GMK CENTER

ROLE OF STEEL INDUSTRY

in Green Energy transition

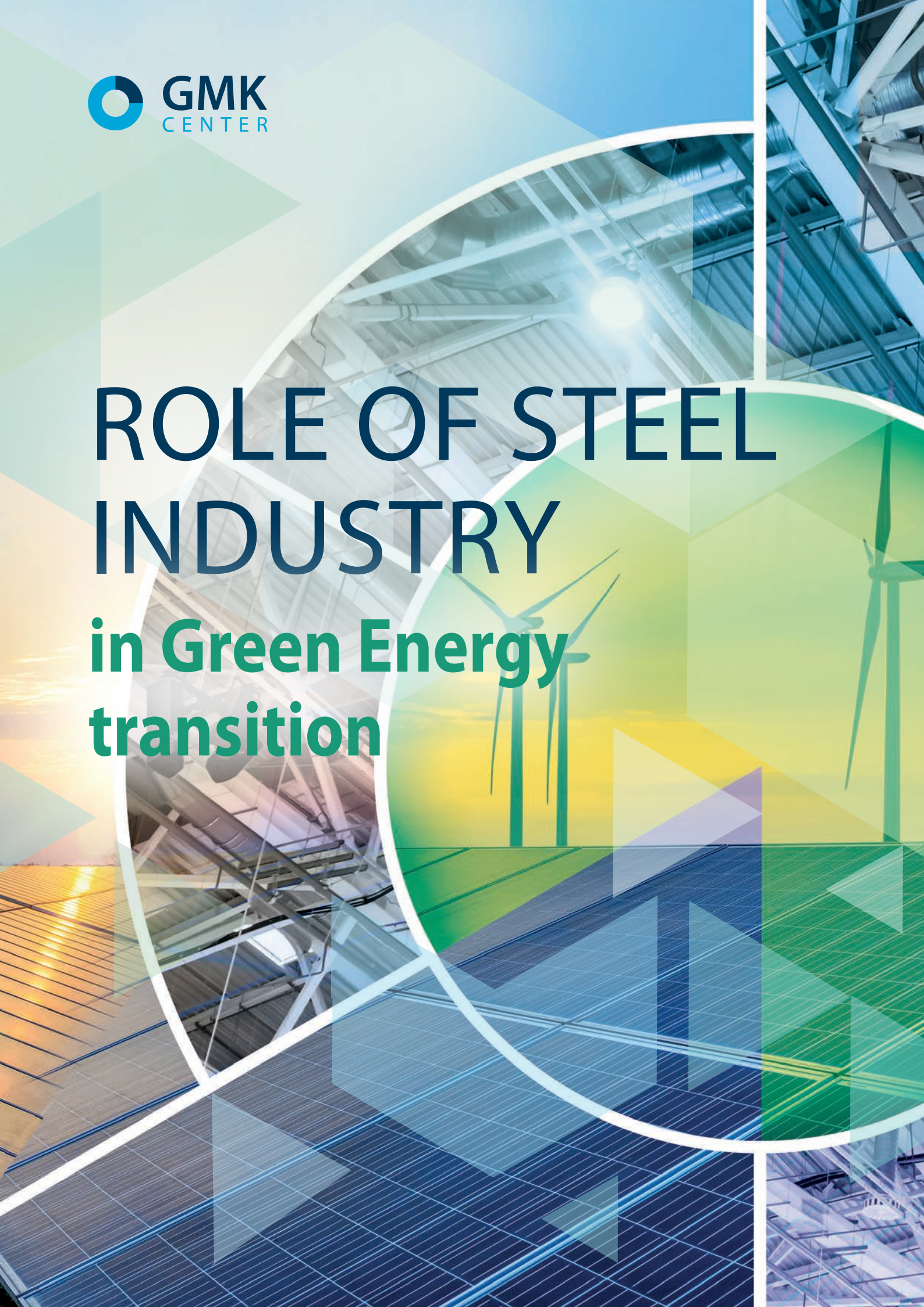

TABLE OF CONTENTS

INTRODUCTION

GMK Center Director
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Green energy transition is a new phenomenon, which began with the Paris Agreement. All the parties have committed to contribute to reduction in greenhouse gas emissions in order to limit climate change.

Green energy transition is not just a fancy trend but a new reality. A number of countries announced that they plan to achieve carbon neutrality by 2050–2060. Examples include the European Green Deal or Ukraine's Green Energy Transition Concept. Decarbonization is becoming indispensable for further international cooperation. For instance, EU intends to introduce trade restrictions on carbon-intensive imports (CBAM). Other countries are prepared to follow its example, thus giving a yet bigger impetus to reduction of greenhouse gas emissions.

Apparently, green energy transition will result in profound structural transformation of economy. Conventional industries will transform while new economic sectors and business activities emerge.

These changes will affect essential aspects of our daily life, like housing and transport. Likewise, a wide range of sectors, such as energy, heavy industry, etc., should be fully reformed, thus changing the structure of economy. These changes are impossible without the steel industry. Steel as an essential element of infrastructure helps people gain access to social benefits, education, increase security and specifically improve environment, as well as assist other sectors in switching to zero-carbon operation.

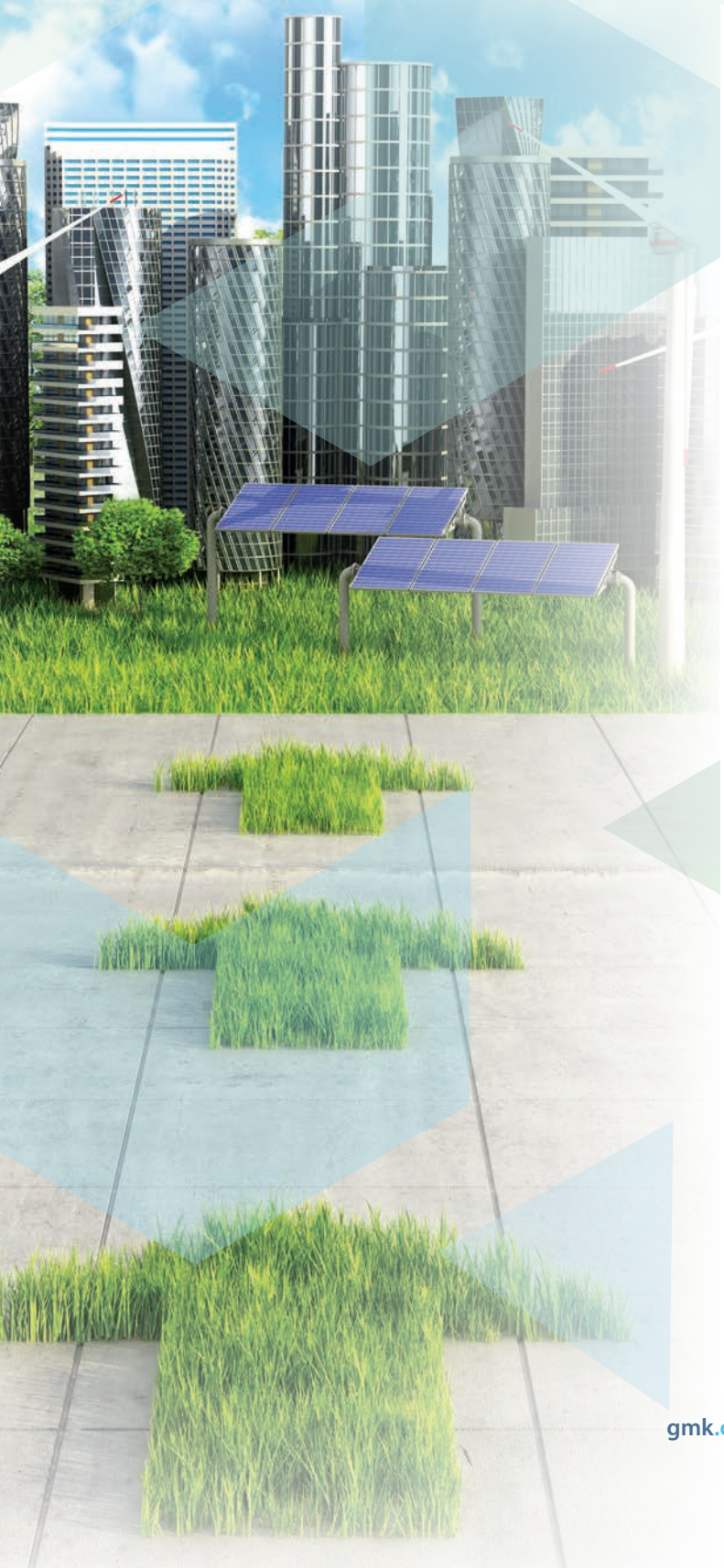
High-tech steel products are far more efficient that conventional materials for instance, in construction. Rigid steel battery frames in electric vehicles allow increasing passenger safety. Structural elements made of steel will help construct vertical trusses and biogas units for decarbonization of agriculture. Naturally, steel is a basic element in renewable energy production where it is used, for instance, in wind turbine towers.

It means that key solutions for achieving carbon neutrality in such sectors as energy, construction, transport, mechanical engineering are based on use of steel. That is why steel will be a driver for successful green transition in the nearest 30 to 40 years.

Metals and steel production also requires structural adjustment of facilities to achieve carbon neutrality. Green transition needs green steel. In other words, the steel industry requires decarbonization, but decarbonization of other sectors depends on the steel industry.

This study is aimed to demonstrate benefits of steel as a material, the wide range of its application, and its key role in the green transition process, to prove that the steel industry is a basic sector in the future economy, indispensable for building up sustainable zero-carbon economy.

SPECIFICS OF GREEN TRANSITION IN CERTAIN SECTORS AND IMPORTANCE OF THE STEEL INDUSTRY



Green energy transition includes replacement of fossil fuels with renewable energy sources for the purpose of cutting down greenhouse gas emissions to zero. The 2015 Paris Agreement on Climate Change kicked off this process.

Green transition poses a number of challenges for businesses relating to changing business models, application of new technologies, and adjustment of supply chains. **The process of "greening" the economy highlights the importance of the steel industry** as key product supplier for successful decarbonization of other sectors, including energy, transport, construction, agriculture, as well as the steel industry itself.

The energy industry is the biggest source of global carbon emissions. One out of three tons of greenhouse gases is generated by energy facilities. Emission reduction prospects in this sector are associated with renewable energy generation progress. At the same time, decarbonization of other sectors envisages increase in electricity consumption. Therefore, attainability of carbon neutrality targets in other sectors depends on the pace of green transition in the energy industry.

Development of virtually every kind of renewable energy generation and distribution grids is based on the use of steel. Specifically, steel is used in manufacture of PV panel frames, pumps, reservoirs, heat exchangers at solar power plants, in manufacture of wind turbine towers and other parts. Steel is needed for manufacture of power transmission poles in distribution and supply systems. Steel is also used for reinforcement of concrete hydroelectric dams.

IEA forecasts a 2.7-fold increase in electricity production by 2050. By then, almost 90% of electricity will be produced from renewable resources. This will create extra demand for steel for renewable energy facilities construction. Global power output from renewable power plants will increase by a factor of 3.4 by 2030 and by 9 times by 2050. According to steel consumption rates per 1 GW, **the global energy industry will need 1.7 billion tons of steel for green energy transition.** This is on par with the current global steel output.

In other words, **all industries need green electricity, while the steel industry is the key supplier of**

materials enabling development of the renewable energy industry. Besides, the steel industry facilitates green energy transition through investments. Indeed, **steelmakers are significant investors in renewable energy projects.**

Construction sector, including construction materials production, accounts for 10% of global CO_2 emissions, with another 28% generated in the process of operation of buildings (indirect emissions). Carbon intensity of steel is 4.9 times lower than that of cement, so **construction-related emissions can be reduced considerably through replacing concrete structures with steelwork.** Besides, steel is 85% recyclable. Which means that **a building made of steel can be disposed of with almost no waste** at the end of its useful life. Environmental friendliness and recyclability of steelwork construction will certainly increase the demand for it. Enhancement of environmental certification of buildings that may become compulsory in future will also back the demand.

Building operation emissions can be reduced through implementing energy efficiency measures and applying ZEB (zero energy building) technologies. Virtually all such solutions are based on the use of steel. For instance, steel window frames show much lower heat diffusion, much like steel sandwich panels not only allow to reduce heat loss, but also make the building structure much lighter. Steel is also used in a range of other ZEB technologies, such as steel tubed energy piles, radiant heating systems, heat pumps, etc. **The steel industry thus allows the real estate sector to be more efficient in terms of resource consumption.**

Investments in energy efficiency of buildings and construction of "carbon neutral buildings" demonstrate a high macro-level return, much exceeding returns on investments in renewable energy. Each $1 million invested in energy efficiency of buildings allows to create 15 new jobs while, for instance, wind power generation accounts for only 2 new jobs and hydrogen production 6 new jobs respectively. That is why **considerable investments into energy efficiency are expected, which will support the demand for steel.**

Transport ranks high in terms of global greenhouse gas emissions. It accounts for 24% of total CO_2 emissions, of which 18% is generated by automotive transport. The top priority in motor transport decarbonization is replacement of internal combustion engines with electric motors.

Steel is an essential material that is irreplaceable for the purposes of electric mobility development. Electric vehicle battery cases are made of steel. Thus applied, steel ensures passenger safety due to its inherent durability and fire resistance. Thin-gauge electrical steel enables greater electric motor efficiency. Environmental compatibility and lightweight potential of steelwork structures have already enabled major vehicle manufacturers to reduce the use of aluminum in body parts in favor of steel.

Steel has high potential for upgrade compared to substitute products. For instance, **steel has a substantial lightweight potential.** According to Thyssenkrupp, vehicle weight can be reduced by 25–35% due to the use of AHSS. **It makes steel the most advanced material in**

terms of energy transition in transport, where vehicle weight reduction is an important factor of emission cutdown.

For electric vehicles, steel consumption will increase 7.7 million tons by 2050, which might seem insignificant, but it's actually a good result, considering expected weight reduction of future vehicles.

Expansion of new means of high-speed electric transport is also based on usage of steel.

Mechanical engineering plays a prominent role in the green energy transition because of the full-scale change of technologies in a range of economy sectors that will take place in this process. **Application of new technologies requires replacement of equipment:** CO_2 capture installations, electrolytic "green" hydrogen generators, innovative heating, cooling, and air conditioning systems, CO_2 disposal and biofuel production equipment, etc.

Mechanical engineering is one of the largest steel consumers in the world. **Steel is the key construction material for machinery and equipment. That is why decarbonization of economy is impossible without steel.** According to BCG, decarbonization of the global economy will require €10 trillion in equipment investments until 2050. In the light of metal intensity estimates, mechanical engineering will require 122 million tons of steel until 2050. This steel will be employed to secure green transition in all sectors of economy.

The highest CO_2 emissions among other industries accrue to the steel industry (6.0% of the global volumes), cement industry (6.6%), chemical and petrochemical industry (3.9%). Most decarbonization methods require either new equipment or modernization of the existing one. Specifically, the use of biogas or biomass as fuel in the cement industry is only possible if the currently operating kilns are redesigned. New equipment is required for CO_2 capture, green hydrogen production, plastic recycling. Use of biomaterials as raw material in the chemical industry can result in transformation of conventional production technologies. The core construction material for equipment is steel.

Decarbonization of agriculture is based on its own unique approaches that are not suitable in other sectors. However, it still requires new equipment like biogas units or vertical trusses (automatized racking complexes for multilevel plant cultivation through hydroponics and aeroponics). That is why decarbonization of agriculture is unimaginable without steel.

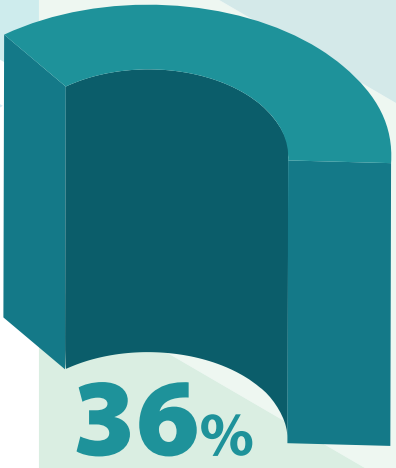
Consequently, **such benefits of steel as high environmental compatibility as compared to substitute materials, recyclability, and upgrade potential will ensure growing demand for steel for the purposes of green transition. The steel industry plays the key role in the green energy transition as its products facilitate decarbonization of other sectors. Therefore, the steel industry will keep contributing to the economy. Besides, the importance of the steel industry will only grow, given the significance of this sector for the green energy transition.**

ENERGY

Power industry is now the largest source of CO_2 emissions in the world. As of 2020, the sector has emitted 12.3 gigatons of CO_2, 74% of which accrued to coal-fired power plants, 22% to gas-fired ones, and 4% to those firing oil products. Large emissions determine the leading role of the energy industry in decarbonization. The chance to achieve carbon neutrality targets in other sectors depends on the speed and pace of green transition in this particular industry.

Decarbonization of the global economy will require additional electricity supply since electrification of transport and industrial processes is a major way to reduce greenhouse gas emissions. Utilization of electricity (provided that it is generated from renewable sources) allows us to move away from burning fossil fuels resulting in CO_2 emissions. IEA thus forecasts that the share of electricity in total energy consumption will grow from 19.7% in 2020 to 49.1% in 2050, while the total energy demand in this period will decrease by 16.5%.

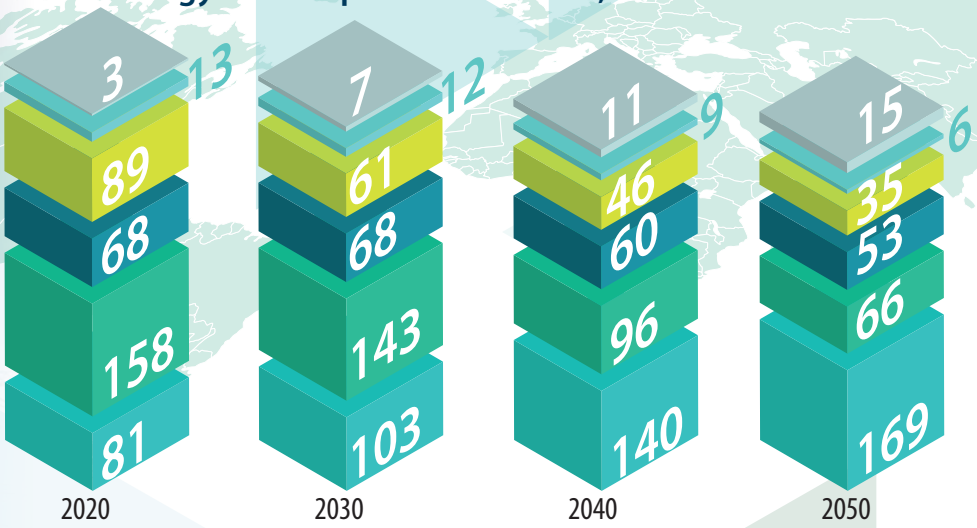
The energy industry's share in global greenhouse gas emissions in 2019



Data source: IEA

Transition from fossil fuels to electricity is a defining characteristic of the green energy transition in many sectors

Global energy consumption breakdown, EJ

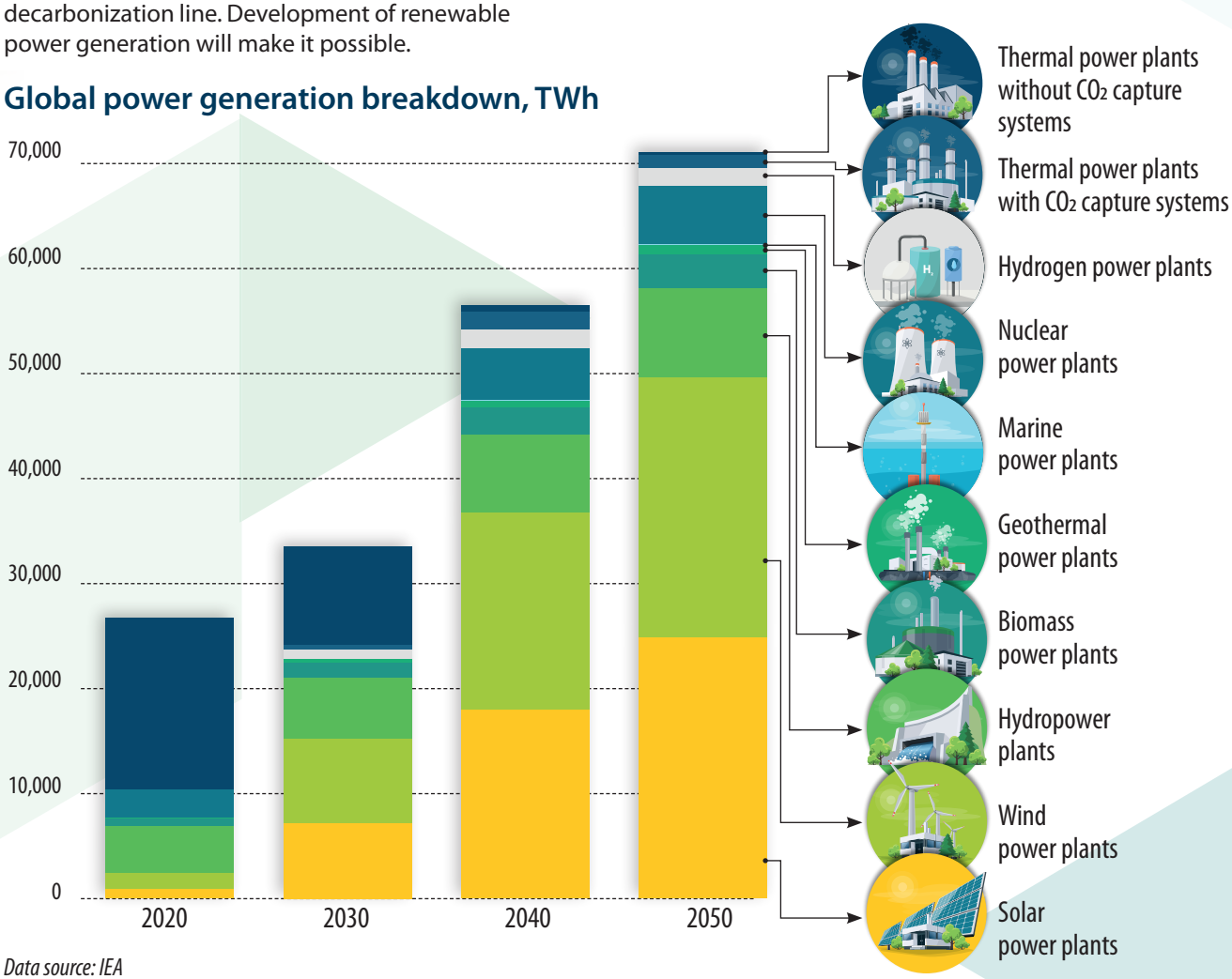


Data source: IEA

As IEA puts it, CO_2 emissions in the energy industry should fall to zero in 2030s in advanced economies and in 2040s in developing economies. This is the only realistic scenario of achieving carbon neutrality on the global scale by 2050. I.e. the energy industry should be the first down the decarbonization line. Development of renewable power generation will make it possible.

All the industries are in need of green electricity while the steel industry is the key supplier of materials enabling development of the renewable energy industry

Global power generation breakdown, TWh

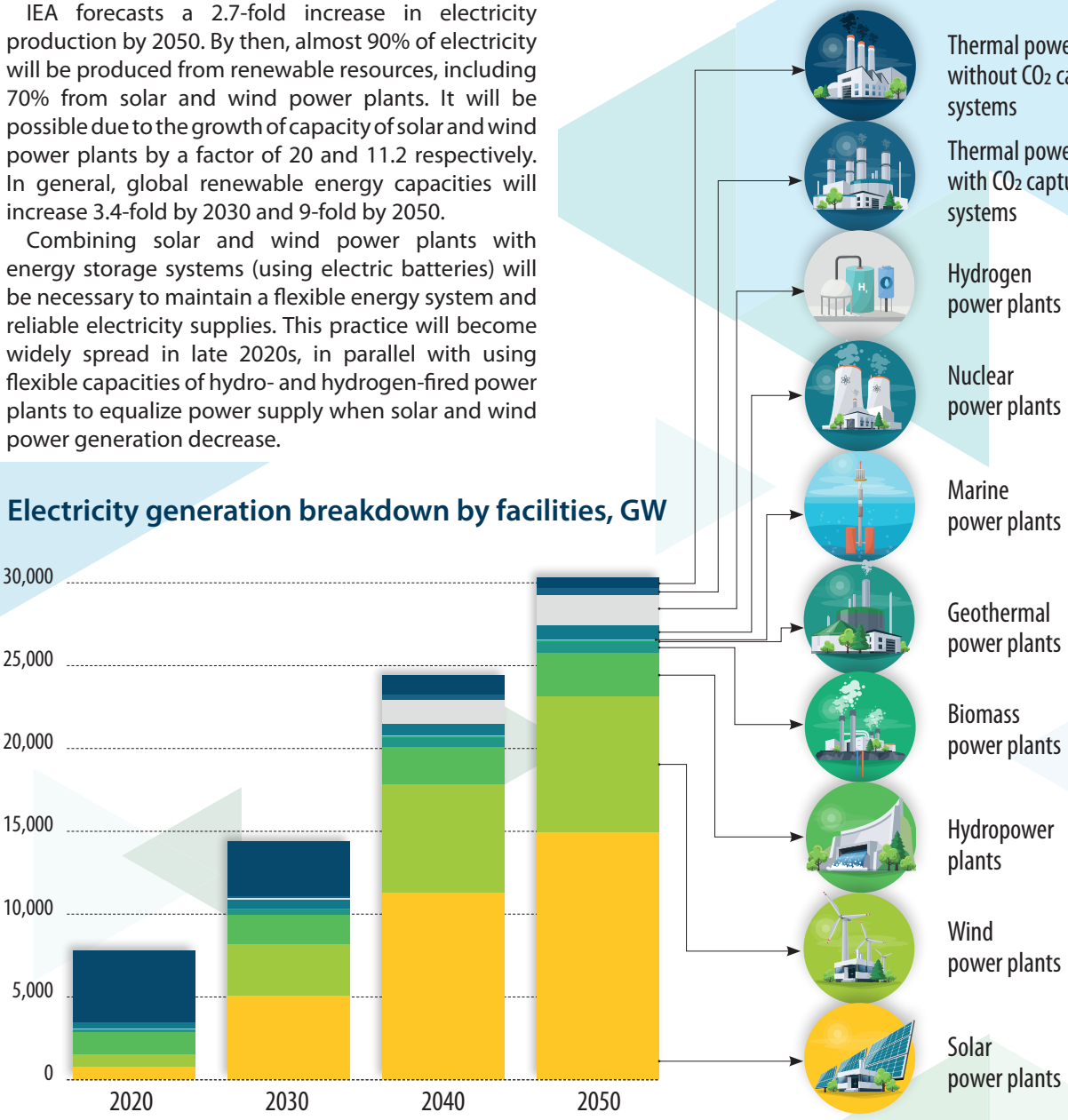


Data source: IEA

IEA forecasts a 2.7-fold increase in electricity production by 2050. By then, almost 90% of electricity will be produced from renewable resources, including 70% from solar and wind power plants. It will be possible due to the growth of capacity of solar and wind power plants by a factor of 20 and 11.2 respectively. In general, global renewable energy capacities will increase 3.4-fold by 2030 and 9-fold by 2050.

Combining solar and wind power plants with energy storage systems (using electric batteries) will be necessary to maintain a flexible energy system and reliable electricity supplies. This practice will become widely spread in late 2020s, in parallel with using flexible capacities of hydro- and hydrogen-fired power plants to equalize power supply when solar and wind power generation decrease.

Electricity generation breakdown by facilities, GW



Data source: IEA

Electricity transmission and distribution network development will be instrumental for transformation of the energy industry. Apparently, growing electricity consumption will require extra capacity from transmission networks. According to IEA estimates, the length of power grids, erected during the last 140 years globally, should double by 2040 and increase by another 25% by 2050.

Development of virtually every segment of the energy industry, such as renewable energy installations and distribution grids, depends on steel.

Advantages of using steel in electricity generation and distribution:

- Reusability.
- Ensuring structure safety and mechanical integrity.
- Hard and durable material.
- Higher cost efficiency compared to other materials.
- Accuracy in size.
- Steel pipelines as fuel (incl. hydrogen) transportation technique have minimum environmental impact.
- Wind turbine towers made of steel are easy to install and maintain.

How steel helps develop renewable energy

PV solar power plants

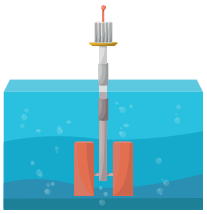
Consist of panels that directly convert solar power to electric power

PV panel frame

Power plants based on concentrated solar power systems

Use mirrors or lenses to concentrate solar power. Sun rays heat liquid that turns into turbine steam

Pumps, reservoirs, heat exchangers



Marine power plants (wave and tidal)

Tidal power plant operation is based on daily tidal surges and ebbs while wave power plants utilize the energy of wave motion

Steel pile is a basic component of tidal current turbines
Wave power plant components are made of steel

Hydropower plants

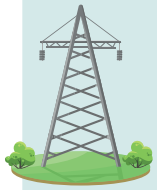
Use river water motion

Reinforcement of concrete dams

Wind power plants

Use wind power

Steel is used for wind turbine manufacturing (almost in every element — from foundation to tower and generator)



Power transmission and distribution systems

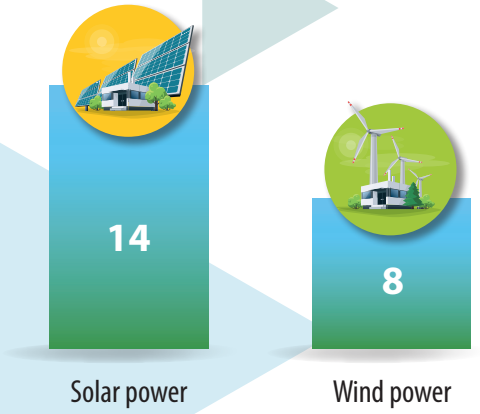
Power transmission lines and associated equipment for electricity supply to customers

Transformers
Generators and electric motors
Power transmission poles and steel cables

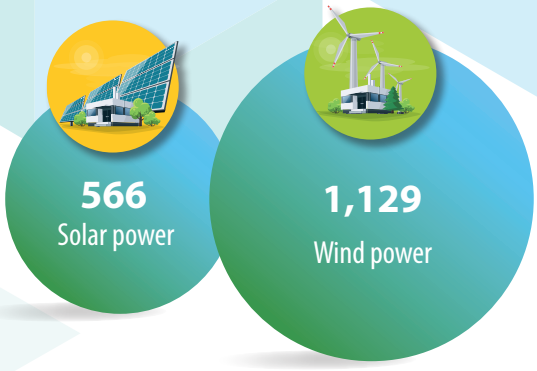
According to ArcelorMittal, construction of a 1 MW solar power plant requires 35 to 45 tons of steel, while construction of a wind power plant of equivalent capacity requires 120 to 180 tons. Therefore, if we take the average of these values, construction of new solar and wind power generating facilities in 2021–2050 will require around 1.7 billion tons of steel. This is on par with the current global steel output.

1.7 billion tons of steel is required for the green energy transition in the energy industry

Estimated cumulative capacity surplus in 2021–2050, thousands GW



Steel to be consumed in the renewable energy sector in 2021–2050, million tons



Data source: IEA, GMK Center estimations

The steel industry and the energy industry are interdependent where decarbonization is concerned. On one hand, the steel industry needs green electricity. On the other hand, energy needs green steel. Therefore, decarbonization of these industries should be conducted in parallel to enable their advancement in the same direction. Considering the importance of clean electricity for their operations, many steelmakers invest into renewable energy. For instance, Salzgitter promotes wind power generation, Gerdau uses solar power, and ArcelorMittal takes advantage of both and is also engaged in a power storage battery development project.

The steel industry facilitates green transition in the energy industry through investments. Indeed, steelmakers are significant investors in renewable energy projects

FACTS AND FIGURES

Steel is the world's **No. 1** material in terms of recycled volumes. Over 600 million tons of steel scrap is recycled yearly

Steel products are **85%** recyclable. This is how much scrap in average can be extracted from steel products during recycling

25 billion tons of steel have been recycled in the world since 1900

82.5% of steel packaging in the EU is recycled

98% of raw materials used in steel production is recyclable as either final products or byproducts, meaning that the steel industry is able to achieve the zero waste target

A new steel product can be released in **60 days** after it has been recycled

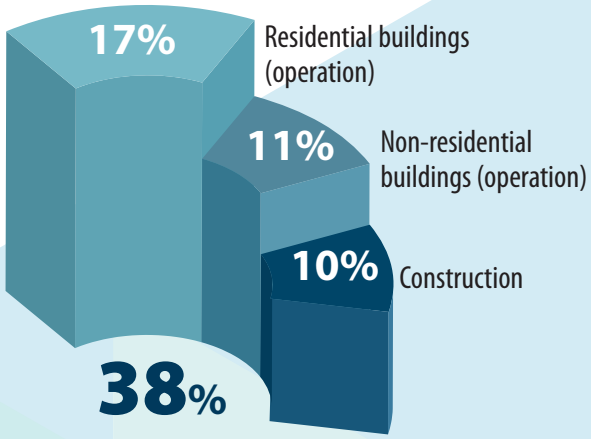
Any steel product by an average of **37%** consists of recycled steel

CONSTRUCTION

Steel will be a basic construction material in future. Every modern architectural solution is based on the use of steel. For example, The Shard (London) being the tallest building in the EU, Burj Khalifa, Beijing National Stadium, also known as the Bird's Nest, and many others. All the significant architectural objects are based on steelwork structures. Building appearance is a major factor of its commercial appeal. Steel is the construction material of the future.

Its popularity growth will be facilitated by a wide range of factors. Steelwork construction will help achieve advantages in commercial efficiency, ecological performance, user comfort, and appeal of buildings. But what is crucially important is that use of steel allows achieving sustainable development targets and reducing emissions in the area of building construction and management.

Construction's share in the global greenhouse gas emissions in 2019*

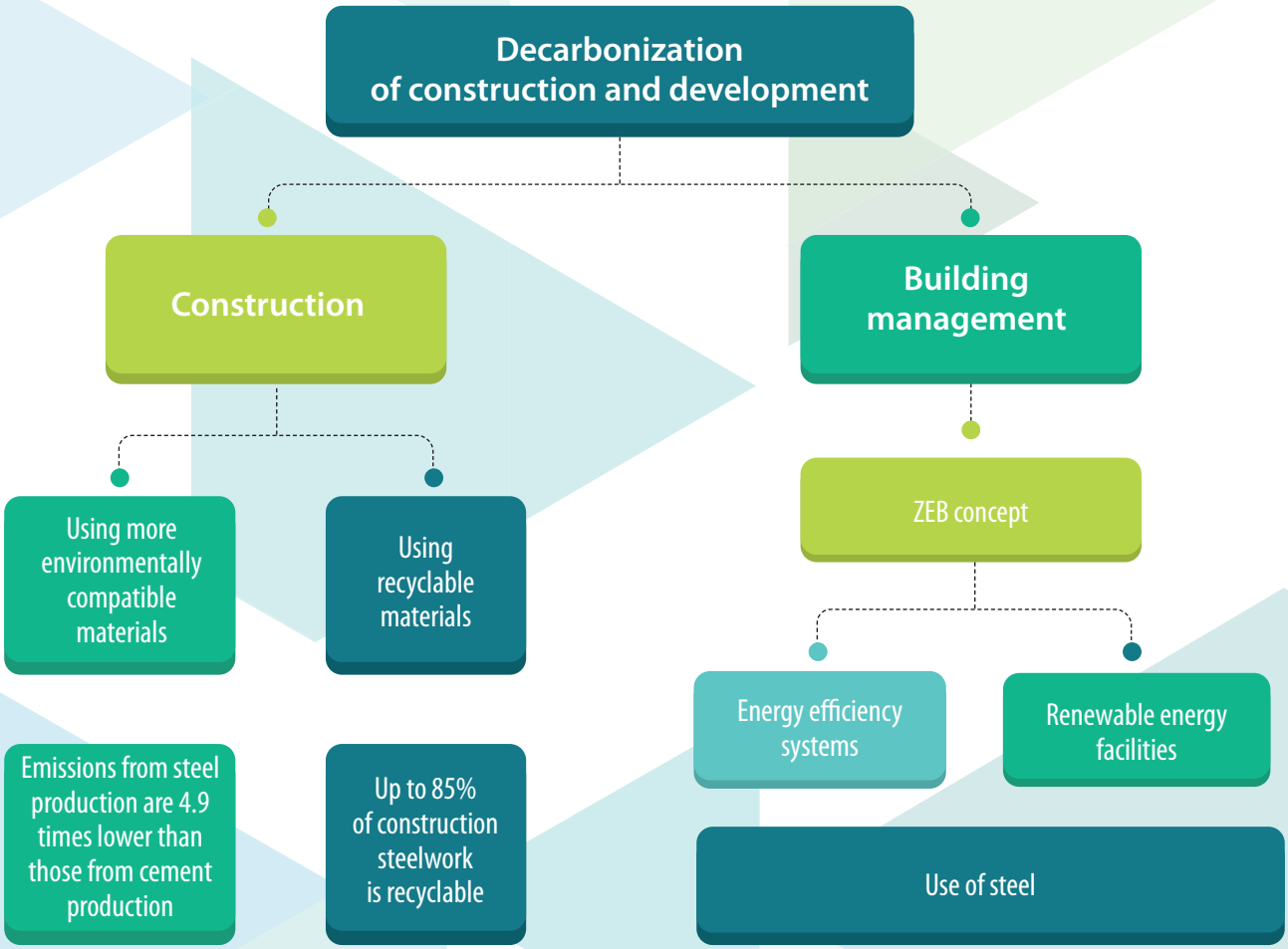


** direct and indirect emissions*
Data source: IEA

Construction and development are major sources of greenhouse gas emissions in the world. They account for 38% of global emissions, 10% (3.5 billion tons CO_2) of which accrue to construction operations and production of construction materials. Another 28% of emissions (10 billion tons CO_2) is attributed to building management (operational emissions) as a result of energy consumption for heating, air conditioning, lighting, etc. Considerable efforts and investments are expected to be focused on this area in the coming years. IEA expects construction-related emissions to reduce 50% by 2030 so that the declared carbon neutrality objectives can be achieved. And by 2050, operational emissions should be cut down to zero.

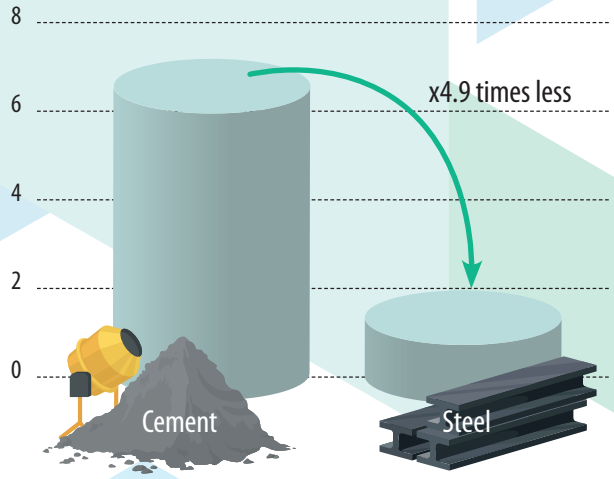
Reduction of emissions from construction and development is possible through renovation of existing buildings and their life extension, use of materials produced with lower emissions and recyclable materials, energy efficiency improvement. All these approaches are associated with the use of steel.

How steel helps reduce CO_2 emissions in construction and development



Considering the difference in carbon footprint between steel and cement one can assume that CO_2 emissions can be reduced even today by replacing concrete building frames with steel ones. Besides, steel sandwich panels are more lightweight for specified thermal conductivity. It means both efficient application of steel as wall material and reduction of foundation weight, which, in its turn, results in less emissions.

CO_2 emissions per $1 of product cost, kg



Data source: McKinsey & Company

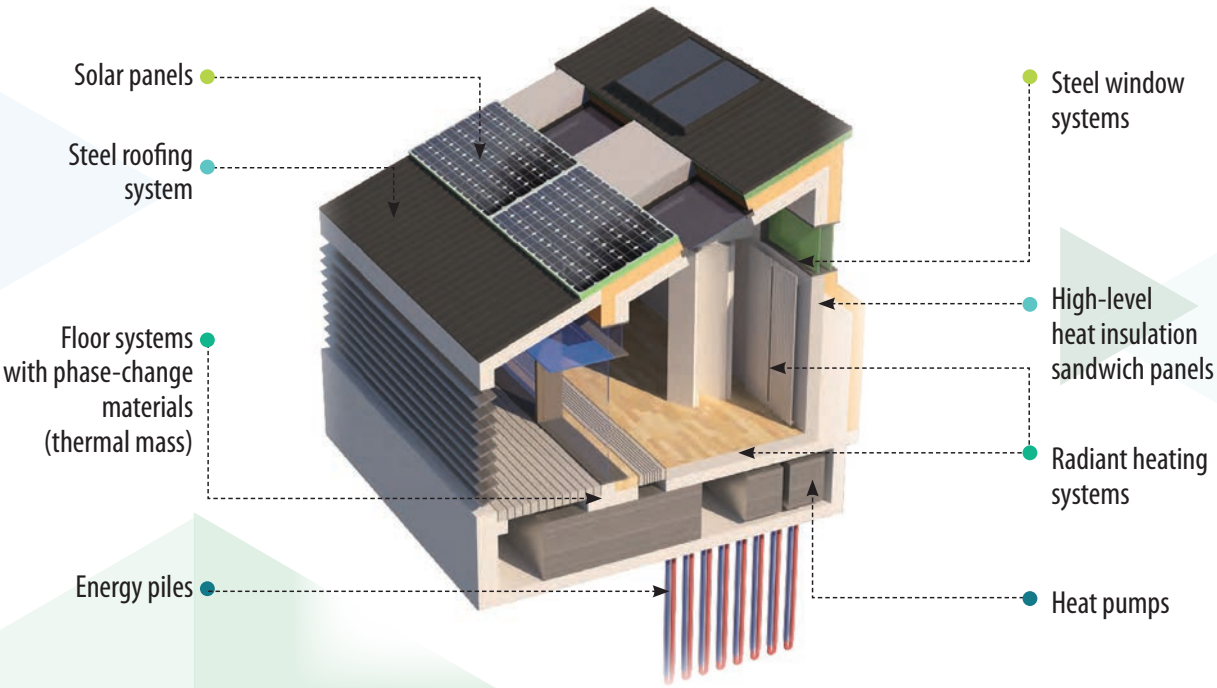
Up to 85% of construction products made of steel can be extracted and recycled an unlimited number of times. That is why a building made of steel has salvage value, i.e. is more profitable for its owner as it may be possible to generate some revenue from scrap sale after demolition. Besides, steel buildings can be remodeled or moved to another location without extra costs for materials.

Carbon intensity of steel is 4.9 times lower than that of cement, so construction-related emissions can be reduced considerably through replacing concrete structures with steelwork

Environmental certification of construction will facilitate usage of steel as a basic construction material. A number of such certification standards exist even today: LEED (Leadership in Energy and Environmental Design), WELL Building Standard, Fitwel. As steel has a lower carbon footprint than cement, for example, steel buildings will have an advantage when it comes to environmental certification. In future, to achieve carbon neutrality, environmental certification of construction might become a requirement for obtaining construction permits. According to the World Steel Associations, the number of LEED Certificates issued in the U.S. in 2006 did not exceed 300, but reached 67 thousand in 2018. So, steel may soon become a dominant material in construction.

However, building operation causes much more emissions. A concept of ZEB (zero energy building) has become increasingly popular nowadays. It refers to buildings that generate as much energy as they consume or even more. This concept envisages application of multiple solutions aimed at increasing energy efficiency together with renewable energy generation installations. Such solutions are based on the use of steel.

Application of steel in ZEB systems



Data source: Best practices guide for Steel Applications in Zero Energy Building

Solar panels. Steel is used for manufacturing solar battery frames and mounting brackets. Electricity is generated within the very building that consumes it.

Steel window systems. Steel is the most durable and wear-resistant material among those used for window structures. Steel shows 4 times lower thermal conductivity than aluminum. Hence steel windows are ideal for increased heat insulation. Window structures made of steel preserve their original appearance up to 50 years and are fireproof.

Virtually all ZEB solutions are based on the use of steel. The steel industry thus allows the development sector be more efficient in terms of resource consumption

Energy piles. Energy piles are piles with embedded steel pipes (pipeline) to integrate a geothermal heat exchanger with the piled foundation, thus using geothermal power. Energy piles also allow residual and solar power to be accumulated using the layer of soil underlying the building. This is a solution for both heating and cooling of buildings in a form of underfloor heating or ceiling cooling systems.

High-level heat insulation sandwich panels. Steel sandwich panel (steel sheets with mineral wool in-between) has a higher heat insulation value than a regular wall of equal thickness. Such structures are more lightweight too. High speed of assembly is also worth mentioning.

Radiant heating systems. Radiant heating refers to a method of heating through radiative heat transfer originating

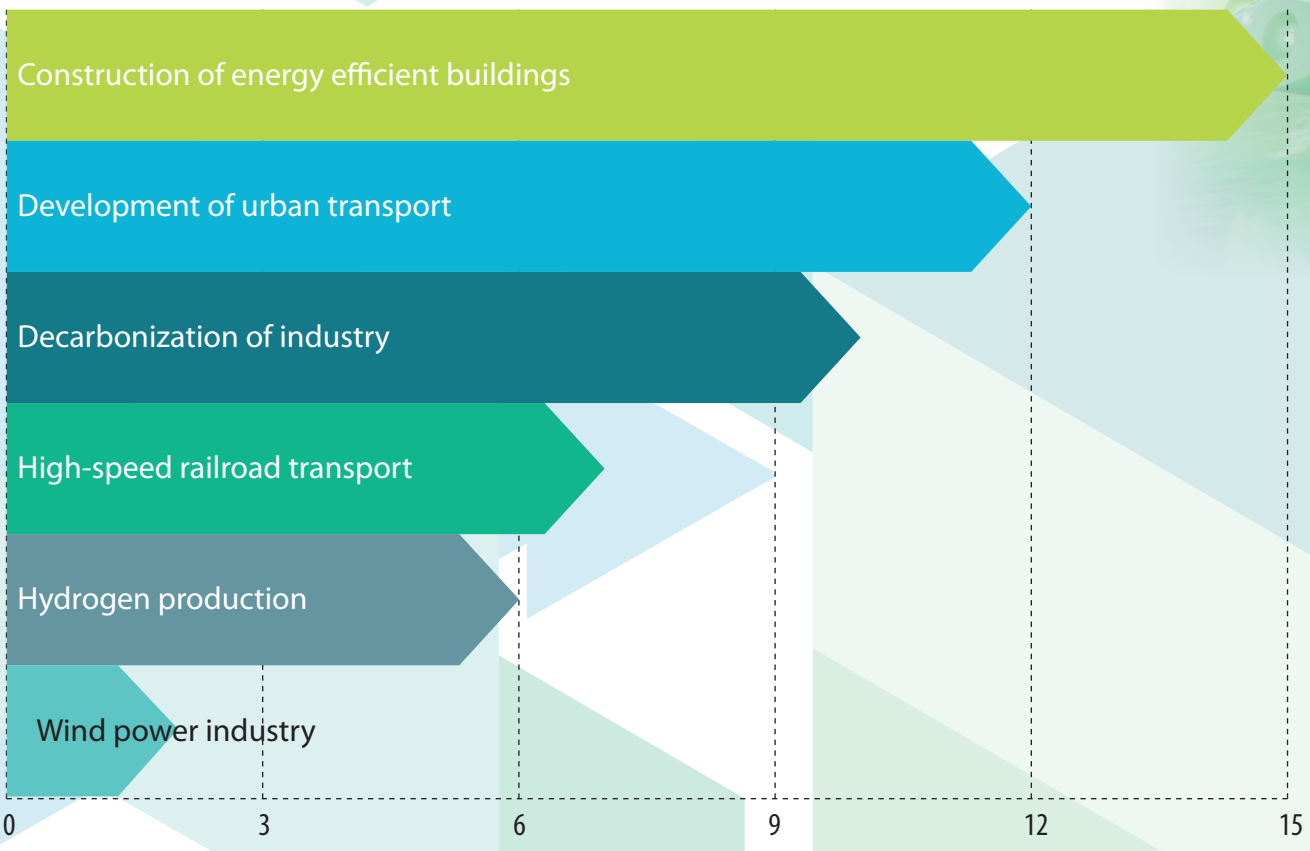
from the surfaces of ceiling, walls, floor, heated up with any heat carrier. This method uses steel pipes embedded in special wall panels. Similar systems are used for interior cooling as well.

Floor system with phase-change materials. Thermal mass smooths out temperature fluctuations by absorbing excess heat when ambient temperature is higher than the building temperature or by releasing it when it is lower. This effect is obtained through the use of special phase-change materials (PCM). A steel tank is filled with PCM thus increasing its heating or cooling capacity by 3 to 4 times.

Heat pumps. Air-water heat pumps are used for both heating and cooling of premises. Such pumps generate up to 5 kW of heating energy per 1 kW of consumed electricity. Their exterior modules collect heat from outside air, the temperature increases under pressure and is transferred to water, which heats the interior.

Indirect emissions make the bulk of a building's operational emissions. That is why an alternative way to increase energy efficiency of buildings is to develop the renewable energy sector. In other words, if buildings use green energy for their operation, then they will have zero indirect emissions. Importantly, however, investments in energy efficiency of buildings and construction of "carbon neutral buildings" will have a high macro-level return, much higher than that of renewable energy.

Quantity of new jobs resulting from $1 million investments



Data source: IEA

Each $1 million invested in construction of energy efficient buildings and ZEB allows to create 15 new jobs — a figure that other green sectors are far from: wind power generation accounts for only 2 new jobs, hydrogen production 6 new jobs, decarbonization of industry 10 new jobs. Governments will therefore prioritize stimulation of construction decarbonization as it is more profitable at the macro level.

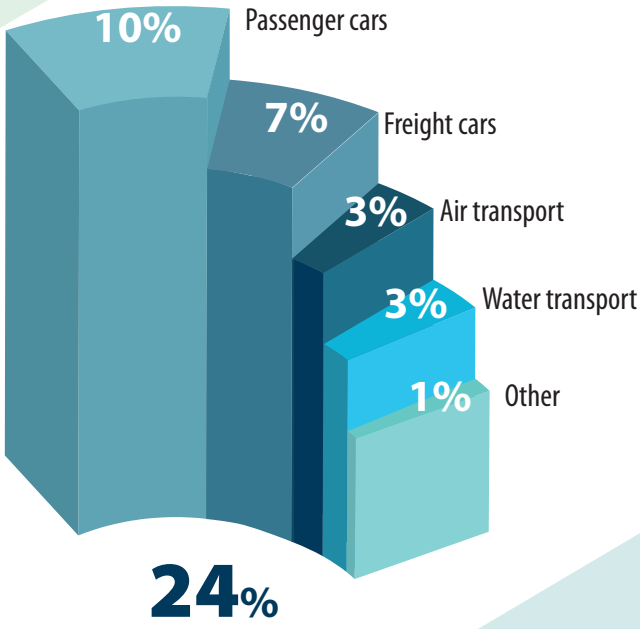
TRANSPORT

Transport was among the first sectors to experience effects and possibilities of the green transition since it accounts for 24% of global greenhouse gas emissions. Automotive transport shares the bulk of this volume, specifically 18%.

IEA forecasts a 8.5% reduction of emissions from transport by 2030. The top priority in transport decarbonization is replacement of internal combustion engines with electric motors. Steel is an essential material that is irreplaceable for the purposes of electric mobility development.

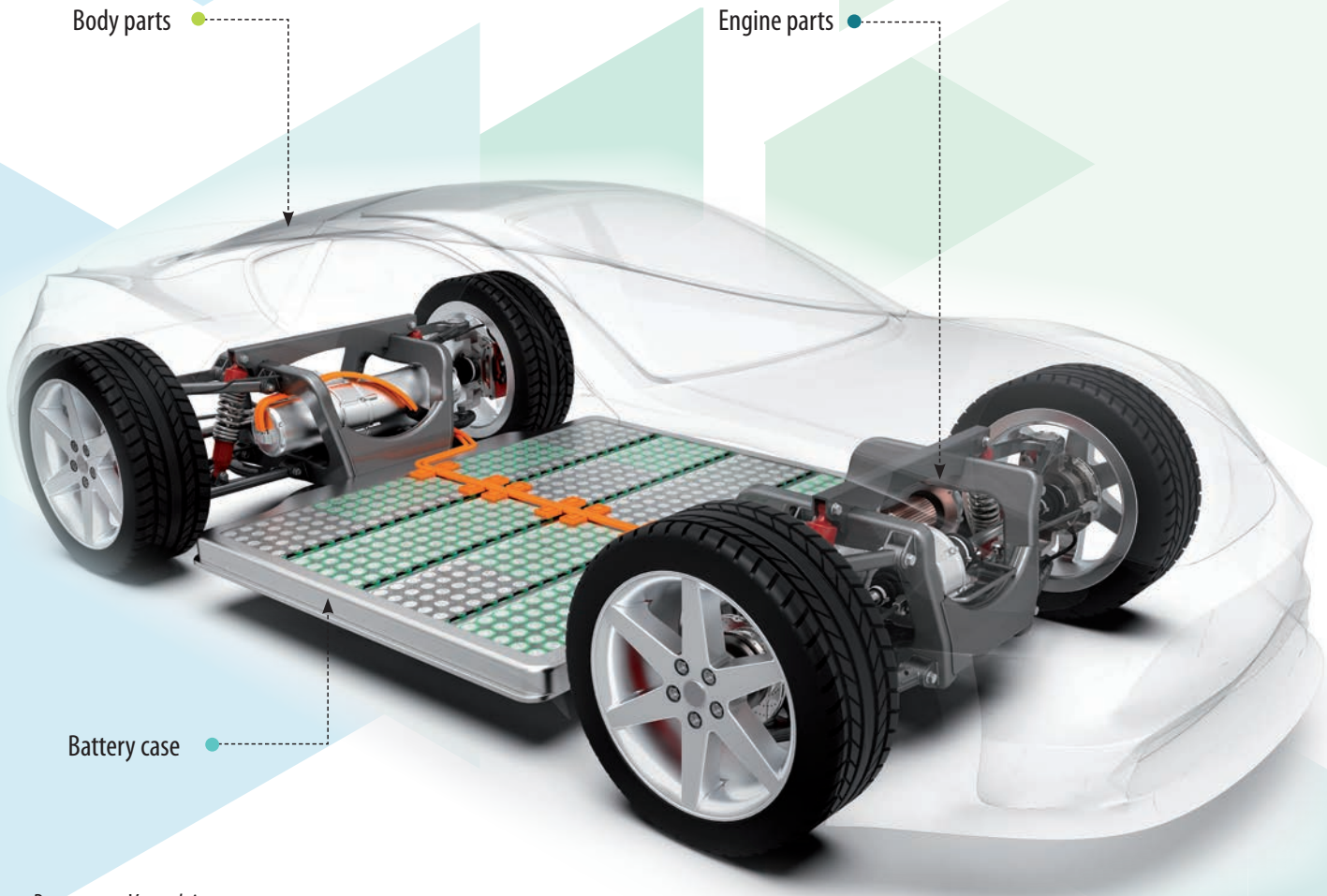
A modern battery electric vehicle (BEV) emits 30% more carbon throughout its lifecycle than an internal combustion engine (ICE) vehicle. The bulk of EV emissions are indirect emissions. That is why emission reduction differs considerably depending on the power consumption pattern

Transport's share in global greenhouse gas emissions in 2019



Data source: IEA

How steel helps enhance electric mobility



Data source: Voestalpine

Battery case. Electric battery is the key component of future vehicles. Battery cost comprises up to 50% of an electric vehicle's prime cost. Besides, battery weight is 25% of the total vehicle weight. The most important, yet contradictory problems in battery casing design are reducing their weight and at the same time increasing their safety. Weight reduction is essential for increasing running range of the vehicle. Safety refers to its strain and distortion protection in case of accident as well as fire resistance. Battery damage compromises passenger safety. But steel offers a solution to both of these problems.

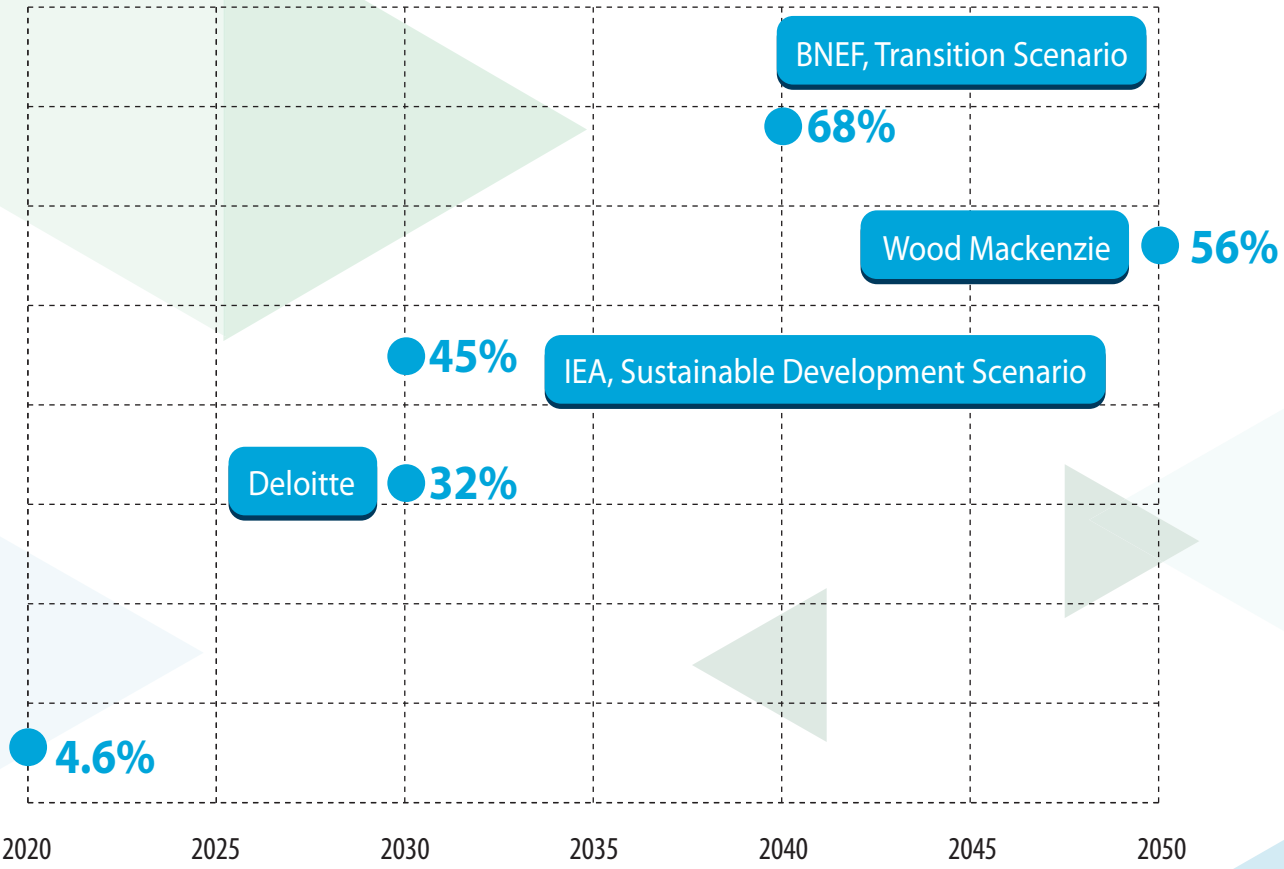
Steel is much more durable than aluminum, titanium or any other battery casing materials, so a product that features equivalent durability will be lighter and by 50% cheaper.

Steel has a substantial potential for upgrade, including weight reduction. This increases viability of steel application for the green energy transition in transport, where weight is an essential parameter of vehicles

Steel is the number one product on fire protection matters. Tests showed that for a battery case of 0.8 mm thick steel the temperature rises to 1000°C after 20 minutes on fire. It is far beyond 1.1 mm thick aluminum, which melts after only 30 seconds on fire. Battery protection means passenger safety.

Besides, even today, steel is a more environmentally compatible product with a 50% lower carbon footprint than aluminum, for instance. After all, the essence of electric mobility lies in combating climate change. That is why it is only reasonable to utilize more environmentally compatible materials.

Expected growth of the EV share in passenger vehicle sales

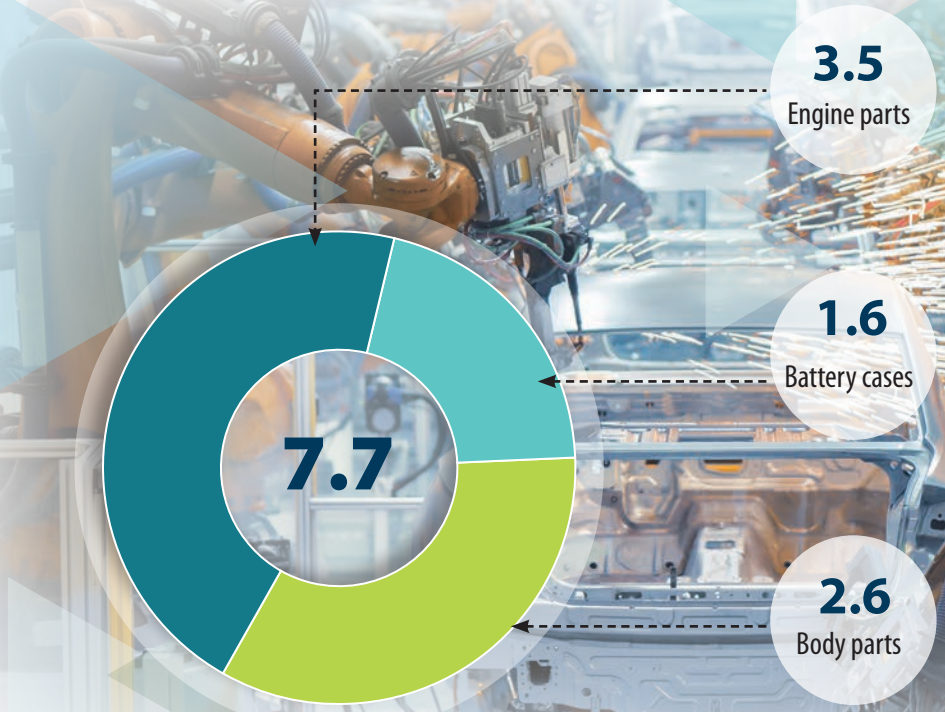


Data source: companies' data

The EV segment is the most growing one in the world and this trend will continue in future. Changes in consumer preferences as well as governmental restrains and resulting shifts in vehicle manufacturers' strategies will serve this purpose. Consequently, this will induce growing demand for steel.

Even today, steel is a more environmentally compatible product with a 50% lower carbon footprint than aluminum. The objective of electric mobility expansion is combating climate change. The use of steel for vehicle manufacturing will therefore be a matter of priority

Growth in demand for steel for vehicle manufacturing in 2050, million tons



Data source: Voestalpine, GMK Center estimations

According to the estimates made by Voestalpine, added demand for steel among global vehicle manufacturers in 2050 will reach 1.6 million tons for EV battery casing and 2.6 million tons for body parts. As estimated by GMK Center based on the data of average steel consumption for electric motor production, added steel demand in the electric motor segment in 2050 will total 3.5 million tons. So, total steel consumption for electric vehicles will increase by 7.7 million tons by 2050, which might seem insignificant, but it's actually a good result, considering the expected weight reduction of future vehicles.

Decarbonization opportunities for other means of transport

A considerable portion of global greenhouse gas emissions, i.e. 7%, accrues to **road freight transport**. However, decarbonization of this sector presents some specific difficulties. Today, there are almost no electric motor vehicles in the global truck fleet. Still, a range of large carriers, retailers, mail companies have declared their transition to electric vehicles by 2040–2050. Furthermore, IEA assumes that 57% of reduced emissions from motor trucks will be linked to use of electricity and hydrogen. Steel applications related to green transition in the motor truck sector are similar to those for the passenger vehicle sector. But electrification of freight transport is a long term outlook.

As for **air transport**, almost every aircraft is powered by kerosene, which is a petroleum-derived product. Air transport is thus an emitting sector with a 3% share in the total amount of emissions. Emission reduction prospects in this sector are solely associated with alternative fuels, namely synthetic fuels and biofuel. Decarbonization of this sector is less dependent on steel.

Water transport is the most environmentally compatible means of transport. In spite of that, maritime fleet is nearly totally comprised of ships that use petroleum-derived fuels and is therefore carbon intensive. 3% of global CO2 emissions accrue to water transport. A number of standards are in place to limit emissions in this sector. For instant, the IMO standard envisages reduction of greenhouse gas emissions from water transport by 2050 by 50% of their 2008 level. Decarbonization of water transport is largely associated with increasing fuel efficiency and utilizing alternative fuels, such as biofuel. This is why water transport will create an added demand for steel in such sectors as energy and mechanical engineering.

Advancement of **high-speed railroad transport** itself does not require decarbonization, but is instrumental for electric mobility, which, in its turn, facilitates emission reduction in other sectors like road transport and civil aviation. Advancement of railroad transport is a highly metal-intense area requiring infrastructure adjustment, rolling stock manufacturing, etc. Advancement of high-speed railroad transport will result in development of tourism, regional economic growth, emission reduction and growing demand for steel.

Development of electric mobility and new means of high-speed electric transport is also based on usage of steel

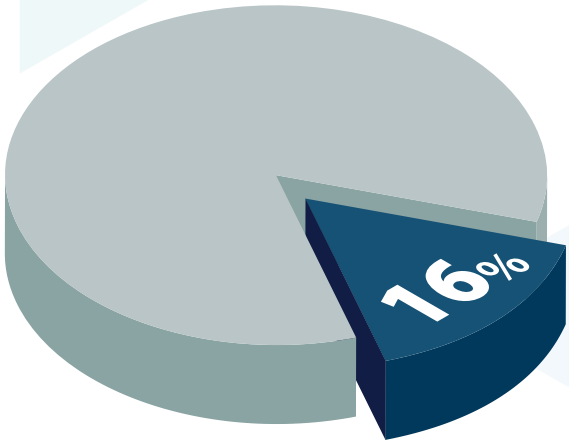
MECHANICAL ENGINEERING

Mechanical engineering plays a key role in the green energy transition for the latter requires reforming entire sectors of economy, including electric power industry, mechanical engineering, chemical, cement industries, etc. Consequently, new equipment will be required, such as CO_2 capture installations, green hydrogen electrolyzers, innovative heating, cooling, and air conditioning systems, CO_2 disposal and biofuel production equipment, etc.

Mechanical engineering is one of the largest steel consumers in the world. Steel is the key construction material for machinery and equipment, including those related to reduction of CO_2 emissions. Decarbonization of economy is impossible without steel.

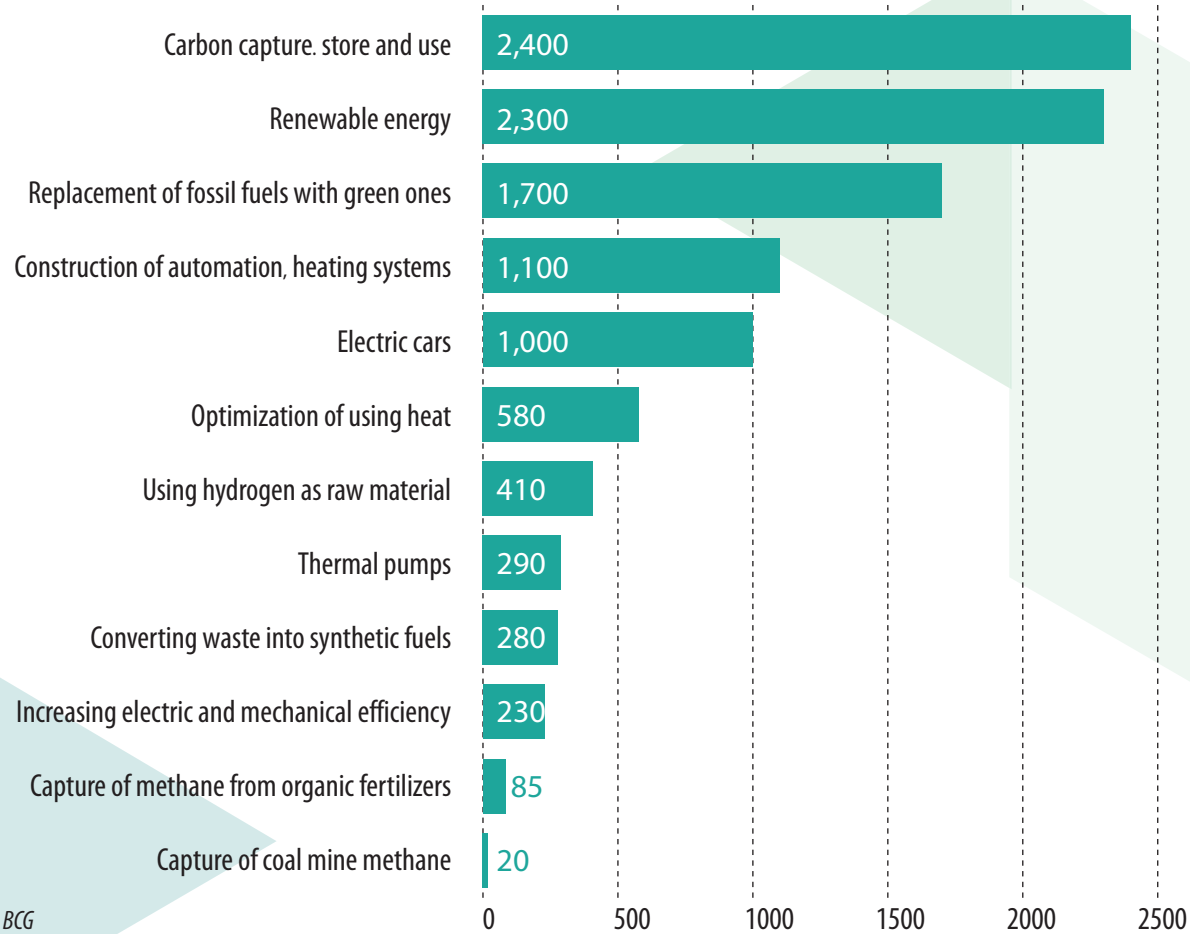
As estimated by BCG, supplies of equipment incorporating best available technologies can reduce global CO_2 emissions by 13 Gt (37% of total emissions). Improving the existing technologies and introducing new ones can further reduce global CO_2 emissions by another 17 Gt (49% of total global emissions).

Share of mechanical engineering in global steel consumption in 2019



Data source: Worldsteel

Cumulative investments in greenhouse gas emission reduction by 2050, € billion



Data source: BCG

BCG experts see the highest potential for greenhouse gas emission reduction in application of carbon capture, store and use, advancement of renewable energy generation, substitution of fossil fuels with green ones, and expansion of electric vehicle fleet. Accordingly, the same areas will require the largest investments.

Prospective implementation horizon varies from technology to technology. Active development of the renewable energy sector appears to be the most realistic for the nearest future. These technologies are regarded as the most advanced and ready-to-use ones.

Electric transport development depends on battery design innovations and deployment of charging station networks. This is the reason why, although electric vehicles are already available on market today, their further advancement is suppressed by external factors.

Substitution of conventional fuels with green ones as well as carbon capture, store and use is a distant prospect. That requires further research, scaling of available technologies, manufacturers' preparedness to re-engineering of business processes.

Green energy transition requires a total technological overhaul with subsequent replacement of equipment. Steel is the key construction material for machinery and equipment. That is why decarbonization of economy is impossible without steel

It is apparent that decarbonization of economy will proceed in a staged manner. Each stage will require specific technologies. That is why the demand for mechanical engineering products is bound to change, and machine builders will be forced to reorient themselves in accordance with the customers' needs.

122

million tons

of steel will be required to produce decarbonizing equipment in 2020–2050

Specifically, use of hydrogen for various purposes (for power storage, as a fuel for transport and raw material in industry) is regarded as a promising trend. Large-scale introduction of hydrogen into industrial processes will be possible after 2030 and requires solutions to a number of challenges related to construction of commercial-scale electrolysis plants as well as availability of green electricity.

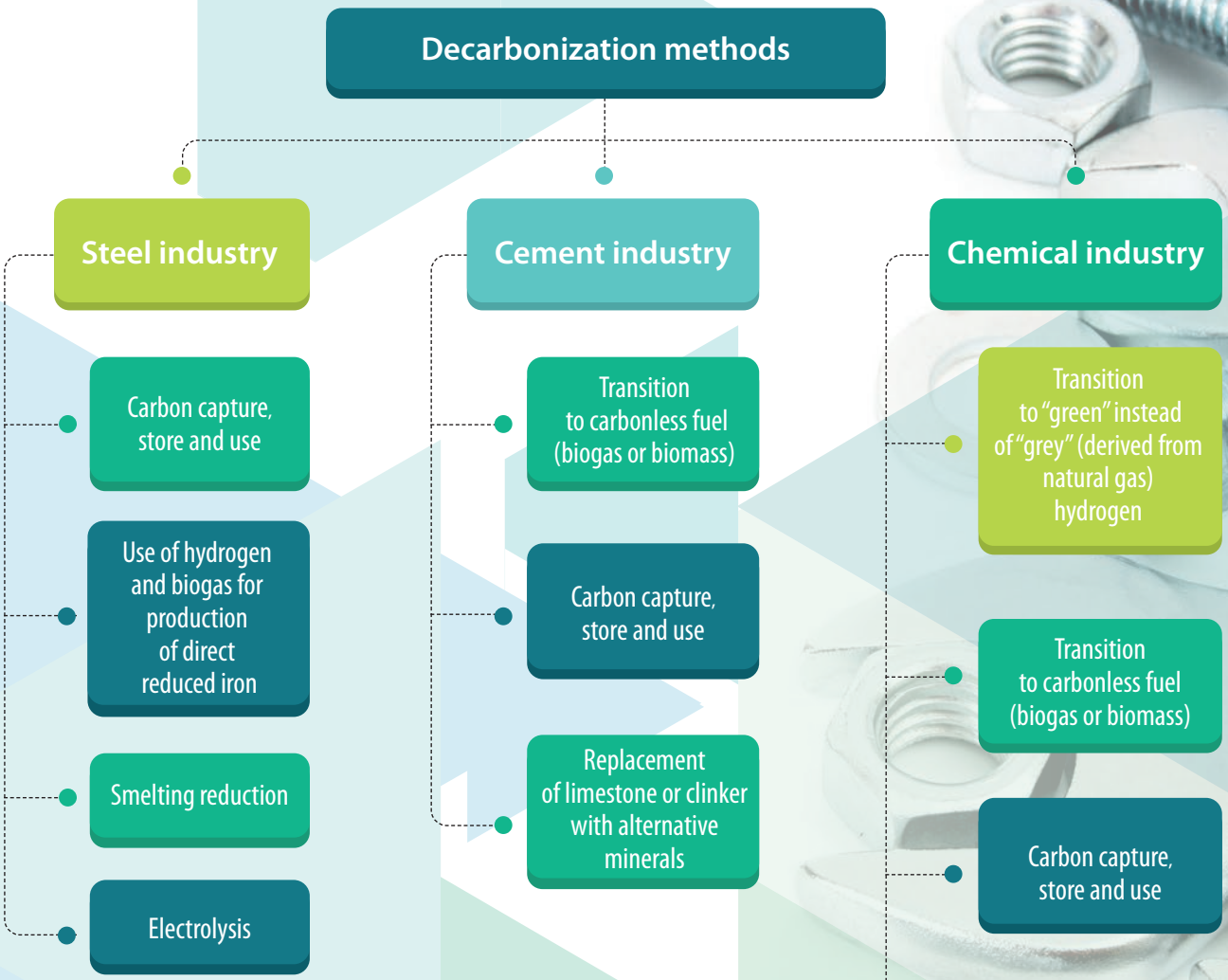
According to BCG, decarbonization of the global economy will require €10 trillion in equipment investments by 2050. Ultimately, these investments will shape the demand for mechanical engineering products. It is a favorable opportunity for machine builders to contribute to greenhouse emission reduction while maintaining the demand for steel products.

As estimated by GMK Center, depending on amounts of potentially promising investments into decarbonizing equipment, machine builders will use a total of 122 million tons of steel in 2020–2050. This steel will be employed to secure green transition in all sectors of economy.

OTHER SECTORS

The highest CO_2 emissions among industrial sectors accrue to the steel industry (6.0% of the global volumes), cement industry (6.6%), chemical and petrochemical industry (3.9%). Decarbonization of these sectors is important for the green energy transition and has certain common features.

Green transition in specific industries



Most decarbonization methods require either new equipment or modernization of the existing one. Specifically, the use of biogas or biomass as fuel in the cement industry is only possible if the currently operating kilns are redesigned. New equipment is required for CO_2 capture, green hydrogen production, plastic recycling. Use of biomaterials as raw material in the chemical industry can result in transformation of conventional production technologies.

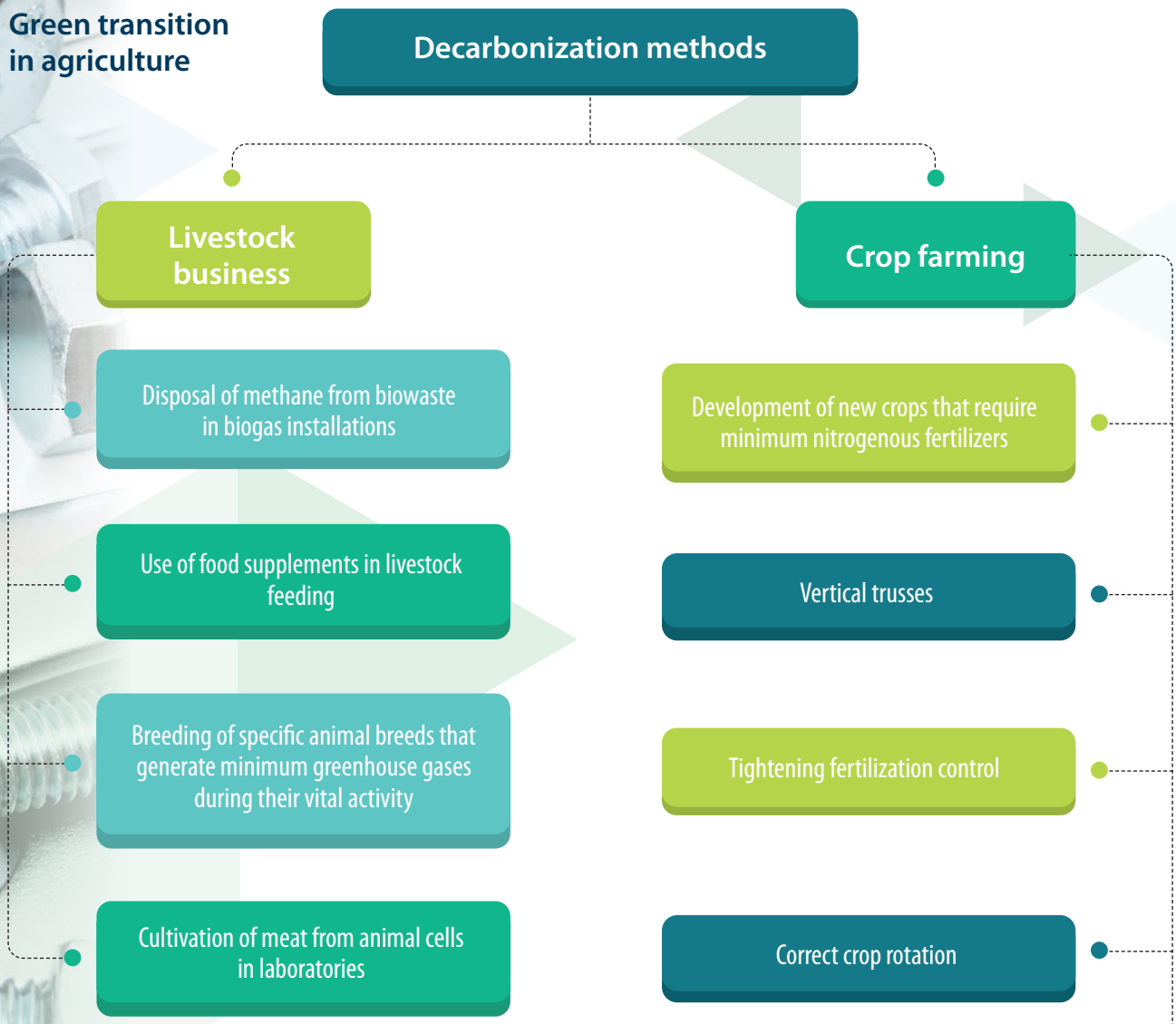
The core construction material for equipment is steel. For these reasons the steel industry itself requires decarbonization for one part, and for the other part decarbonization of other sectors depends on the steel industry.

Decarbonization of cement, chemical, and other industries will create additional demand for steel. Steel will therefore define the future of these sectors and the entire economy.

Decarbonization of agriculture is usually given unfairly overlooked while according to the estimates made by the International Panel on Climate Change, agriculture together with forestry and other land tenure generates 24% of global greenhouse emissions. Decarbonization in agriculture is generally deemed to include prevention of methane (CH_4) and nitrogen oxide (N_2O) emissions as well. Methane is a major pollutant in livestock business. As estimated by FAO, it accounts for 50% of the sector's greenhouse emissions (the remaining 50% are shared between N_2O and CO_2).

The steel industry itself requires decarbonization for one part, and for the other part decarbonization of other sectors depends on the steel industry

Green transition in agriculture



Decarbonization of agriculture is based on its own unique approaches that are not suitable in other sectors. However, it still requires new equipment like biogas units or vertical trusses (automatized racking complexes for multilevel plant cultivation through hydroponics and aeroponics). That is why decarbonization of agriculture is unimaginable without steel. Steel is a basis for new agricultural equipment and new agricultural production facilities.

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