Application of Renewable Energy Sources in Powering Equipment and Machinery

Spis treści

Abstract: Contemporary aspirations to reduce global warming are resulting in the more and more widespread application of Low Carbon and Renewable Energy Sources (RES). The pace of this process has been further accelerated by the COVID-19 pandemic and the drive to make the economy more competitive and innovative. The article shows a cross-section of the plans, opportunities and statistics of RES implementation into the global energy mix, both in macro-scale form and from the point of view of distributed installations. It also focuses on the implementation of RES within the equipment and machinery, transportation and widely understood industry.

1. Increasing importance of Renewable Energy Sources

Contemporary climate change, never before seen naturally on such a scale, is collectively referred to as global warming. According to Knutsen et al. more than 50% of the global temperature increase since 1951 is to be attributed to human activity. These are the most conservative estimates, as many studies put this share at more than 90%. As Lynas et al. points out, there is no dispute in the scientific community about the anthropogenicity of global warming. As of 2021, more than 99% of peer-reviewed scientific papers on the subject point to arguments supporting this thesis. Interestingly, as Supran et al. points out, awareness of this fact has not been questioned for years (at least since the 1960s) even in the fossil fuel extraction and processing and automobile manufacturing community. For example, the predictive accuracy of ExxonMobil's internal climate models can be estimated at 63% - 83%. Their estimated temperature increase of about 0.2°C every decade since 1970 coincides with values obtained by independent scientific studies. This makes one wonder about the motivation behind the long-standing denial and then downplaying the effects of global warming in the official statements of these companies (an extensive analysis of this phenomenon is presented in the material).

Anthropogenic global warming is by no means solely due to carbon dioxide emissions. As Howarth et al. point out, energy based on the combustion of natural gas is also a factor. Its main component is methane, which can accumulate 84 times more heat per unit mass than CO2. Although the latter lasts much longer in the atmosphere (300 to 1,000 years, compared to about 10 years for methane), Howarth et al. estimate that for shale gas, methane emissions during the extraction process have a greater impact on global warming than CO2 emissions from burning the gas; and shale gas exploitation itself has a larger carbon footprint than the use of coal (by about 20%) and oil. The cited analyses affect the need for changes in thinking about the use of shale gas (e.g., in the US) and natural gas (e.g., in the EU) as a so-called “transition fuel” between coal- and oil-based energy and the widespread use of Renewable Energy Sources (RES). For the European community, the large-scale use of natural gas poses an additional problem in the context of the conflict in Ukraine. As recently as 2021, 25% of oil, 20% of coal and 37% of natural gas came from Russia (cf.). The sanctions, imposed on the country for triggering the war, have prompted a search for other energy imports, reminding us of the importance of energy independence and resulting in the European REPowerEU initiative (cf.).

Renewable energy sources are also driving economic change. The European Council’s Fit for 55 package includes legislative proposals aimed at updating and unifying existing EU legislation and initiating new initiatives on the topic of RES. 42% of the budget (more than €5.7 billion) of the Horizon Europe research initiative for 2023 - 2024 is earmarked for achieving key climate action goals, finding innovative solutions to reduce greenhouse gas emissions and adapt to climate change. A report by think tanks E3G and EMBER (cf.) indicates that from March to September 2022, 24% of electricity generated in the EU came from RES, reducing natural gas imports by about 8 million m3, leading to savings of about €11 billion. A report by the International Renewable Energy Agency (IRENA, cf.) indicates a rapid decline in the price of energy generated by RES. As of 2021, the LCOE (Levelized Cost of Energy) of hydropower and wind power were 11% and 39% lower, respectively, than for conventional power.

The growth of RES is a fact, regardless of whether it is caused by global warming, the desire to become independent from imports of energy resources or the need to increase innovation and competitiveness of the economy. It should be expected that with the development of RES technologies and energy storage methods, the share of RES in the global energy mix will steadily increase.

2. Renewable Energy Sources - classification, statistics and challenges

The group of renewable energy sources includes all energy sources the renewal of which occurs naturally on time scales close to or shorter than the human lifespan. According to the definition adopted by the EU, RES include “energy from non-fossil renewable sources, namely wind energy, solar energy (solar thermal and photovoltaic energy) and geothermal energy, ambient energy, tidal, wave and other ocean energy, hydropower, biomass and gas from landfills, wastewater treatment plants and biological sources (biogas).”

According to the BP Statistical Review of World Energy report, 80.2 EJ (13.5%) of the energy consumed globally in 2021 came from RES, including 40.3 EJ from hydropower alone. RES provided 27.8% of the electricity consumed during the period, thus ranking behind the dominant coal power (36.0%) and ahead of gas power (22.9%) and nuclear power (9.8%). Hydropower alone provided 15.0% of electricity during this period, indicating the high advancement and popularity of this technology. However, between 2011 and 2021, global hydroelectric power generation increased by only 1.5% (down 1.8% in 2021 alone), and other RES - by 12.6% (up 15.0% in 2021 alone). The rapid growth of solar power (up 22.3% in 2021) and wind power (17.0%) is driven by technology development and economies of scale, resulting in cost reductions. Against this backdrop, other RES technologies (primarily geothermal and biomass) are far less important, with an 8.7% year-on-year increase in 2021, resulting in a 20.8% share in the RES mix. However, the development of biogas-based power generation is particularly interesting, especially in countries with relatively intensive agricultural activity, such as France, Germany and Poland.

The document Energy Policy of Poland until 2040 is an important tool, shaping the energy mix in Poland. It identifies hydrogen and energy storage technologies, as well as smart energy management and electromobility as the main directions of energy technology development. The policy is aimed at reducing the share of coal in electricity generation to 56% in 2030 and introducing nuclear power into the national energy mix, but also making RES play an important role in the Polish energy policy. Their share in gross final energy consumption is expected to rise to a minimum of 23% by 2030. The lion's share of the energy after the transition is to be provided by photovoltaics (installed capacity of 10 - 16 GW in 2040) and offshore wind power (11 GW). Unfortunately, these ambitious RES targets are not matched by specifics on the important aspect of power grid balancing and energy storage. The relatively vague provisions and lack of a quantified target make one question the possibility of realizing a fair and credible energy transition.

The rapid pace of RES technology development and its potential risks are well illustrated by the aforementioned offshore energy industry. According to the IRENA report, LCOE fell by about 60% between 2010 and 2021, and while it remains more than twice as high as for onshore wind farms, the cost-effectiveness of these solutions can be expected to increase further. It is significant that the relocation of wind turbines offshore, away from human settlements, brings additional benefits: it reduces the risk of accidents involving bystanders and does not result in a reduction in the value of surrounding land. At the same time, offshore energy generates advanced engineering problems. Researchers at the University of Maine identify among them, first and foremost, the effects of waves and fatigue loading on horizontal and vertical axis turbines. Other problems also include cable and port infrastructure and anchoring wind turbines in the seabed. In the latter case, underwater drilling can lead to increased acoustic emissions, resulting in the need to develop specialized protection, such as bubble curtains. Their role is to absorb and attenuate acoustic energy. Opponents of wind power try to point to the impact of such emissions on increased whale mortality, but this is refuted by specialists, who point to increased maritime traffic as the main source of the problem. A real-world example of the interaction between offshore energy and the environment is bird migration. On May 13, 2023, the

Dutch wind farms Borseele and Egmond aan Zee were halted for four hours to allow birds to migrate over the North Sea. To reduce the risk of collisions, research is being conducted on painting individual rotor blades black to increase their visibility during the day.

In summary, the RES power industry encompasses a wide range of technologies with varying degrees of advancement and reliability. Observation of past trends and ongoing research make it possible to forecast a further decrease in the LCOE of these solutions while increasing their reliability, leading to their even greater competitiveness and presence in the global energy mix.

3. Renewable Energy Sources in Practical Applications

According to the data cited above, the integration of RES in energy systems is - on a smaller or larger scale - a global daily reality, especially with regard to electricity generation. This study will focus on the use of RES as directly as possible, to power equipment and machinery. For the purposes of the article, this is assumed to include transportation and technological machines, performing specific tasks using a driving machine.

1) RES in the propulsion of transport machinery

According to the REN21 report, the transportation sector's share of global end-use energy demand is almost 1/3 and growing rapidly (by 7.8% in 2021). At the same time, it is one of the sectors least penetrated by RES (4.1% in 2020), which is almost exclusively (about 88%) limited to biofuels. 78% of energy consumption in the transportation sector is attributable to road transport, 11% to maritime transport, and 8% to aviation; a similar percentage breakdown covers CO2 emissions. DNV report summarizes major prospects for transportation development in terms of RES:

- Electrification wherever possible,

- Replacing fossil fuels with biofuels,

- Preparation for widespread introduction of hydrogen technologies.

2) Electrification of the transport sector

According to DNV forecasts, 23% of the transportation sector's energy needs in 2050 will be met by electric vehicles (EVs). It will power 80% of land vehicles, but only 4% of maritime traffic and 2% of air traffic. This is due to much easier access to charging points for cars and trucks, but also less emphasis on energy density than in aviation and energy requirements than in maritime transport. 70% of trucks in Europe travel less than 250 kilometers in a single trip, so their electrification should pose no problems. Trucks used in international long-distance transportation seem more difficult to electrify, but in this segment fast charging solutions such as Megawatt Charging System (MCS) and/or battery swap stations on transit routes are being developed.

The main challenge for the development of the electromobility sector is the investment costs, which are currently significantly higher than in combustion technologies. Subsidies, which aim to generate economies of scale that will make prices fall as EV popularity increases, are important in this case. Other significant factors are the education of society and popularization of the technology. As the Tesla Powerwall example shows, electromobility can be an important link in prosumer RES systems. The experience of the electric car manufacturer was used to design an energy storage facility that can be part of a prosumer home installation. The use of micro-sources in this case, such as small wind turbines or a home photovoltaic installation, makes it possible to significantly reduce transportation costs, especially in urban areas. The production of electricity from RES for own transportation needs also reduces the need for chargers, the installation of which, by the way, is very challenging due to very high power requirements.

3) Modern biofuels

Clearly, the prospects for widespread electrification are not viable in regions where there is no adequate infrastructure for electricity production and distribution. In such places (e.g., some countries in sub-Saharan Africa or Latin America), the preferred solution is to replace conventional fuels with biofuels, especially third and fourth generation. Currently, the most popular biofuels (in terms of production) in Europe are vegetable oil-based biodiesel (80%), while in the US it is corn ethanol (70%). However, these so-called first-generation biofuels use edible or forest biomass, which is met with criticism regarding the sustainability of energy and consumer crops and extensive exploitation of forest resources. High hopes are thus placed on biofuels produced from algae (e.g. biodiesel, bioethanol, biogas, depending on the processing method). These plants can be grown on non-agricultural land, in wastewater, in collectors and hybrid systems. Thus, they do not have to compete with consumer crops, and the size of the culture is relatively simply scalable. A step further are fourth-generation biofuels, which include so-called artificial photosynthesis technologies. These include organisms (algae, cyanobacteria) that are genetically modified and produce biofuel based on water, CO2 and solar energy. A related class of solutions is synthetic fuel produced from solar energy converted to chemical energy, usually by reducing protons to hydrogen or carbon dioxide to organic compounds. The fourth generation of biofuels is also e-fuels, storing electrical energy in the chemical bonds of liquids (butanol, biodiesel) and gases (methane, butane).

The common denominator of all the technologies described, however, is the cost, even resulting in calls to “cut out” this branch of energy altogether. In 2023, biodiesel prices in Europe were about 70% to 130% higher than diesel, while bioethanol prices were about 50% to 100% higher than gasoline prices. Despite years of research and pilots, the development of efficient and cost-effective processes for growing, harvesting and processing algae into fuel is still at an early stage. Fourth-generation biofuels, on the other hand, are still mostly scientific concepts. It seems, however, that biofuels will continue to be an important means of increasing the share of RES in transportation for many years to come, especially in regions where other solutions may not be applicable on an ad hoc basis.

4) Hydrogen technologies

In the atmosphere, hydrogen is a flammable gas and its energy use is associated with significant costs as well as process/technology complexity and challenges in terms of efficiency and safety. On top of that - it has traditionally been produced by means of coal and gas, with the release of CO2 (so-called gray hydrogen). Today, the vast majority of production takes place at or near key industrial consumers.

However, thinking about hydrogen is changing significantly as its importance as an energy store increases. Hydrogen can be produced in several ways, with varying efficiency, greenhouse gas emissions and environmental impact, depending on the method and feedstock used. The use of CO2 capture and storage (CCS) technology makes it possible to produce so-called “blue hydrogen” from fossil fuels, without emitting greenhouse gases. Green hydrogen, on the other hand, is produced using RES energy, most often by electrolysis. Due to the relatively low energy density of hydrogen gas, liquefaction or further processing, such as into ammonia, e-methanol and e-kerosene, is preferential. However, the use of such transition fuels or direct combustion of hydrogen in fuel cells on a large scale is still a distant prospect, requiring appropriate infrastructure and production methods - as of 2023, blue and green hydrogen account for less than 1% of the total production of this fuel. In 2021, the number of fuel cell hydrogen electric vehicles was 51600 units, 82% of which were cars. Advances in fuel cell technology have now made it possible to increase the range of vehicles to around 1,500 kilometers and faster refueling. The PRC leads the way in hydrogen technology, where the majority of the hydrogen fleet is buses and trucks, using a network of 146 charging stations (as of 2021). Blue and green hydrogen are also touted as viable ways to decarbonize maritime and air transportation.

5) Other RES technologies in the transportation sector

In recent years, there has been a lot of interest in the application of wind energy to maritime transportation. Sailboats are a solution that has been used for decades in sailing, especially sports sailing, such as the America's Cup Regatta. The use of this solution in industrial marine transportation is proposed by Oceanbird. The proposed RO-RO ferry will have a capacity of about 7,000 cars, about 220 meters long, 40 meters wide and 70 meters high above the water. The ambition is to start sailing in early 2027. Another way of partially harnessing wind energy are so-called rotorcraft, using Flettner rotors: rotating cylinders that produce lifting force when air masses move (Magnus effect). An example is the 10000-ton E-Ship 1, which has 4 rotors 27 meters high and 4 meters in diameter, achieving fuel savings of 30 to 40 percent at 16 knots.

Solar energy has been considered for use in aviation. At high altitudes, photovoltaic cells can achieve greater efficiency due to reduced atmospheric interference. However, such concepts have not currently progressed beyond the concept stage, such as SolarFlight, and solar propulsion seems to be of little benefit from an aerodynamic point of view - the area of photovoltaic panels would require a significant increase in wing area, which would translate into a drastic increase in drag. However, this solution can be a flight support for aircraft powered by battery electricity.

6) RES in powering conversion machinery

Industry is one of the most important sectors of the economy: in 2021 it was responsible for generating about ¼ of global GDP, ¼ of CO_2 emissions, and 1/3 of final energy consumption. The most energy-intensive sectors are the steel and chemical industries; together with the cement and petrochemical industries, they also account for about 70% of industrial CO_2 emissions. In industrial applications, the main form of energy is process heat, accounting for about 75% of consumption. Other areas of use include powering equipment and machinery and also non-manufacturing activities (such as lighting). As of 2020, 16.8% of the energy consumed by industry came from renewable sources - such as through the use of waste biomass in the paper industry or the exploitation of geothermal sources.

A key buzzword of the green transformation in industrial issues is, as in transportation, electrification. This trend is primarily concerned with the production of low- and medium-temperature heat (e.g., in food processing or the pharmaceutical industry), but also with high-temperature heat (e.g., through the use of arc furnaces in the steel industry). In 2022, steelmaker ArcelorMittal invested in wind and solar power plants in Argentina and India, while steelmakers (GMH Group, Salzgitter) and cement producers (Cemex, Suez Cement, Lafarge) and chemical companies (BASF) are signing long-term power purchase contracts with RES operators. Due to the relatively high initial cost of RES investments, their application in the Small and Medium Enterprise (SME) sector is often a great financial burden. As a result, many countries are expanding their decentralized RES financing programs to include SMEs. An example is Chile, which in 2021 expanded its prosumer philosophy support program to include SMEs, and a new French climate action loan supports the energy transition of SMEs.

Interesting initiatives for decentralized RES projects have been developed by some mining companies in Australia, Madagascar and Mali. They provide reliable and affordable energy to both mines and local communities. As a result, they are providing electricity in areas previously mostly excluded from energy supply. Industrial symbiosis and eco-industrial parks are other concepts rapidly gaining popularity. Their idea is based on grouping industries into resource-efficient industrial parks, which are more competitive, risk-resistant and attractive for investment. By integrating the generation of low-cost energy and heat from RES within such a cluster, industries can share energy and material streams.

The production of energy (including electricity) from RES in industry is based primarily on biomass. Its share in the energy mix increased by 46% between 2011 and 2021. In the paper industry, Sappi has replaced coal-fired boilers with biomass-fired ones, and Stora Enso has announced the replacement of fuel oil with renewable packaging oil. The use of biogas can be found mainly in the food sector, where several leading manufacturers operate anaerobic digestion plants to generate heat and electricity for factories. In 2022, Danone pledged to increase its use of biogas (as well as solar and biomass) as part of its decarbonization plan, and in 2021 Unilever and Starbucks joined the US Biogas Alliance. In the chemical industry, biochemicals such as methanol can be used as key substitutes for oil in the decarbonization process.

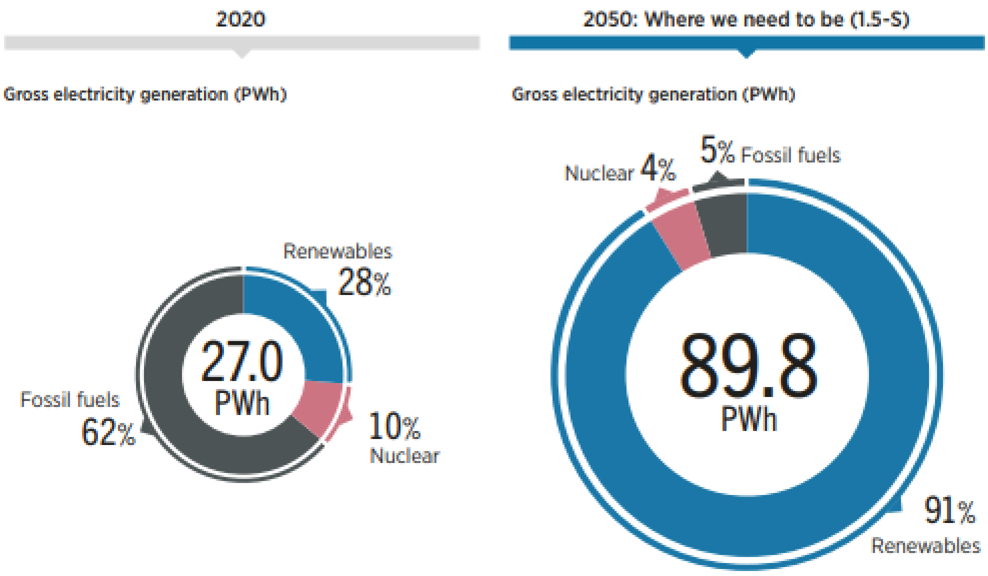
In industrial decarbonization and electrification processes, especially petrochemicals and metallurgy, green hydrogen raises high hopes. However, its applications are still limited due to high production costs and the need for related infrastructure. In 2022, the REPowerEU plan approved two major projects of common European interest to integrate green hydrogen into industrial steel, cement and glass production processes. The production of high-value-added products, such as renewable ammonia (or steel), for domestic and export use is seen as a way to sustainably industrialize EU countries and increase the use of renewable hydrogen in Africa, especially in Southern Africa, Egypt, Kenya and Morocco. Green hydrogen is also being targeted by leading steelmakers from Europe and China. The city of Tangshan announced in 2022 that it intends to become a hydrogen production center and support local steelmakers in using iron from direct hydrogen-based ore reduction. Most of the hydrogen will be produced using coke oven gas, but solar power plants will also be built to produce renewable hydrogen.

Regarding process heat production, solar thermal (heat energy from the sun) and heat pumps also play an important role. On the basis of the analysis presented, however, it should be noted that the use of RES in industry varies considerably depending on the specific subsector and the specifics of the processes and technologies it uses.

4. Summary

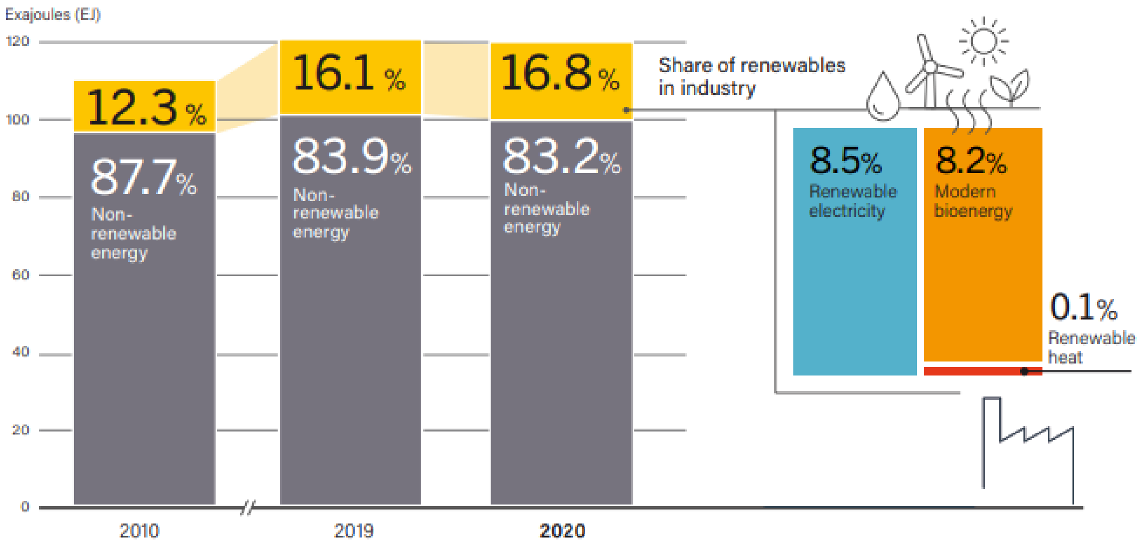
The demand for decarbonization of the economy is nothing new, nor are the scientific theories explaining its need. However, it is crucial not only to carry out the green transition process quickly, but also responsibly and sustainably. It requires the use of Renewable Energy Sources, as well as possibly putting them into clusters involving several types of equipment and energy storage systems. Although the widespread use of RES in the global energy mix is becoming a reality, the demand for 100 percent decarbonization of energy processes still seems a long way off. To achieve this goal, it will be necessary in the future to think of industry and energy as two symbiotic organisms, just as prosumer energy is thought of today.

FIGURE 5 **Power generation needs to more than triple by 2050**



Notes: PWh = petawatt hours.

FIGURE 7.
Renewable Share of Total Final Energy Consumption in Industry, 2010, 2019 and 2020



Note: Modern bioenergy includes heat supplied by district energy networks.
Source: See endnote 7 for this module.

Zero waste ideology in the context of robotics and automated production

There is no doubt that the world is facing several environmental crises – pollution, excessive waste of energy and resources with too many products simply being thrown away and discarded at the end of their lifecycle. Wasting energy and materials and then producing or extracting them to make even more products is not only unsustainable, but also depletes the world's capacity to provide more resources and absorb the waste we produce. This suggests the need for a circular economy - one that uses waste and discarded products and materials as valuable resources, allowing us to reduce the amount of virgin material we need to extract, process and transport.

Extended service life

Thanks to the repetitiveness of their work, robots play an important role in reducing material waste. As a result, robot sales are steadily increasing worldwide, with the latest report from the International Federation of Robotics (IFR) identifying 2021 as a record year, with a record number of more than 500,000 new industrial robots installed in factories around the world.

This growth is an encouragement for robot manufacturers such as ABB, Staubli, Kuka, Mitsubishi and others, and the use of robots undoubtedly brings huge benefits to users - but what happens at the end of a robot's lifecycle?

ABB's drive to ensure the long-term sustainability of its robots starts at the design stage, with some ABB robots in use for more than 35 years. For example, the Swedish engineering company Magnussons received its first ABB robot in 1974. After 42 years of continuous operation, this robot only stopped working when the company closed its production facility in 2016.

ABB offers several solutions to extend the life of robots, such as data-driven services that enable users to take actions that maximise the life of their robots. These services include preventive maintenance, condition-based maintenance (CBM) and Connected Services.

The CBM service enables customers to understand which robots are under the most stress. In industry, this service helped a large automotive manufacturer identify the most stressed robots in its plant, developing preventive maintenance measures to help 280 robots continue working until 2035, despite having already accumulated 25,000 production hours.

Giving robots a second life

When a robot reaches the end of its useful life, ABB offers a remanufacturing and buy-back service where products and components are reused or recycled. Typically, between 60 and 80 per cent of the robot can be reused, while the rest is sent to certified recycling partners. For example, almost all ABB robots used in the automotive industry are given a second life and a fifth of them even a third.

ABB's six remanufacturing centres in Asia, Europe and the US pick up around 250 robots a year, giving them a second life with new or the same customers.

Before being labelled as an ABB-certified remanufactured robot, each used unit undergoes rigorous checks, including a detailed inspection and at least a 16-hour functional test. Each remanufactured robot comes with a two-year warranty and can be upgraded to work with the latest controller.

Purchasing refurbished robots can reduce CO_2 emissions during production by 75 per cent, compared to purchasing new robots. For example, discarding an ABB IRB 6640 robot for scrap would waste 1.4 tonnes of material, mainly metal, which requires a lot of energy and therefore emissions to recover and reprocess.

Stäubli follows a similar strategy. The very high build quality of their robots extends their lifespan - and if a robot reaches the end of its life cycle, it is not simply discarded and replaced, but refurbished and reused.

Energy efficiency

Another extremely important aspect is the issue of power efficiency in industry. There is a growing desire among major industrial robot manufacturers to improve this aspect.

Yaskawa offers a technical solution for recovering the braking energy of the robot to the power grid - as standard and without additional hardware. In their highly varied tasks - such as handling, palletising, joining and processing - industrial robots perform many downward or sideways movements, during which the servo motors dissipate energy and potentially generate electricity. Until now, in older or other robot models on the market, the energy generated has been converted into waste heat by control technology through electrical resistance and lost to the environment.

All of the larger Motoman robot series with payloads up to about 50 kg and the latest YRC1000 robot controllers are able to convert kinetic energy from downward and lateral movements directly into 400 V AC at 50 Hz and feed it back into the operator’s network without additional equipment and reused. Depending on the movement pattern, the robot’s energy requirement is significantly reduced. The extent of the savings in each case essentially depends on the task and the individual movement patterns of the robot. Savings in the range of 8% to 25% can be expected. This can result in an annual consumption of around 2,800 kWh, with savings of around 1,600 kg of CO2 and €1,200. At Yaskawa, energy-saving solutions are an integral part of the global corporate strategy. For example, with its products, the company aims to reduce global CO2 emissions 100-fold by 2025.

As one can see, the use of robotics helps to reduce energy consumption in production in many ways. Thanks to extensive research and development, the robotic systems themselves are becoming more precise and efficient, reducing energy consumption.

In the new generation of TX2-TS2 robots, Stäubli Robotics has developed a new programming function for the robot’s standby mode. This new function saves energy, reducing the robot’s power consumption by up to 50%. The new generation of Stäubli CS9 controllers uses less energy than previous generations. It is the most energy-efficient system based on the VDMA 24608 standard, 10% less energy consumption compared to the previous generation.

Stäubli is also making a huge contribution to sustainability with its digitalisation drive. All robots are compatible with Industry 4.0 and can be easily integrated into intelligent environments. They also have all the necessary interfaces for virtual commissioning, AI applications and the like. This saves users time and money and reduces CO2 emissions.

Building a circular economy with robots

As the world begins to become aware of environmental issues, more and more robot users are embracing the principle of a closed-loop economy. Helping to maximise the lifespan of their robots - reusing them and disposing of them responsibly at the end of their lifecycle.

5. Sources:

https://new.abb.com/news/detail/101281/prsrl-bringing-robots-into-the-circular-economy

https://www.yaskawa.eu.com/header-meta/news-events/article/yaskawa-robots-with-regenerative-braking_n18865

https://www.staubli.com/africa/en/robotics/automatica/sustainability.html