delivering true sustainability.

Legislators and industry decision makers need to understand the importance of analyzing the entire life cycle of a product before making legislative or manufacturing material decisions.

Too many legislative bodies around the world still enact regulations which only affect the "use phase" of a product's life, for example water and energy consumption for washing machines, energy consumption for a refrigerator or CO_2 emissions while driving a vehicle.

This focus on the "use phase" can lead to more expensive alternative lower density materials being employed but which typically have a higher environmental burden when the whole life cycle is considered.

This use phase limitation cannot continue. Life cycle thinking must become a key requirement for all manufacturing decisions.

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Improving Sustainable Competitiveness in Preparation for a Circular Economy: The Case of POSCO

Sustainable circular economy and steel products

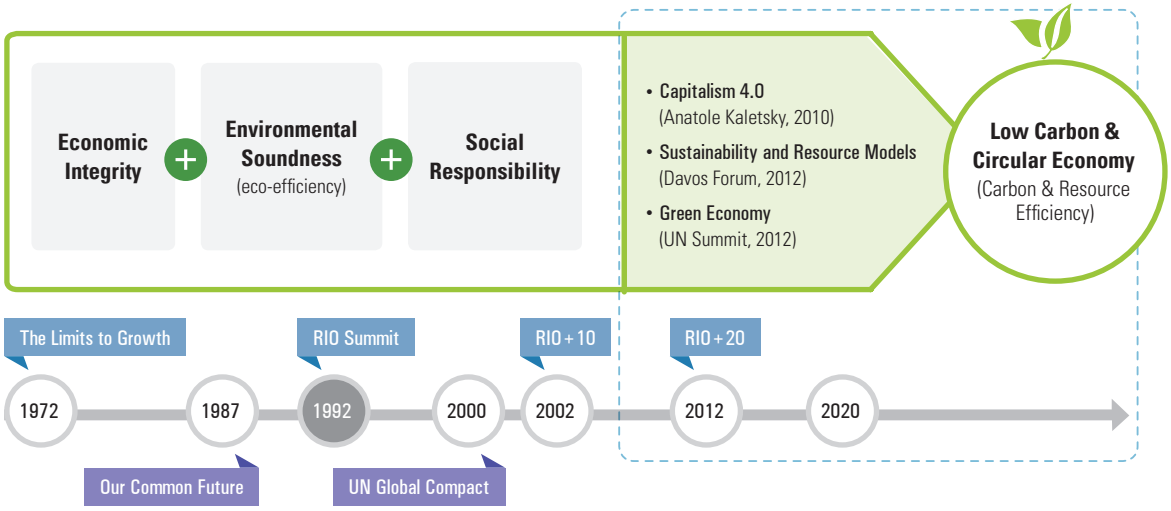
We are now entering an era of "sustainable competitiveness" defined as looking beyond simple economic performance to pursue environmental soundness and balance with the social aspect. Considerable economic research, including Wernerfelt, B. (1984), M.E. Porter (1996), Prahalad, C. K. (2002), Wilson, M. (2003), and Y.G. Ahn (2007), has suggested this concept as a direction for corporate competitiveness. Given the imminent depletion of the natural resources that fueled the Industrial Revolution, such as oil, coal, and gas, and growing environmental concerns regarding the use of fossil fuels, both academia and industry are paying keen attention to sustainable competitiveness as a new means for achieving competitiveness. At the 2012 World Economic Forum, economists and scholars stressed the importance of a transition by the global economy to a circular economy to address pressing environmental issues such as resource scarcity, climate change, fine dust, wastes, and toxic chemicals—the key challenges for sustainable competitiveness.

When looking at the steel industry from the perspective of sustainability and a circular economy, process and product should be considered separately. In terms of the steel-making process, steel is not free from environmental concerns such as energy scarcity, CO_2, fine dust, and wastes.

For the products, however, the drawbacks of the steel-making process can be overcome. Lightweight steel products help to reduce CO_2 and NOx emissions and improve fuel efficiency and give a tremendous opportunity to the overall industrial ecosystem and society.

In particular, steel has a much longer service life than other materials, so it contributes greatly to improving efficiency in a circular economy. With its high recycling rate, infinite recyclability, and relatively easy removal of impurities, steel has proven to be a key material for addressing resource scarcity.

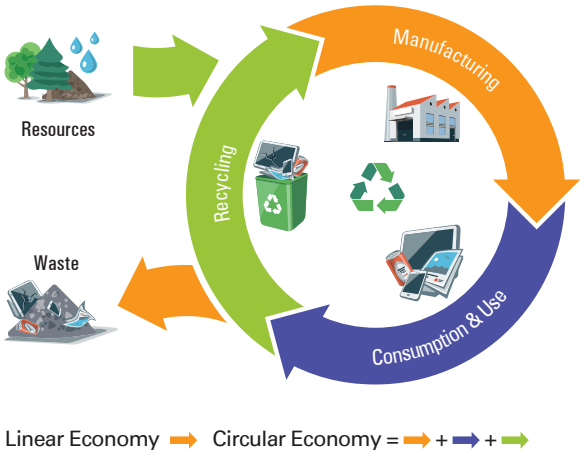
Figure 1. Global Discussions on Sustainable Competitiveness and the Structure of a Circular Economy



Source: Compiled by the author

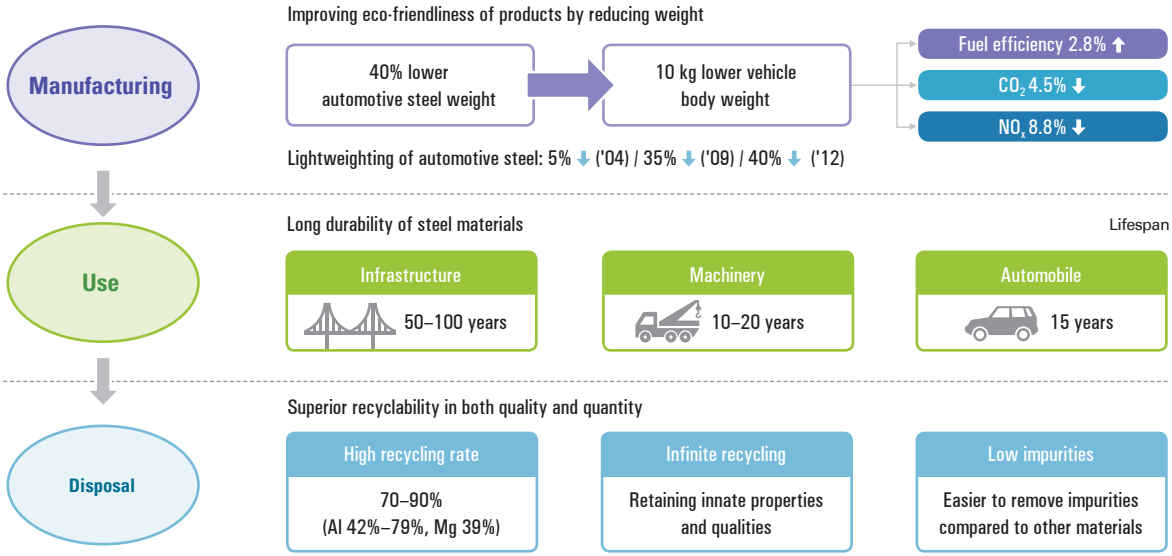
Considering the extent of current iron ore reserves, steel can become a cornerstone for a sustainable circular economy and industrial ecosystem. Steel slag, a by-product of steelmaking, provides an alternative to cement and can be used as a fertilizer to help increase agricultural production, demonstrating how steel can stand at the center of the shift to a new industrial ecosystem.

Life Cycle Assessment (LCA) is a technique used to determine the potential impacts of a product at all stages based on life cycle thinking. The global community uses this technique to identify products suitable for a circular economy. Ever since the International Organization for Standardization (ISO) adopted LCA as a global standard in the mid-1990s, it has been used for product development and marketing strategy. ISO is also discussing a new and improved global standard for a circular economy as a global standard.



Source: Shutterstock

Figure 2. The Contribution of Steel Products to a Circular Economy from the Life Cycle Perspective



Source: POSRI

Taking up the OECD's Polluter-Pays Principle (PPP) and Process and Product Methods (PPM), the European Community adopted its Integrated Product Policy (IPP) based on life cycle thinking and life cycle assessment in 2000. Several directives and regulations have taken effect based upon the IPP, including the Restriction of Hazardous Substances (RoHS) in Electric & Electronic Equipment, Waste Electrical and Electronic Equipment (WEEE), End-of-Life Vehicle (ELV), and Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH).

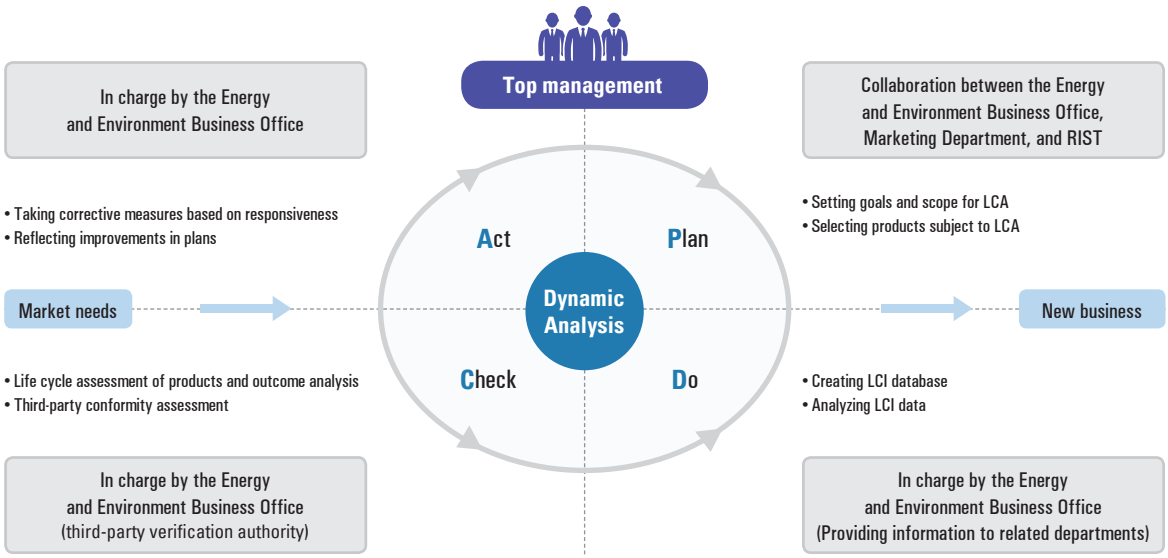
These are already being used as a basis for global and domestic regulations and will become a sticking point in future trade concerns.

Clearly, steel products will be subject to more stringent regulations. This article discusses POSCO's preparations and measures for improving its sustainable competitiveness in the face of shifting global and domestic market conditions.

POSCO's responses for a circular economy era

The economic system of the future will pursue not only traditional economic profits, but also environmental soundness and social needs for sustainable growth. This requires all economic players to cooperate on dealing with environmental and social challenges. In particular, sustainability will be highly dependent on the capability to alleviate or address resource scarcity. In this process, the recyclability or eco-friendliness of

Figure 3. POSCO's Approach to Sustainable Competitiveness



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resources will have a significant influence. For these reasons, POSCO has been seeking the improvement of the steel-making process, product development, and utilization of by-products from the full life cycle perspective. Considering that the steel-making process is energy-intensive and burdensome to the environment, the company has been working to enhance energy and carbon efficiency and emplace eco-friendly process technologies. It has designed high-performance lightweight steel products with improved recyclability and circularity. By doing so, POSCO helps to make steel-consuming industries less carbon-producing and more eco-friendly. This contributes to the overall sustainable competitiveness of all global industry. Furthermore, it undergoes third-party monitoring and supervisions (conformity assessment) to assure the sustainability of products and ensure customer trust in a society seeking low-carbon eco-friendliness.

To this end, POSCO has adopted Life Cycle Thinking and Analysis as a basic methodology and been interested in the global discussion on Life Cycle Analysis since the mid-1990s. POSCO has developed the Life Cycle Inventory (LCI) database and analytics suitable for steel-making processes and products. It has also actively participated in the global discussion surrounding Life Cycle Analysis, such as Environmental Labeling (ISO 14020) and Life Cycle Assessment (ISO 14040) under ISO/TC/207. In addition, it has developed products and improved recyclability of by-prod-

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ucts from the sustainability perspective and it has been certified by international certification bodies to ensure customer trust in the eco-friendliness of its products and by-products. POSCO has a dynamic Plan-Do-Check-Act (PDCA) approach in place for continual improvement. It is conducting Life Cycle Thinking and Analysis from the PDCA perspective for improving circularity of products. The "Plan" phase sets the goals and scope for LCA and selects designated products.

During the "Do" phase, database is compiled for LCA. In this process, informatization by data analysis is important for interpretation of the environmental impacts from the perspective of whole life thinking.

The "Check" stage conducts Life Cycle Assessment for evaluation, and the outcomes are subject to third-party conformity assessment.

Finally, in the "Act" phase, the outcomes are reported to top management and used to take corrective action taking into account the original targets. The next plan phase is then initiated and the PDCA cycle is infinitely repeated for trouble-shooting and continuous improvement.

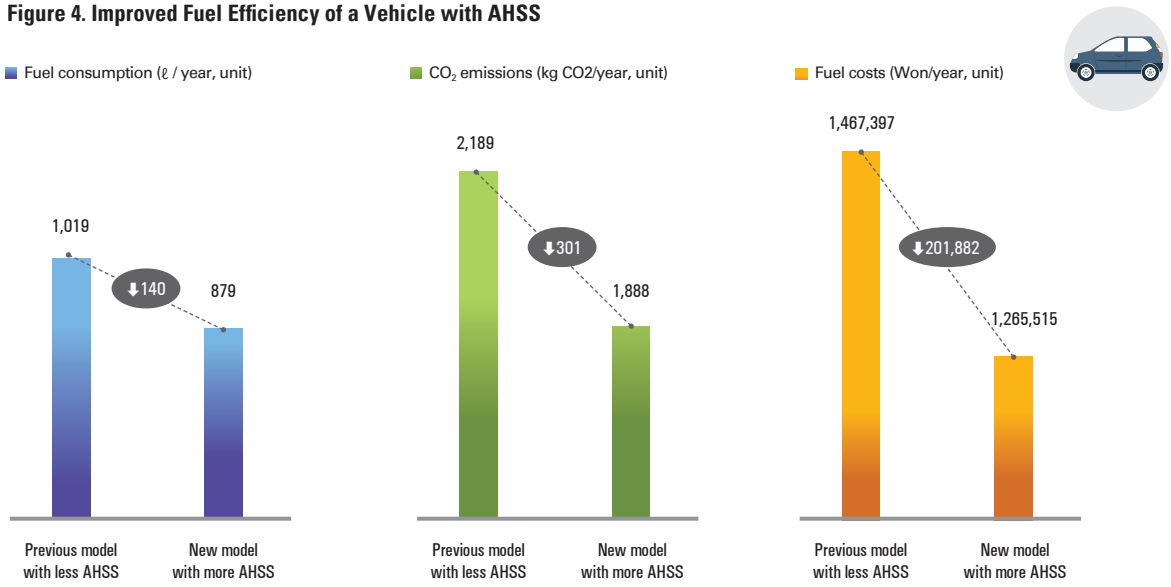
These processes are conducted in close cooperation with the Energy and Environment Business Office, Department of Technology Management, RIST, and Marketing Department.

POSCO products from a sustainability perspective

POSCO believes that sustainable competitiveness can be attained only when process and product are innovated in terms of eco-friendliness and recyclability. Therefore, it has spared no efforts in producing steel products offering higher performance and lighter weight. Based on whole life cycle thinking, It is applying LCA to develop products from the perspective of sustainable competitiveness and improve especially their eco-friendliness.

Representative products to which LCA was applied include advanced high strength steel (AHSS), Hyper NO electrical sheet, Giga Steel,

Figure 4. Improved Fuel Efficiency of a Vehicle with AHSS



and PosMAC. POSCO has also developed its PosMent cement with a higher slag content to improve overall resource efficiency and reduce CO_2 emissions. Through the recycling of steel scrap and off-gas, it is strengthening its eco-friendliness and improving profitability. Below are details on some examples of POSCO's preparations for a sustainable circular economy.

❶ Advanced high strength steel (AHSS) – Lighter car bodies to raise fuel efficiency

AHSS applied to gasoline vehicles reduces vehicle body weight, improving fuel efficiency and reducing greenhouse gas emissions

In close cooperation with its domestic automaker partners, POSCO begins suggesting steel products from the design stage and has developed lightweight products that enhance fuel efficiency and reduce greenhouse gas emissions.

AHSS is about 10 percent lighter but more than twice as strong as conventional steel sheets for cars. A new 2016 model using more AHSS is 130 kg lighter than the 2015 model with less AHSS but boasts even higher crash performance. Annval fuel use of a vehicle is reducsd by 140ℓ CO_2 emissions by 301kg and fuel costs by KRW 201,882. If Applying the Lifetime Driving Distance (LTDD), the new model can reduce fuel use per vehicle by around 2 kℓ, CO_2 emissions by 4.4 tCO_2 and fuel costs by KRW 3 million.[1]

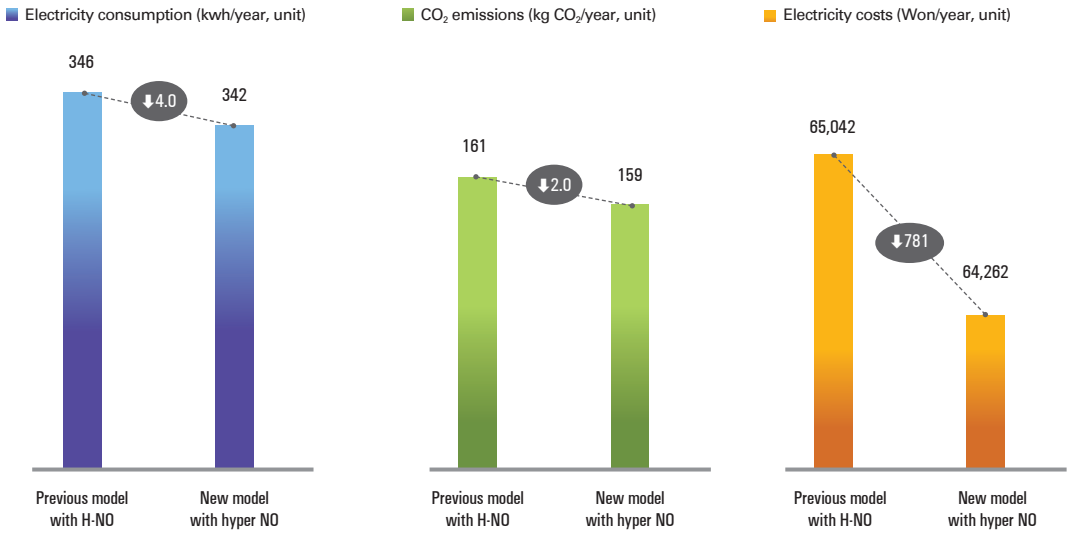
❷ Hyper NO electric sheet – Reducing electricity consumption of home appliances through improved motor efficiency

Improving power efficiency in home appliances to reduce energy consumption and cut greenhouse gas emissions

POSCO has developed a top-grade non-oriented electrical steel, Hyper NO.

1 A lifetime driving distance (LTDD) of 200,000 km from the World Auto Steel UCSB model has been applied.

Figure 5. Improved Power Consumption of a High-Efficiency Motor with Hyper NO



Hyper NO can be used in motor cores, a key component in motors that converts electric power to mechanical power. It helps to make motors more efficient and improves the energy efficiency of home appliances.

Motor cores with Hyper NO minimize core losses, thereby improving the power efficiency of home appliances using compressor motors with these motor cores.

In a pilot test, a refrigerator using a motor with Hyper NO in place of a compressor motor with a conventional motor core saw its compressor motor efficiency improve by up to 1.5% and electricity use efficiency rise by 1.2%.[2]

If these figures were applied to the total sales for the refrigerator model, it would reduce annual electrical power consumption by 2.1 GWh and save annual electric costs of KRW 390 million.

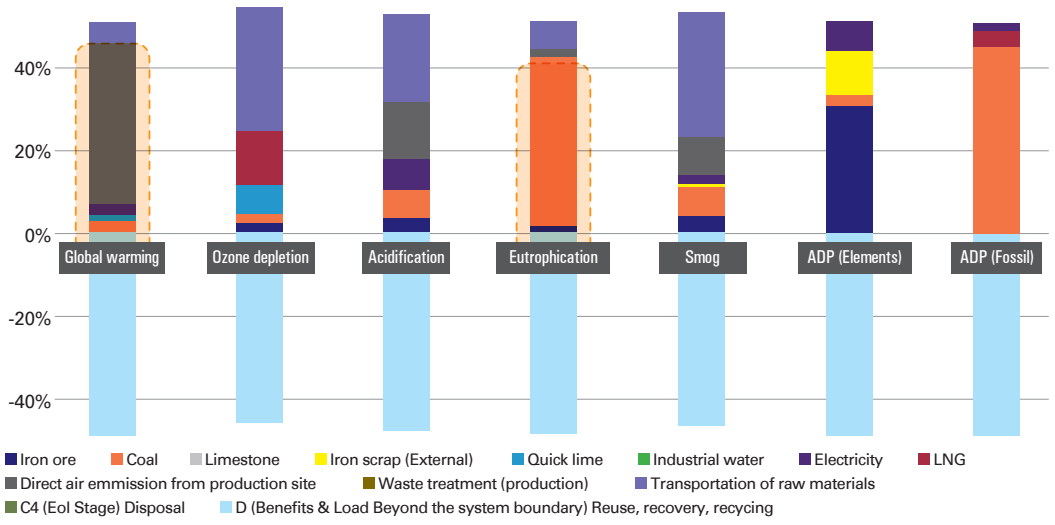
Moreover, assuming that a high-efficiency motor with Hyper NO steel were used in all refrigerators sold in Korea, it would reduce annual electrical power consumption by 89.5 GWh and annual electric costs by KRW 16.8 billion.

❸ PosMAC and Giga Steel – Building the Life Cycle Inventory database and conducting third-party certification

Preparing for a low-carbon circular economy characterized by eco-friendliness and recycling of resources through a full life cycle database and third-party certification

2 Assuming that motor accounts for 80% of electricity consumption of a refrigerator (Source: manufacturer)

Figure 6. Life Cycle Assessment (LCA) of PosMAC by Environmental Impact Category (Tentative result)



Acknowledging that the future will be characterized by a circular economy dominated by sustainable competitiveness, POSCO believes that eco-friendliness, and recyclability in particular, will become a key to product quality.

The company has begun evaluating the eco-friendliness of its steel products based on whole life cycle thinking. A first for a Korean steelmaker, POSCO established the Life Cycle Inventory database (LCI).[3]

Since January 2018, it has been preparing for obtaining Environmental Product Declaration (EPD)[4] certification at home and abroad.

It has selected PosMAC[5], the construction steel materials produced at the Pohang Steelworks and Giga Steel[6] for automobiles produced at the Gwangyang Steelworks as its WP (World's Premium) products.

In May 2018, it compiled quantitative environmental informationw on PosMAC taking into consideration the extraction of raw materials, supply, manufacture (cradle-to-gate) and recyclability. This information can be used for setting directions for reducing the environmental impact of the steel production process by considering the use of resources and energy in the whole life cycle of steel products and potential effects on climate change.

In addition, POSCO is building the environmental information on Giga Steel from the whole life cycle

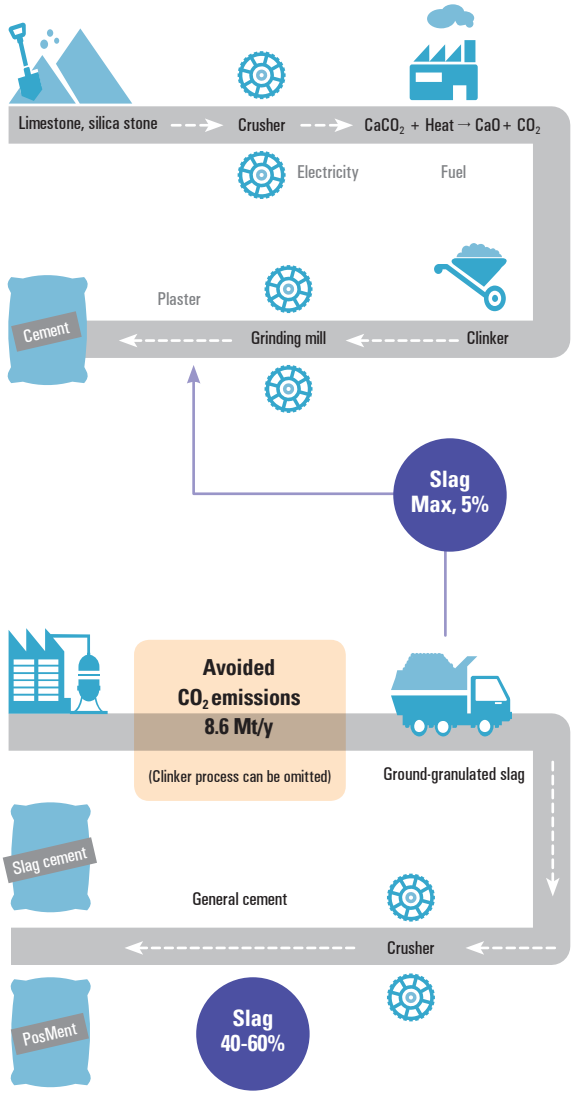
3
The Life Cycle Inventory database (LCI) is a database on resource and energy inputs into product systems and environmental loads released from the systems for all stages of a product's life from raw material extraction to processing, transportation, use, and disposal.

4
The EPD (Environmental Product Declaration) is an objective report that sums up the environmental impact of a product based on components of life cycle assessment: resource consumption, global warming, impact on the ozone layer, acidification, eutrophication, photochemical oxidation, etc.

5
PosMAC (POSCO Magnesium Aluminum alloy Coating product) is a ternary alloy coated steel (Zn, Mg, Al) with high corrosion resistance developed using POSCO technology. It provides five to ten times greater corrosion resistance compared with ordinary hot-dip galvanized steel sheet (GI, GI(H)) of the same coating weight. Its longer life span is highly environmental and economical.

6
Giga Steel is hyper high-strength steel with a tensile strength over 980 MPa (1GPa) mainly used for automobiles to ensure car body safety and improve fuel economy by reducing vehicle weight.

Figure 7. Comparison between Conventional vs. Slag Cement



perspective. It plans to obtain Environmental Product Declaration (EPD) certification from an international certification body and the Korean Ministry of Environment by August 2018.

7 Clinker is made by heating limestone and clay to create a fine powder for cement.

❹ PosMent – Eco-friendly cement with a higher slag content

Developing "PosMent" with a higher slag content, a by-product from the steel-making process, to strengthen the circular industry ecosystem and reduce greenhouse gas emissions

Ground-granulated blast furnace slag is a sand-type slag manufactured by spraying high-pressure water jets on molten slag from a blast furnace. It has a chemical composition similar to cement. As an alternative to cement clinker,[7] granulated slag is used up to 5% in a cement mixture to conserve natural resources such as limestone and reduce energy and CO_2 emissions associated with cement calcination. In cooperation with RIST and POSCO E&C, POSCO developed PosMent in 2012, which has a higher slag content but demonstrates improved physical properties such as pressure resistance and strength. It can reduce CO_2 emissions by up to 60% compared to conventional cement.

In 2017 alone, the company used 10.95 Mt of ground-granulated blast furnace slag for the production of cement and reduced 8.6 Mt of greenhouse gas emissions.

❺ Utilization of process off-gas – Innovative energy efficiency improvement and CO_2 emissions cuts

Using off-gas created in the steel-making process to improve energy efficiency, reduce CO_2 emissions, and minimize electricity costs

POSCO collects most of the off-gas (BFG, COG, LDG, FOG) created in the steel-making process for use as a process energy source and power generation. In 2017, Pohang Steelworks and Gwangyang Steelworks self-supplied 72% of their electricity needs through energy collection equipment, off-gas generators, and LNG power generation equipment, such as Coke Dry Quenching (CDQ) and Top Gas Pressure Recovery Turbines (TRT). This figure has increased by 6%p from the generation rate of 68% in 2016.

To prepare for stricter greenhouse gas restrictions and rising electricity prices in the future, the power generation rate using off-gas will continue to increase.

Suggestions for the future

It is an undeniable fact that the global economy is shifting toward a low-carbon and eco-friendly sustainable circular economy in order to address the potential depletion of energy resources, climate change, and air pollution. The steel industry will not be exempted from these changes in the business environment.

Although steel is a CO_2-and energy-intensive industry, recently developed lightweight and high-strength steel products bolster the sustainable competitiveness of the steel industry, demonstrating that the steel industry can become a representative industry for sustainable competitiveness in a circular economy.

POSCO utilizes Life Cycle Assessment for product development. The company analyzes the recyclability and eco-friendliness of its steel products and by-products from the whole life cycle perspective. It applies the analytic outcomes to product development and processes to cut energy and CO_2 emissions across the entire industrial and social ecosystems. In particular, it seeks to explore new markets by ensuring the eco-friendliness of both its products and by-products through third-party certification.

Thanks to such efforts, the steel industry can remain a staple of industry in the circular economy and POSCO will stand firmly as a sustainable, competitive company.

Reference

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Tata Steel Europe's Approach to the Circular Economy in a Life Cycle Perspective

Steel has excellent credentials as a sustainable material for a circular economy compared to many other engineering materials, on account of, among other attributes, the very high recycling rates throughout its life cycle. There are nonetheless further opportunities for greater circularity in steel and Tata Steel Europe is one of the several steel companies at the forefront of exploring these opportunities. Links between life cycle thinking, the circular economy, and sustainability are many and are at the heart of Tata Steel Europe's own journey towards a more sustainable organization. Examples of the company's activities include its active role in the policy and standards arena, where life cycle and circular economy aspects are increasingly prevalent. Tata Steel Europe's engagement in other initiatives embrace those with a process as well as a product focus. These include customer-centric approaches in communicating on life cycle environmental performance, such as an Environmental Product Declaration Programme, for which the company was awarded the 2017 World Steel Association 'Steelie' for Excellence in Life Cycle Assessment. Tata Steel Europe has retained the principles of its founder and those values are embodied in the company's future vision, to become the leading steel business that is sustainable in every sense. This article concludes with a view of future possibilities for steel to further its circular economy credentials and relevance as a sustainable material and how taking a whole life cycle perspective helps tell its story.

Society around the world is increasingly demanding services; infrastructure and products, energy solutions, buildings and transport (vehicles), as populations and their expectations for development grow.

This demand is concurrent with the need to ad-

dress global environmental issues such as greenhouse gas emissions and resource consumption, delivering a tension which is a fundamental challenge of today.

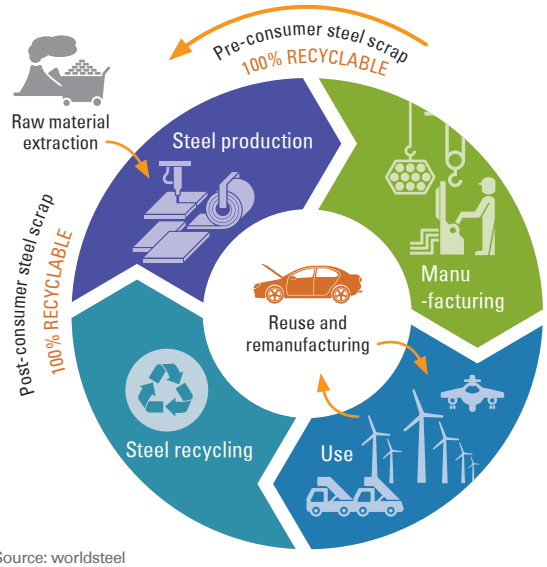
The paradigms of circular economy and material (or resource) efficiency aim to address this sustainability challenge through the principle of delivering the same or greater functionality provided by materials and products, while using fewer resources.

The circular economy is a synthesis of a number of pre-existing, related concepts in sustainability, all underpinned by the objective to maximize or maintain the value (optimize the utility) embodied in materials and products at all times through their life cycle.

There are many initiatives and drivers; in Europe, the European Union Action Plan for the Circular Economy, has built on the concepts and established an ambitious program of innovation and legislation, with measures covering the whole life cycle: from production and consumption to waste management and the market for secondary raw materials, with the objective of "closing the loop" of product life cycles. Specific strategies include, for example, setting new recycling rate targets for packaging materials.

Much of the increasing functionality demanded by society will continue to be delivered or enabled by steel and steel products. Steel already has excellent credentials and a strong story to tell as a circular material compared to many other engineering materials, on account of, for example, the very high recycling rates after manufacture and use phases of its life cycle (Figure 1).

Figure 1. The Life Cycle of Steel



Source: worldsteel

There are nonetheless further opportunities for greater circularity in steel and Tata Steel Europe is one of the several steel companies at the forefront of exploring these opportunities. However, it is not necessarily the case that all strategies for greater circularity will lead to an improvement in environmental terms and therefore it is essential that opportunities, initiatives and new product developments are evaluated to help answer the questions: what is worth recovering and why is recovery worth?

Life Cycle Assessment (LCA), as a technique for the evaluation of the environmental benefits and impacts of systems, has a key role in answering those questions, for example in terms of greenhouse gas emissions. Tata Steel Europe's team of life cycle experts are focusing on discovering and communicating those answers.

Why has Tata Steel Europe adopted life cycle thinking?

Tata Steel Europe recognizes full life cycle thinking, from the sourcing of feedstock materials like iron ore and scrap to the fate of products at end-of-life, plays a significant part in the company's journey towards a more sustainable organization.

There are three primary drivers for this journey:

❶ Commercial

Across all the market sectors, Tata Steel Europe serves its customers and other stakeholders' expectations and requirements which are becoming more demanding when it comes to sustainability and the circular economy. Customers need to be sure that materials are sourced from responsible suppliers and Tata Steel Europe has responded to this requirement by embarking on a program of certification to the responsible sourcing standard, BES 6001.

❷ Standards and regulations

Taking a whole life cycle approach is vital if the goals of environmental improvement through greater circularity are to be met. This is being recognized in the development of international standards and legislation, which are increasingly including LCA and related environmental themes. The international standard for environmental management systems (ISO 14001) now includes clauses on the life cycle perspective, meaning that companies seeking certification must consider the environmental impacts of their activities, products, and services beyond the boundary of their immediate operations. A new ISO standard currently in development (ISO / DIS 20915) will give guidance when conducting a life cycle environmental study of steel.

Aside from ISO standards, different regions of the world have their own frameworks for environmental and sustainability legislation. Tata Steel Europe, along with others in the steel and broader metals sector, actively engages in the development of national, regional and international standards and regulation founded on life cycle thinking, including the examples above.

The company is also a partner in the European Commission's Product Environmental Footprint (PEF) program and provides experts for the development of standards that cover Environmental Product Declarations (EPDs). However, greater participation in standards development from steel industry representatives around the world is required to articulate and argue for the importance of whole life cycle approaches against alternatives.

Engagement with the development of international sustainability standards is critical to ensure that there is a level playing field for steel in markets like construction.

❸ Tata brand

When Jamsetji Tata founded what was to become the Tata Group of Companies in 1868, his well-documented beliefs in what we might nowadays call 'sustainability' were imprinted so strongly on the Group that even now, 150 years later, his statement that "In a free enterprise, the commu-

Steel has a clear role as part of the solution for decarbonization, greater material efficiency and circularity.
Tata Steel Europe recognizes that this will consist of new processes in steelmaking and through the enabling role of steel products in society and is actively pursuing new developments in both.

nity is not just another stakeholder in business, but is in fact the very purpose of its existence" still runs through the core of the Group.

Tata Steel Europe has not lost the principles of its founder and his values are still embodied in the vision for the future, to become the leading steel business that is sustainable in every sense. "Sustainability is about being able to demonstrate to your stakeholders—such as governments, customers, but also society—that you will be relevant to them not just today, but also in the future," says Roger Steens, Director Sustainability, Tata Steel Europe.

What are Tata Steel Europe's activities?

Steel has a clear role as part of the solution for decarbonization, greater material efficiency and circularity. Tata Steel Europe recognizes that this will consist of new processes in steelmaking and through the enabling role of steel products in society and is actively pursuing new developments in both.

❶ Steel processes

One of the areas where Tata Steel Europe is leading the way on sustainable production is through the revolutionary HIsarna process.

HIsarna is a breakthrough technology, a substitute for the blast furnace process, with the potential for future production of steel with a 20% smaller carbon footprint. The HIsarna installation produces carbon dioxide that is ideally suited for immediate carbon capture and utilization or storage (CCUS), which could lead to an 80% reduction in CO_2 emissions from the steel production process.

HIsarna is also expected to play a crucial role in achieving future recycling ambitions in the circular economy, allowing for high levels (up to 50%) of steel scrap input, a wide range of steel production by-products to be reused and the recovery of zinc from galvanized scrap, further closing the loop of the steel manufacturing pro-

Figure 2. Tata Steel Europe's HIsarna Pilot Plant

Source: Tata Steel Europe

cess. The HIsarna pilot plant, at Tata Steel Europe's IJmuiden site in the Netherlands (Figure 2), with a capacity of 60,000 tonnes of iron per year, has entered its fifth test campaign and is at the forefront of the global search for the step change in steelmaking needed to address environmental concerns.

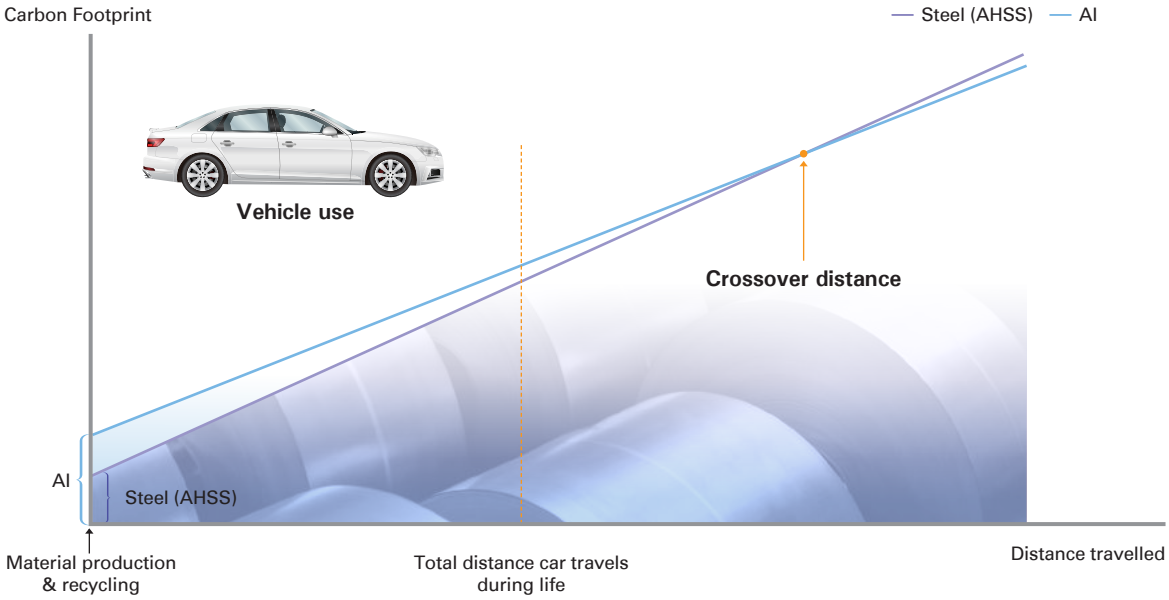
❷ Steel products and services

As well as the opportunities for circularity in steel making processes, which, other than HIsarna, are often based on the established principles of industrial symbiosis (e.g. utilizing wastes from other sectors as valuable process feedstock), some of the more innovative conversations and greater opportunities for greater circularity in society are based on steel products and their role as enablers through the life cycle.

These opportunities are realized, for example, through greater product durability, the design of products to enable enhanced recovery of materials (including for recycling and reuse) at the end of product life and using less material to provide the same (or better) functionality, such as in light-weighting of vehicles or packaging. This is of course consistent with what the steel industry has been doing for many years, through the development of advanced high strength steel grades and is another testament to steel's excellent credentials as the perfect material with which 'to do more with less' in a circular economy.

Heather Wijdekop, Tata Steel Europe's Director Marketing and Business Development, has long recognized these credentials, saying "Steel

Figure 3. Carbon Footprint in Materials Production and Use Phase (Al vs. Steel (AHSS))



truly is a sustainable material, with a powerful combination of functional properties and whole life cycle performance. Think about safe and lightweight vehicles through the use of advanced high strength steel, durable construction products lasting and looking good for decades, if not centuries, and steel packaging which is easily recovered after use rather than being discarded. Steel can be used over and over again without loss of its inherent properties and underpins the transition to a lower carbon, more circular world, adding value to society, true to Jamsetji Tata's principles."

Our own product development is indeed geared towards developing steel grades and steel products that are able to improve the sustainability performance of our customers. These approaches have led to the development of many products which specifically address energy-efficiency issues within end-user markets. For example, a range of our advanced high-strength steel makes cars lighter and more fuel efficient.

Life cycle studies have shown that approximately three quarters of all emissions related to vehicles occur in the use phase and therefore there is now a significant focus on vehicle mass reduction and alternative powertrain technologies to improve fuel economy. For both of these cases, the technological solutions for reducing emissions should be analysed by taking a full life cycle perspective, to avoid an unintended increase of CO_2 emissions in material production and at end-of-life (Figure 3). Steel has an important role to play here because new grades of Advanced

Figure 4. Demountable Connections in Fokker 7/8 Distribution Center, Schiphol Airport, the Netherlands

High Strength Steel (AHSS) have been developed which allow vehicle light-weighting without compromising on manufacturing emissions 'embodied' in products.

Tata Steel Europe has been at the forefront of the Future Steel Vehicle project, led by WorldAutoSteel, in which its concept car, based on a battery electric vehicle platform, uses the latest steel technology and has a body that is 35% lighter than conventional steel grades, plus a five star safety rating. These results were achieved at no additional overall cost and with no increase in the environmental impact of its production, compared to using materials other than steel to achieve the same standards.

Tata Steel Europe's product innovation in support of greater performance through the whole life cycle includes, as well as grades for light weighting of vehicles and advanced coatings for more durable products in the construction sector, high performance electrical steels that deliver use phase benefits through more efficient motors and fewer transformer losses in electrical power grids. Indeed, when a life cycle perspective is taken, it becomes clear that, across a wide range of applications, the benefits of using advanced steel products outweigh the impacts of making steel.

The company is also engaged in collaborative working to reduce yield loss in the steel supply chain through its distribution and service centers incorporating state–of–the–art tailor welded blanking facilities for automotive and other customers. The Active Classroom at Swansea University in the UK is a Tata Steel Europe-sponsored full-scale building demonstration project, in which design for end-of-life to optimize the value and utility of materials and products at the point of material recovery is a key feature. Elements of design for deconstruction include removable and re-usable steel screw pile foundations, off-site manufactured panels, which are also removable and re-usable and the use of recyclable materials for the main structure.

Incorporating a range of Tata Steel Europe products, the building has also been designed and built to test and prove the 'buildings as power sta-

tions' concept for the education sector. Similarly, the Fokker 7/8 Distribution Center at Schiphol Airport in the Netherlands (Figure 4) includes elements of design for deconstruction such as adapted anchor bolts for demountable beam and column connections. Key elements to success are standardization, traceability, demountability, and supply chain cooperation.

One further area where Tata Steel Europe's new product developments can reduce environmental impacts across the whole life cycle is in steel packaging, where the use of a three-layer polymer coating system (Protact®) provides a reliable food-safe barrier between the steel substrate and the packaging contents. Protact® removes the need for cost-intensive unit operations in can-making plants, eliminating volatile organic compound (VOC) emissions and reducing energy and water consumption.

❸ Measurement and communication

Taking a full life cycle approach is increasingly demanded by our stakeholders and is an opportunity for steel as it helps in articulating the strong sustainability narrative that steel has. There are significant opportunities in higher value products and to displace less 'circular' materials. Life Cycle Assessment and Sustainability Assessments are tools that are available to support products and markets and in their development (e.g. as part of new product development processes), through the provision of credible quantitative and qualitative sustainability information.

Along with a continuous effort to optimize production processes to minimize energy use and CO_2 emissions associated with manufacture, Tata Steel Europe also facilitates its customers in making their products more sustainable. In order to help do so, LCA is extensively used to advise our customers in the design of their products made from steel. For over 20 years, we have been supplying life cycle data on our products and during this time we have grown our expertise in the field of LCA, which has been internationally recognized. In 2017, Tata Steel Europe won its fourth World Steel Association 'Steelie' for Excellence in LCA, awarded for our 'Creation of an Environmental Product Declaration (EPD) Program.' An EPD is an internationally recognized communication tool for conveying potential environmental impacts associated with a product across the whole life cycle. Establishing the independently verified program (the first steel

Figure 5. Tata Steel CEO Thachat V. Narendran (left) Accepting the 2017 'Steelie' Award for 'Excellence in LCA' for Tata Steel Europe's Environmental Product Declaration Program

company to do so) allows the production of EPDs in accordance with the relevant standards (Figure 5). Tata Steel Europe's previous worldsteel 'Steelie' awards for LCA were for studies highlighting the credentials of steel against competitor materials, a case study of steel reuse and for the development of a comprehensive LCA model for construction applications. In terms of manufacturing data, Tata Steel Europe has detailed Life Cycle Inventories (LCIs) for over 85% of our product range in a 'cradle to gate' format. Working closely with worldsteel and many other steel companies, our LCIs contribute to industry–best standard life cycle average datasets for products such as hot–rolled coil and structural steel. These average datasets are freely available to users of life cycle environmental data, including customers, consultants, and students for use in their work. worldsteel's life cycle program is an excellent example of the industry working together in the interests of making the best possible information available in support of steel. And of course, the more companies that participate, the more representative and credible the results will be.

Future

As macro trends such as more efficient use of resources, circular economy, climate change, increasing sustainability expectations of steel customers and the growing availability of end-of-life steel develop further, it will become ever more incumbent on the steel industry to innovate and be part of the solution to these global challenges.

Innovations such as Tata Steel Europe's recently launched mobile canning concept could be part of this future. According to the United Nations Environment Program, a third of all food production worldwide is lost or wasted before it even reaches

Getting more functionality from the same resource is critical to environmental improvement over the whole life cycle. A key enabler for greater circularity is having the right information available at the point of making a decision about the optimal use of products and materials. Industry 4.0 is one concept covering the exchange of digital data across many manufacturing technologies and industrial systems, not just steel.

consumers. This is mainly via the post-harvest handling, storage, processing, packaging and distribution stages, i.e. before it even reaches a retailer. The mobile canning line would allow farmers, anywhere in the world, to process and preserve their produce on site, not only reducing the amount of food lost but also eradicating lost revenue for producers caused by spoilt goods, another example of steel's role as an enabler for sustainability.

Getting more functionality from the same (or less) resource is critical to environmental improvement over the whole life cycle. A key enabler in this and other strategies for greater circularity is having the right information available at the point of making a decision about the optimal use, now and in the future, of products and materials. Industry 4.0 is one concept covering the exchange of digital data across many manufacturing technologies and industrial systems, not just steel.

In the construction sector, digital platforms such as Buildings Material Passports (BMP) and Buildings Information Modelling (BIM) are becoming widely used through the design, manufacture, and operation of a building, including for future reference regarding suitability for reuse. New initiatives in the sector are also seeking to integrate environmental information (such as LCA) about construction products into BIM, so that choices can be made on environmental criteria as well as others. Tata Steel Europe's 'DNA profiler', developed to support construction customers meet new industry standards and enable circularity in the building industry, is one such example.

Steel, through its strength, durability, recyclability and many other attributes, has excellent circular economy credentials, more so than many other materials. Taking a whole life cycle perspective helps tell its story.

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Steel in a Circular Economy: Change, Impact, and Prospects

Today a linear "take, make, and dispose" economic model is regarded as reaching its limits. As a sustainable growth model to overcome such limits, a circular economy is increasingly being discussed at the global level. The shift to a circular economy may bring tremendous changes to supply and demand of the steel industry and ultimately its future competitiveness. On the demand side, the falling steel unit requirement of steel-consuming industries, expanding service life of steel products, and falling demand for new steel products will fuel a decline in steel demand. On the production side, however, it provides a chance to take advantage of certain hidden strengths of steel—high-quality, high-quantity recycling.

To this end, some challenges should be addressed: improving the purity of scrap and maximizing recyclability; the ease of reuse and remanufacture taken into account from the design stage; and building a cooperative linkage system with steel-consuming industries. To deal with opportunities and threats, the steel industry should ensure circularity of steel to maintain its competitive edge and prove to steel-consuming industries and society at large that steel is a competitive material for the circular economy era.

The USD 76 trillion global economy[1] has been built on a linear "take, make, and dispose" economic model. We "take" raw materials from the ground, "make" products, and then "dispose" of them. Through this process, resources are depleted, wastes increase, and the environment becomes polluted. Many experts believe that the development of non-conventional energy sources such as shale gas are merely delaying the inevitable oil depletion. Other key minerals, such as copper and iron ore, are expected to run out within 50-100

1 According to the World Bank, global GDP (current USD) recorded USD 75.87trillion in 2016.

years.[2] Every year the world generates more than 2.1 billion tons of waste, an amount that is expected to triple by 2100.[3] Climate change, the most pressing environmental issue of the 21st century, is having an aggravating impact. What is worse, it is ever-harder to satisfy the growing demand stemming from rapid global population growth and urbanization.[4] The concept of a "circular economy" is emerging as a solution to these problems.

In fact, the "circular economy" is a long-established notion that dates back to at least the 1970s when resource depletion and environmental pollution were widespread. Since then, a circular economy has become a vison and agenda for the international community, including at the UN, and a policy goal for governments. The concept has recently been treated as a significant and largely untapped business opportunity for industry. Since 2013, the World Economic Forum (WEF) has been suggesting a circular economy as a global business agenda and called for industry to take action.

The World Business Council on Sustainable Development (WBCSD) has adopted a circular economy as for the mission for its Vision 2050. Many global consulting firms, including Mckinsey & Company and Accenture, have emphasized that a circular economy will provide tremendous business opportunities, and many companies are already building circular economy business models.

For instance, Renault is remanu-

2
US Energy Information Administration Statistics (2015), Valero, A. and Antonio V. (2010)

3
"World Waste Facts, The World Counts" (2017), World Bank Statistics (2016)

4
The gap between the supply and demand of natural resources is predicted to reach eight billion tonnes by 2030. This translates to USD 4.5 trillion of lost economic growth by 2030 and up to USD 25 trillion by 2050. The world population is expected to reach 9.5 billion by 2050. (Accenture, WEF, World Bank)

In a circular economy, resources are used repeatedly rather than being depleted, and the ultimate destination of a product is not waste but a further product. It means that companies must take a fresh look at resources and waste. For the steel industry, the transiation to a circular economy will bring about rapid changes in supply and demand as well as impact its future competitiveness in quite a different manner compared to in the past.

facturing thousands or even tens of thousands of mechanical parts, from water pumps to engines, and uses these components to repair vehicles that are in use. The company not only creates jobs and profits through this practice, but also saves over 80% of the energy that manufacturing a brand-new part would have required. Renault redesigns selected components to make them easier to reuse and remanufacture, and it is exploring new areas for sharing profits with suppliers and recycling companies in order to expand its business model.

With more than 100 zero-waste facilities, GM is generating over USD 1 billion in profits through recycling and reuse of waste.

Philips has pioneered the collection and recycling of used lighting in the EU. It has recently expanded its "lighting-as-a-service," through which users pay only for the light they use rather than purchasing lighting equipment. These kinds of cases are evident in a wide range of sectors and global companies.

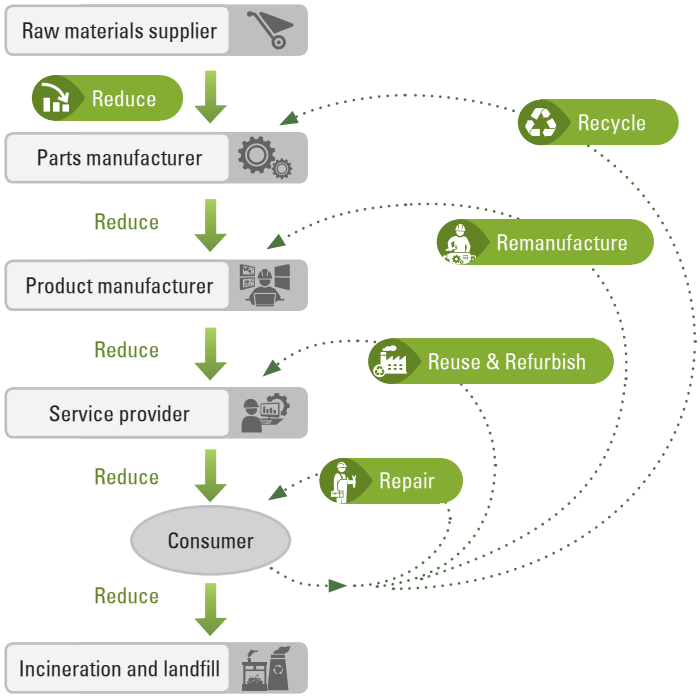
The circular economy is a paradigm shift that goes beyond sustainable production and consumption to pursue sustainable development. This article explores the meaning and progress of the circular economy and the changes and impact they will bring to the steel industry.

Understanding a circular economy

When it comes to the idea of a circular economy, we often simply imagine recycling. However, this provides only one part of a circular economy. A circular economy sustains the added value in products for as long as possible and eliminates waste. It holds resources within the economy when a product has reached the end of its life so that they can be productively used again and again and create further value (European Com-

Figure 1. The Concept of a Circular Economy

6R[5]	
Recycle	A series of activities by which discarded materials are collected, sorted, processed, and used in the production of new products
Remanufacture	Returning a used product to its original performance with a warranty that is equivalent to or better than that of a newly manufactured product
Reuse	Using a product multiple times within its functional life by different end users
Refurbish	Bringing a product back to required aesthetic specifications
Repair	Fixing faults or damage to bring a product back to the required functioning order
Reduce	Decreasing the amount of material, energy, and other resources used to create the product



Source: Compiled by the author based on technical materials on a circular economy by the Ellen MacArthur Foundation and McKinsey (2015) and Circular economy diagram by Philips

mission, 2014). It fundamentally means the decoupling of economic growth from resource use and environmental pollution. Simply put, past economic growth has inevitably boosted resource use and environmental pollution, but in a circular economy, economic growth is attainable while reducing the use of resources and alleviating environmental pollution. More than that, it ultimately means economic growth that is not dependent on limited resources and energy.

In a circular economy, resources are used repeatedly rather than being depleted, and the ultimate destination of a product is not waste but a further product. It means that companies must take a fresh look at resources and waste. All waste has potential value as a resource. From this point of view, there no longer exists waste. This concept can be realized by the "6Rs" (reduce, repair, refurbish, reuse, remanufacture, and recycle), an approach expanded from the conventional "3Rs" (reduce, reuse, and recycle).

Many organizations, including the Ellen MacArthur Foundation and Accenture, have concluded that a circular economy will create both environmental and economic benefits: reduced use of resources, improved resource productivity, minimized risks from price

5 "Reducing Waste: Repair, Recondition, Remanufacture or Recycle?", A.M. King (2006), "Steel in the circular economy, A life cycle perspective", worldsteel (2016), National Recycling Coalition & Carbon Trust website

fluctuations in raw materials, and new opportunities for business innovation, just to name a few.

This translates into USD 4.5 trillion of economic benefits worldwide by 2030 and EUR 1.8 trillion to the EU alone.[6] For instance, the steel industry could save up to 100 Mt of iron ore by 2025 by improving the circularity of materials flows, and this would help the steel industry conserve raw materials costs and reduce raw materials prices, thus potentially reducing demand-driven volatility.[7]

In addition, many other circular economy business models are being implemented and deveoped. In 2014, Accenture classified five new business models for the circular economy by analyzing more than 120 case studies of companies: Circular supply-chain; Recovery and recycling; Product life-extension; Sharing platform; and Product as a service (PaaS). In 2015, IMSA suggested six circular business models, including Short cycle, Long cycle, Cascades, and Pure circles. Furthermore, Forum for the Future and Unilever co-developed ten business model archetypes for a circular economy in 2016: Closed loop recycling, Downcycling, Upcycling, Industrial symbiosis, and Collection services, among others.[8]

These research outcomes suggest that a circular economy is not merely an abstract ideal, but has already reached the level of being practical and applicable in business. A circular economy started as a solution to environmental problems, but companies facing limited growth are now adopting it as a business model for growth.

Enablers for a circular economy

What are the enablers of a circular economy? Key enablers that will accelerate the transformation and innovation of industries and companies can be found in the areas of policy, technology, and customers.

To promote both the transition to a circular economy and business growth, innovative policy and institutional changes should follow. Many countries, including the EU, are setting mid- to long-term targets to shift to a circular economy. They are meeting these targets through policies and regulations such as setting goals for resource productivity by sector and product; publishing recycling rates; encouraging reuse and remanufacfuning and strictly regulating reclamation and incineration.

In January 2018, the EU released its new "Circular Economy Package" setting waste recycling and reclamation targets to be achieved by 2030. In particular, it aims to recycle 100% of plastic packaging. To achieve this goal, it is implementing directives for waste control, reuse as secondary raw materials, and eco-designs. Furthermore, the EU is standardizing environmental information disclosure on the life cycle of a product. It expects that companies in the region will be able to save more than EUR 600 million in costs and create two million additional jobs if a circular economy is adopted.[9] Facing resource depletion

6 "Waste to Wealth: The Circular Economy Advantage", Accenture (2015), "Growth Within: A Circular Economy Vision for a Competitive Europe", Ellen MacArthur Foundation, SUN, and McKinsey (2015)

7 "Intelligent Assets Unlocking the Circular Economy Potential", Ellen MacArthur Foundation and WEF (2015)

8 "Circular Advantage", Accenture (2014), "Circular Business Model Scan", IMSA (2015), "The Circular Economy Business Model Toolkit ", Forum for the Future (2016)

9 EU Circular Economy Package (http://ec.europa.eu/environment/circular-economy/index_en.htm)

and environmental pollution in the process of rapid economic growth, China put a low-carbon, circular economy on the national agenda in the 13th Five-Year Plan released in 2015. China also pledged to build a framework for a circular economy and increase its recycling rate to over 40% by 2020. In January 2018, China banned the import of foreign plastic waste, bolstering the system for a circular economy. The China Association of Circular Economy (CACE) estimated the value of China's waste recycling industries to be approximately USD 293 billion in 2015 and its future market potential is projected to become the global leader.[10]

Together with the strengthening of policies for a circular economy, the most noticeable enabler is the advancement of digital technology and engineering innovations. The fundamental distinction between the circular and linear economy is that resource management abandons traditional practices of resource extraction and production and instead takes life cycle approach to pre- and post-production.

Digital technologies enable the collection of massive amounts of data and resource flows can be managed through innovative technologies such as mobile, machine-to-machine communication, cloud computing, and big data analysis. This is laying a fundamental basis for the transition to a circular economy.[11]

Representative examples include monitoring and analyzing customer patterns when using and disposing of products and emplacing a tracking and collection system across the entire supply chain. Finally, just like with other great shifts, the most important enabler of the transition to a circular economy is the customers themselves, or in other words, market change. This change in value is all made possible by the development of new technologies.

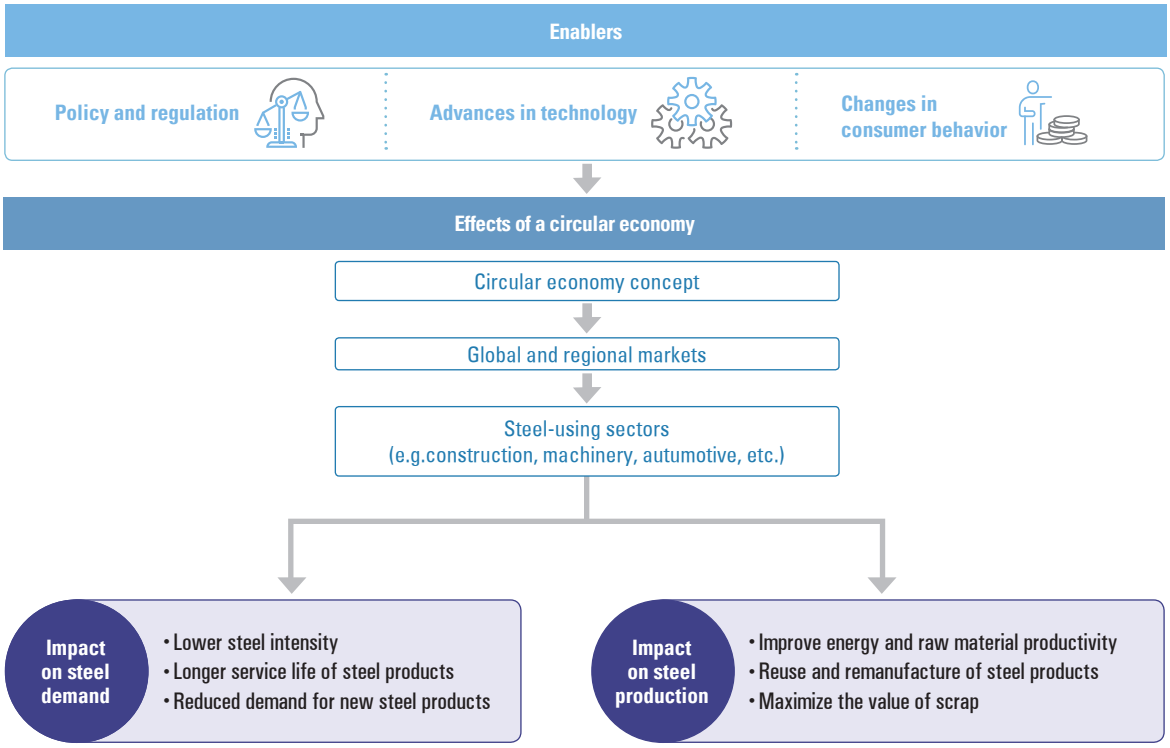
Notably, customer demand for eco-friendliness is increasingly expanding in scope. Despite the global economic recession, the eco-friendly goods and services market reached EUR 4.2 trillion in 2012 and has increased by as much as 4% annually since 2010.[12] More and more customers want products made from eco-friendly raw materials that were prepared with less energy, have a minimal impact on the environment, and are easily recyclable after disposal. In other words, "circularity of a product" has become a new

10
China Association of Circular Economy (December 2013)

11
Accenture suggested 10 innovative technologies to support circular economy business models in 2015: Mobile, Machine-to-Machine (M2M) Communication, Cloud Computing, Social, Big Data Analysis, Modular Design Technology, Life and Material Science Technology, Trace and Return Systems, and 3D Printing.

12
UK Department of Energy and Climate Change (July 2013)

Figure 2. The Impact of a Circular Economy on the Steel Industry



Source: Compiled by the author

value for customers.

Impact of a circular economy on the steel industry

The steel industry has maintained the competitive edge of steel being the cheapest and most economical material through continuous efforts at ensuring high-performance lightweight products. Thanks to such efforts, it has secured a large proportion of steel-consuming industries amid the fierce competition among materials.

However, the transition to a circular economy, which will entail tremendous shifts in production and consumption in the global economy, will bring about rapid changes in supply and demand within the steel industry as well as impact its future competitiveness in quite a different manner compared to in the past.

Impact on steel demand

On the supply side, steel-consuming industries including automobiles, shipbuilding, and construction are developing toward a reduction in resource productivity, meaning a reduction of unit requirements and steel intensity. Less steel

materials will be consumed to produce the same amount of steel products. Although steel-consuming industries will sustain or raise the current production level, steel demand could decline.

In particular, steel intensity in the automotive industry is expected to fall to 80% of 2015 levels by 2035 due to the increased manufacture of electric vehicles, improved fuel economy, lighter weight, and lower steel intensity.[13] This trend will be accelerated by circular economy policies such as producer responsibility to recycle end-of-life vehicles and the expansion of the market for remanufactured automotive parts.

A product's service life is also an important factor in changes of steel demand. In a circular economy, durable products have a greater competitive edge than do less durable products; therefore, steel-containing goods are developed to have as long a useful life as possible. This will primarily lead to a decline in new demand. Based on the concept of a circular economy, the extended use of sharing products, i.e. car sharing, will further accelerate this trend.

However, there is a quite opposite analysis noting that product service life is being significantly reduced as steel-consuming industries diversify and demand for metals by new growth industries is rapidly changing. In 2012, the Korea Evaluation Institute of Industrial Technology (KEIT) suggested that general-purpose steel has a service life exceeding decades, whereas that of high-end metal products is merely 5-10 years.

To sum up the causes of supply-side changes and the impact of a circular economy, the falling steel unit requirement of steel-consuming industries, expanding service life of steel products, and falling demand for new steel products will fuel a decline in steel demand. A report by Accenture suggests that in the baseline forecast global steel demand will grow by a CAGR of 1.4% through 2035, but after applying the impact of a circular economy, the projection drops by 0.3%p (130 million tones, on a crude steel basis) to a CAGR of 1.4%.[14]

As a key material for a low-carbon circular economy, ensuring the competitiveness of steel products is a pivotal task for the survival and sustainability of the steel industry.

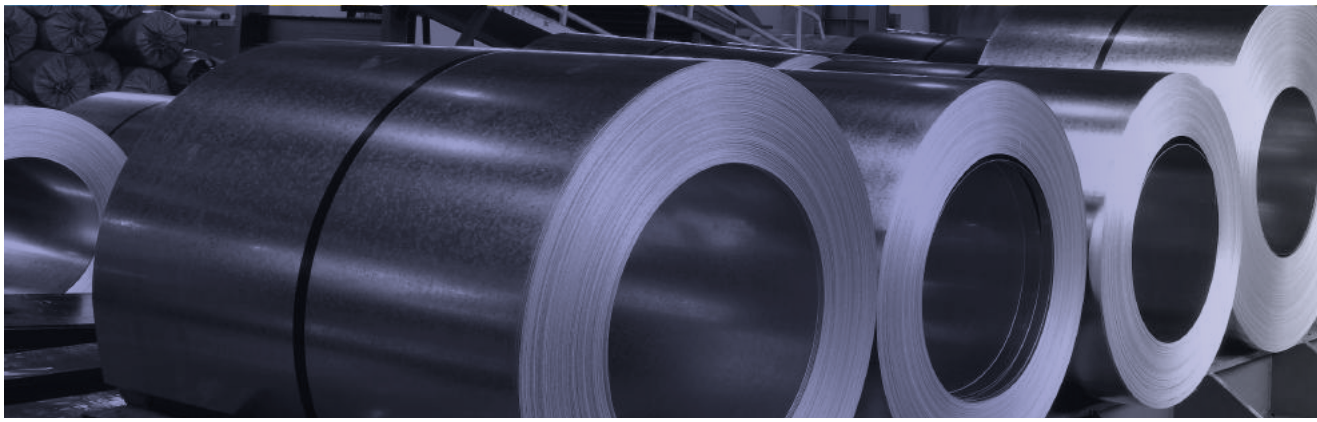
Impact on steel production

At the steel-making process stage, resource productivity is being improved and environmental impact is being minimized through the development of innovative technology and introduction of new types of production methods. Since the 1960s, the global steel industry has cut the energy required to produce a tonne of crude steel by more than 60%[15], and resource productivity has been continuously improved in response to high volatility in raw materials prices. Despite

13 Steel Contents Per Vehicle, 1,546 kg in 2015, 1,391 kg in 2025, 1,252 kg in 2035, POSRI analysis (2017)

14 "Steel demand beyond 2030, Forecast Scenario", presented to the OECD, Accenture (2017)

15 "Steel's Contribution to a Low Carbon Future", worldsteel (2014)



such efforts, the steel industry is often regarded as being energy and CO_2 intensive. Currently, the steel industry is being asked to innovate even beyond its efforts of the past. This is where tangible changes should come in the mid- to long-term as many countries work to reduce the carbon footprint of the steel-making process by restricting greenhouse gas emissions.

The potential for the recycling of scrap is the largest advantage of steel and a project that should be developed further. Steel scrap has over a 90% recycling rate (UNEP, 2011) and can be infinitely recycled without any loss to its properties (worldsteel, 2015). However, there are numerous barriers, such as customers' behavior patterns in using and disposing of steel, the level of technology for separating and removing impurities during the recycling of steel, recyclability consideration at the product design stage, and lack of integration of supply chains by country and region.

Without addressing purity challenges, more than half of the old steel scrap generated annually will have to be down-cycled by 2050.[16]

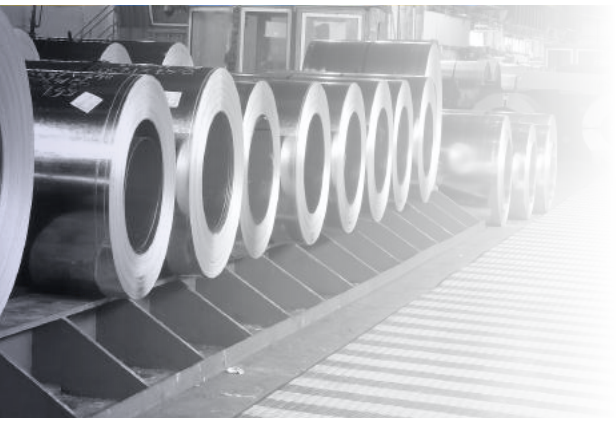
The Ellen McArthur Foundation & WEF (2015) has placed steel in the "Golden Oldies" category, which means that a high volume of recyclable materials are widely collected, but they suffer from contamination and quality loss in the cycle. It has stressed that improving the purity of scrap and maximizing recyclability are challenges to be addressed.[17] In addition, the integration or linkage of scrap supply chains by country and region is the most important challenge for maximizing recyclability and expanding related businesses.

These shifting conditions for recycling scrap will accelerate the increase in the share of electric arc furnaces (EAF), which is forecast to rise from 25.3% in 2016 to 39.9% by 2035.[18] Combined

16 "Understanding Steel Recovery and Recycling Rate and Limitation to Recycling", Bowyer et al (2015)

17 "Towards the Circular Economy", Ellen McArthur Foundation and WEF (2015)

18 "Steel demand beyond 2030", Accenture (2017)



with stricter environmental regulations and policies for promoting a circular economy, this trend will become particularly evident in China.

The recycling of scrap through recovery is being expanded to include the reusing and remanufacturing of steel products. To this end, the ease of reuse and remanufacture should be taken into account from the design stage, and it is essential to build a cooperative linkage system with steel-consuming industries. In addition, further developments will be made in the methods for recycling slag and by-product gas created from steel-making process and the ways of making them into new products.

What's next

The shift to a circular economy has already begun. Related policies and regulations will be strengthened to drive this transformation. The advancement in technologies will further accelerate this process while customer demand for products that adapt to such changes grows continuously.

This transformation poses a challenge to the steel industry, but at the same time it provides a chance to take advantage of certain hidden strengths of steel—high-quality, high-quantity recycling. Global steel companies, including POSCO and Tata Steel Europe, are trying to take this chance by embedding life cycle thinking and seeking innovation in their production processes and products based on life cycle thinking. Developing automotive steels through environmental load analysis of the full life cycle of a vehicle and creating slag cement from steel by-products are some good examples.

In the meantime, worldsteel sees the circularity of steel based on the 4Rs (reduce, reuse, remanufacture, and recycle) is the best means to ensure the competitive edge of steel amid the fierce competition among materials.

Over the last three to four decades, the steel industry has been trying to minimize energy use and environmental pollution associated with manufacture and actively publicizing such efforts. However, over the next 50 years, it is increasingly essential for the steel industry to prove to steel-consuming industries and society at large that steel is a competitive material for the circular economy era.

As a key material for a low-carbon circular economy, ensuring the competitiveness of steel products is a pivotal task for the survival and sustainability of the steel industry. This is why we must pay keen attention to the circular economy.