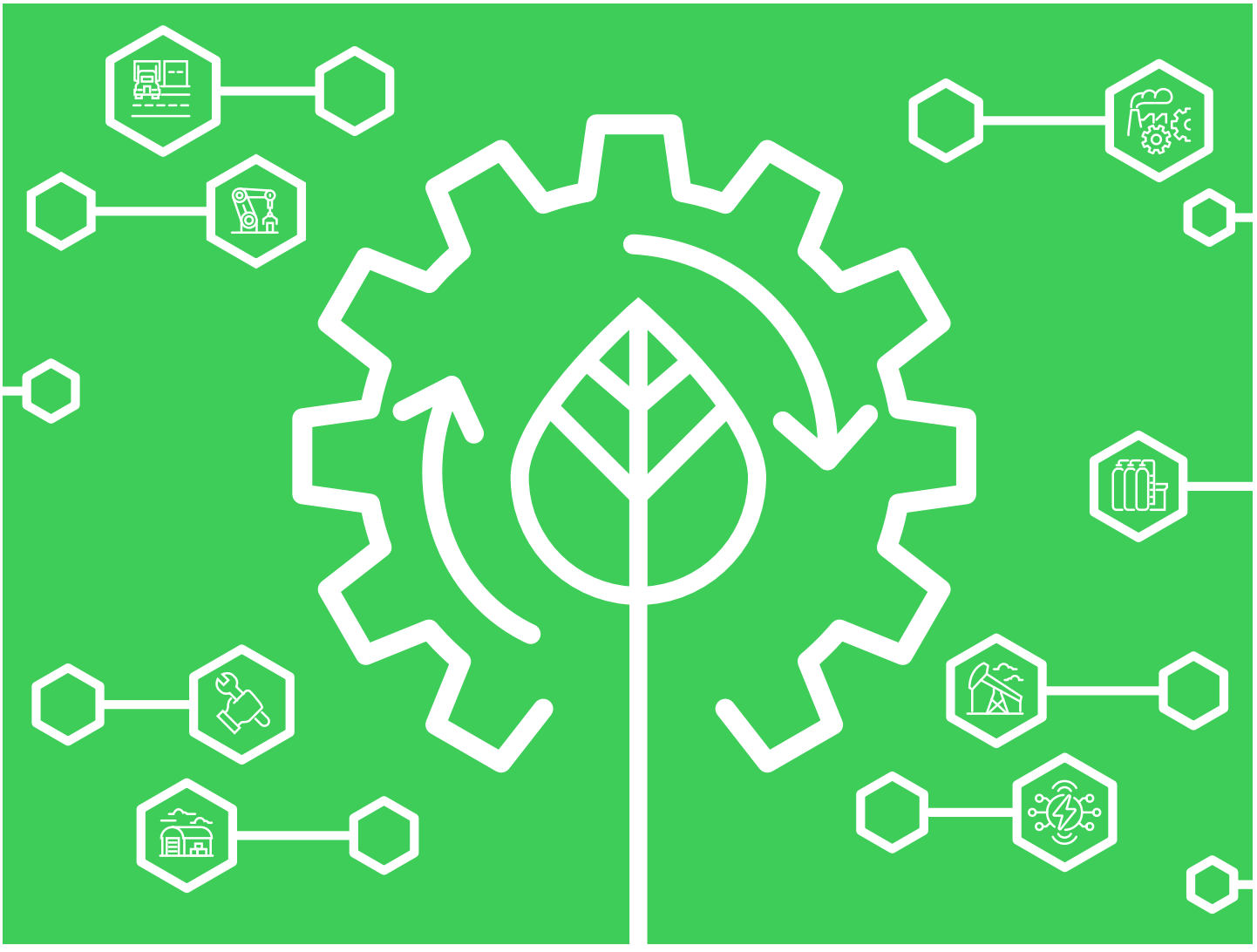
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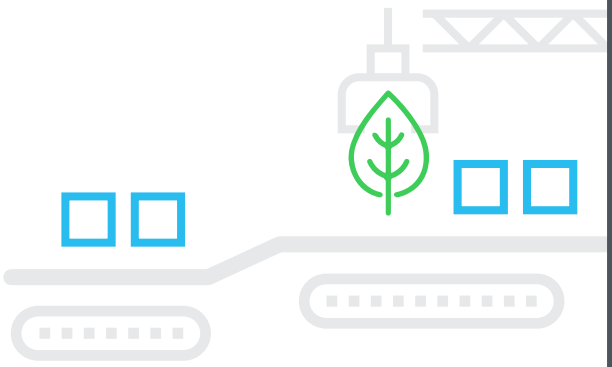
Produced in association with

Schneider Electric

How global businesses use insight and innovation to make their manufacturing processes and assets carbon neutral.

Equipment management and sustainability





Key takeaways

1. Modernizing manufacturing processes reduces the amount of equipment, energy, and raw materials used in production and can significantly cut CO2 emissions.

2. The factory floor can act as an important "command-and-control" point for a larger decarbonization journey, particularly now as the sustainability emphasis of firms expands to include Scope 1, 2, and 3 emissions.

3. The key to overcoming sustainable manufacturing hurdles is to increase access to visibility through data analytics and digitally connected supply chains.

4. The circular economy is a progressive journey of many steps, which begins with viable business plans for managing materials and energy in the immediate term, and revamping "design-for-sustainability" manufacturing processes for long-term circularity.

5. The primary goal of accelerating decarbonization in manufacturing processes is to increase efficiency, which requires both leaner processes and manufacturing facilities that can be segmented into smaller, more flexible, and modular components. This allows producers to adjust assembly lines, processes, and material inputs so that they are more precisely calibrated to better forecast data for on-demand customized manufacturing.

Sustainability and the factory floor

The carbon impact of the world's manufacturing industries has held the imagination of climate change activists for decades. The belching factory smokestack was one of the first salient targets of the decarbonization movement, beginning with the passage of the US Clean Air Act in 1970.[1] Today, with ever-dire projections of the impact that global warming will have on sustainable life on the planet, the role that enterprises play in mitigating climate change has come into even sharper relief. Firms increasingly need to demonstrate concrete sustainability goals to maintain customer loyalty and investor confidence. Nine out of 10 Fortune 500 companies publish sustainability reports – nearly 100 have committed to carbon neutrality, and over 70 are committing to Science Based Targets, a greenhouse gas reduction framework established by the United Nations Global Compact and the World Wide Fund for Nature.[2]

Decarbonization in the manufacturing process, through improving equipment operations, reducing waste, and making products with less carbon-intensive inputs, is increasingly fitting into global firms' broader green agendas. But, more work on this clearly needs to be done. In its 2022 Corporate Climate Responsibility Monitor, the New Climate Institute reviewed the net-zero commitments of 25 large corporations and found their emission-reduction efforts would only achieve 40% reductions on average (see Figure 1), and only three of the companies (none of them manufacturing firms) would achieve 90% decarbonization by their target dates.[3]

Manufacturers have several levers to pull in their efforts to decarbonization. One is to diversify their energy sources away from fossil fuel-based electricity, purchasing from renewable energy producers or developing photovoltaic microgrids to produce their own green power. Another lever is to accelerate the efficiency of equipment maintenance and process optimization, using improved data, analytics, and Internet of Things (IoT)-based sensors to identify production-asset faults and assess operating conditions with greater accuracy.

A third lever involves modernizing manufacturing processes to reduce the number of operations and the amount of raw materials used during production, as well as

The key to overcoming sustainable manufacturing hurdles is to increase access to visibility through data analytics and digitally connected supply chains.

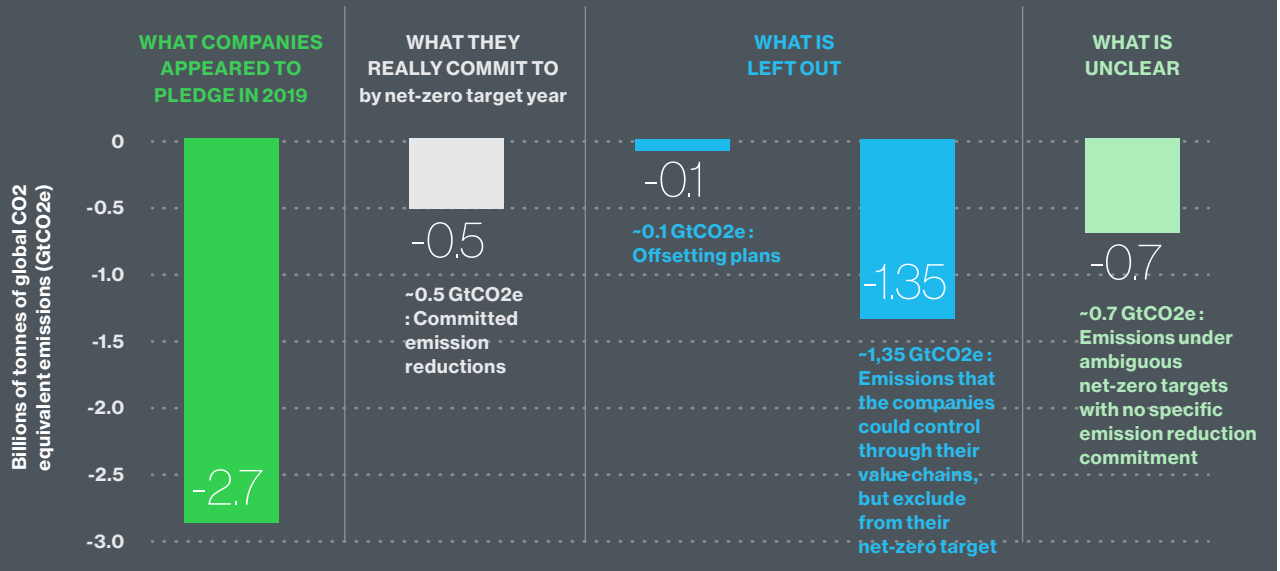


decreasing the usage of machinery and improving the performance of existing machinery. Castrip, a US-based steel technology development group, licenses technology that converts liquid steel into one- to two-millimeter thin strips for use in industrial, automotive, and construction applications. This technology has dramatically reduced the amount of CO2 emitted when converting liquid steel into thin steel strips by 80% to 85% over traditional methods, by decreasing the amount of machinery usage and number of production processes (see Figure 2).

Castrip's director of technology, Walter Blejde, explains how his company's core technology innovation, now some two decades old, has transformed the emissions profile of thin strip steel production. "The conventional thin strip production route has massive capital structures and an energy-intensive production line more than 800 meters long. The Castrip process casts liquid steel directly into sub 2mm thin cast strips and then produces a final thin strip product through a single stand rolling mill," with a total length of only about 50 meters long. Castrip's

Figure 1: Integrity of corporate net-zero pledges

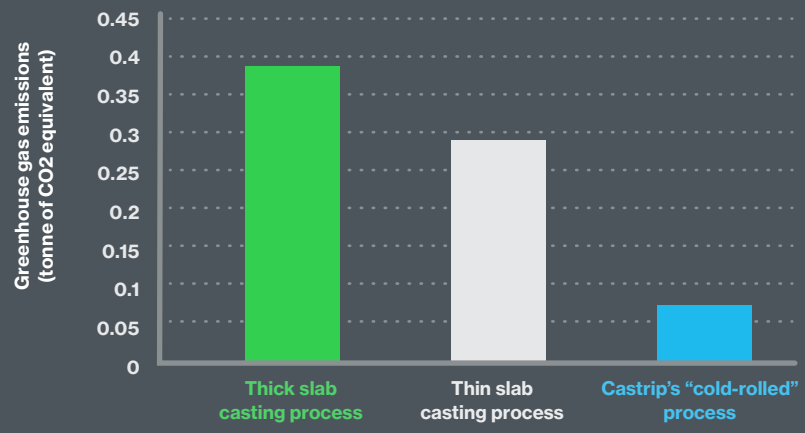
In a 2022 report, the New Climate Institute assessed the combined GHG emission footprint of 25 companies with net-zero targets, including scope 1, 2, and 3. Target dates range from 2025 to 2050.



Source: New Climate Institute, February 2022[4]

Figure 2: Comparison of CO2 emissions for flat-rolled steel processes

Steel processor Castrip licenses technology that reduces the amount of CO2 emitted when converting liquid steel into thin strips for industrial, automotive, and construction applications by 80% to 85% compared to traditional methods using a "cold-rolled" process.



While thin slab casting – where steel is cast directly to slabs 30mm to 60mm thick – reduces the energy used in steel manufacturing, Castrip's "flat-rolling" process makes even greater carbon reductions, by removing many of the processes that consume energy and generate heat.

Source: Compiled by MIT Technology Review Insights based on data from Castrip and Nucor Steel, 2011[5]

approach has extracted many of the processes which consume energy and generate heat, thus significantly reducing a mill's carbon footprint. Blejde points out, however, that initially these process improvements were not explicitly designed to reduce energy intensity. "The initial driver was to develop a low capital, smaller capacity thin strip production plant for niche markets with about a half a million metric tons annual capacity." The carbon friendliness of the Castrip process was initially a fortunate side benefit and has now turned into a core selling point.

The ongoing challenge, however, is to continue to decrease energy intensity. "We have already made the big gains by removing any need to reheat a 250mm thick slab of steel prior to a hot rolling mill and reduced the number of rolling mill stands from six stands to one, as well as eliminating the need to use cold rolling to produce the final product." One area Castrip has been working on for the last two years is exploring the benefits of applying machine learning methodologies to further improve process yields, which "are affected by the skill of the operator, who initiates the set points for various automation control loops. We now using reinforcement learning-based neural networks to develop algorithms to create a self-driving casting machine. This will certainly going to create more energy efficiency gains, which will not be like the earlier big step changes, but they are still measurable," says Blejde.

Reuse, recycle, remanufacture: design for circular manufacturing

Growth in the use of digital technologies to automate machinery and monitor and analyze manufacturing processes – a suite of capabilities commonly referred to as Industry 4.0 – is primarily driven by needs to increase efficiency and reduce waste. Firms are extending the productive capabilities of tools and machinery in manufacturing processes through the use of monitoring and management technologies that can assess performance and proactively predict optimum repair and refurbishment cycles. Such operational strategy, known as condition-based maintenance, can extend the lifespan of manufacturing assets and reduce failure and downtime, all of which not only creates greater operational efficiency, but also directly improves energy-efficiency and optimizes material usage, which helps decrease a production facility's carbon footprint.

The use of such tools can also set a firm on the first steps of a journey toward a business defined by "circular economy" principles, whereby a firm not only produces goods in a carbon-neutral fashion, but relies on refurbished or recycled inputs to manufacture them. Circularity is a progressive journey of many steps. Each step requires a viable long-term business plan for managing materials and energy in the short term, and "design-for-sustainability" manufacturing in the future.

IoT monitoring and measurement sensors deployed on manufacturing assets, and in production and assembly lines, represent a critical element of a firm's efforts to implement circularity. Through condition-based maintenance initiatives, a company is able to reduce its energy expenditure and increase the lifespan and efficiency of its machinery and other production assets. "Performance and condition data gathered by IoT sensors and analyzed by management systems provides the 'next level' of real-time, factory-floor insight, which allows much greater accuracy and effectiveness in condition-based maintenance and modernization schedules," notes Pierre Sagrafena, circularity program leader at Schneider Electric.

Global food manufacturer Nestlé is undergoing digital transformation through its Connected Worker initiative, which focuses on improving operations by increasing paperless information flow to facilitate better decision-making. José Luis Buela Salazar, Nestlé's eurozone maintenance manager, oversees an effort to increase process-control capabilities and maintenance performance for the company's 120 factories in Europe. "Condition monitoring is a long journey," he says. In the first phase, "we used the services of experts on the shop floor to measure equipment performance using manual tools, to report on equipment condition and to schedule maintenance. We are now coming onto a phase '4.0' process, where online sensors monitor equipment and using artificial intelligence with advanced analytic systems allow us to predict future failures." Buela Salazar says Nestlé's objective is to have 80% of its global facilities using advanced condition monitoring, which he estimates will cut maintenance costs by 5% and raise equipment performance by 5% to 7%.

Buela Salazar says much of this improvement is due to an increasingly dense array of IoT-based sensors (each factory has between 150 and 300), "which collect more and more reliable data, allowing us to detect even slight deteriorations at early stages, giving us more time to react, and reducing our need for external maintenance solutions." Currently, Buela Salazar explains, the carbon-reduction benefits of condition-based maintenance are implicit, but this is fast changing. "We have an initiative to install IoT sensors for all major energy-intensive equipment in our facilities globally, to monitor water, gas, and energy consumption for each and make correlations



"We are now coming onto a '4.0' condition monitoring process, where data sensors are online and our maintenance scheduling processes are predictive, using AI to predict failures based on data from hundreds of sensors, often on an hourly basis."

José Luis Buela Salazar, Eurozone Maintenance Manager, Nestlé

with its respective process performance data." This, he says, will help Nestlé achieve a 5% reduction in manufacturing energy consumption in 2023. Such correlation analysis will enable Nestlé to conduct "big data analysis to optimize production line configurations at an integrated level," by combining insight on material usage measurements, energy efficiency of machine and other parameters in a complex food production facility. "Integrating all this data with IoT and machine learning will allow us to see what we have not been able to see to date."

The role that IoT plays in harnessing insights across a manufacturer's entire operations is becoming crucial to

Partner's perspective

Schneider Electric's mission: to be a digital partner for sustainability and efficiency

Sustainability is at the core of Schneider Electric's purpose, culture, and business. Schneider's vision is to empower everyone to make the most of our energy and resources, bringing progress and sustainability for all.

Schneider is committed to accelerating sustainability for all and to being carbon neutral in its operations by 2025 and end-to-end by 2040. The company actively helps its customers and suppliers to better manage energy and reduce their CO2 footprint by 800 million metric tons of CO2 by 2025.

Schneider is continuously developing innovative services for decarbonization. The company is hiring 2,500 new green jobs in consulting, modernization, and maintenance to build and execute sustainability strategies, identify energy savings, diversify its energy portfolio with greener sources, and extend the life of equipment to minimize waste and maximize efficiency.

By considering the design of products throughout their full lifecycle, Schneider Electric enables larger circularity models from take back, refurbishment, reuse, and recycling. As an example, Schneider Electric is committed to phasing out sulfur hexafluoride (SF6) through the launch of its iconic SF6-free equipment as well as the recovery services of this most potent greenhouse gas.

Schneider's innovative Service Plans leverages connected products, analytics, on-site, and remote monitoring expertise to enable optimized condition-based maintenance while preventing equipment failure. Its services also integrate new technology like Electrical Digital Twin or extended reality to make installation more resilient, safe, efficient, and sustainable.

firms achieving their sustainability goals. "We link IoT sensors to our operational models to conduct predictive performance management and determine when assets need maintenance or repair," says John Perrigue, senior director of digital process design at US pharmaceutical and fast-moving consumer goods (FMCG) giant Johnson & Johnson (J&J). "Greater efficiency in our equipment drives lower energy consumption and is enabling some of our production sites to push into carbon-neutral mode." This effort, Perrigue explains, is being taken up by J&J's consumer goods businesses, where sensors are used to govern solar panels, implement wastewater reduction, "and oversee every part of the manufacturing process so we can shrink it down, and reuse as much as possible." Known as Smart Asset Optimization, Perrigue believes this program has slashed average energy costs in the production line by 20% to 25%. It is now being evaluated by J&J's global innovation scouting group to be scaled up and deployed to meet similar requirements in the company's pharmaceutical and medical technology groups.

Extending the use of sensors and predictive tools across the entirety of production facilities – and not just on assets on the assembly line – will increasingly become the norm, explains Schneider's Pierre Sagrafena. He believes every manufacturer must understand three core transformations to achieve carbon neutrality (see Figure 3), and IoT is a critical enabler of each. "IoT can be used to manage microgrids and balance electricity loads as firms accelerate their electricity decarbonization. Digitally simulated, designed then monitored power systems are used to enable process electrification, and IoT-driven data



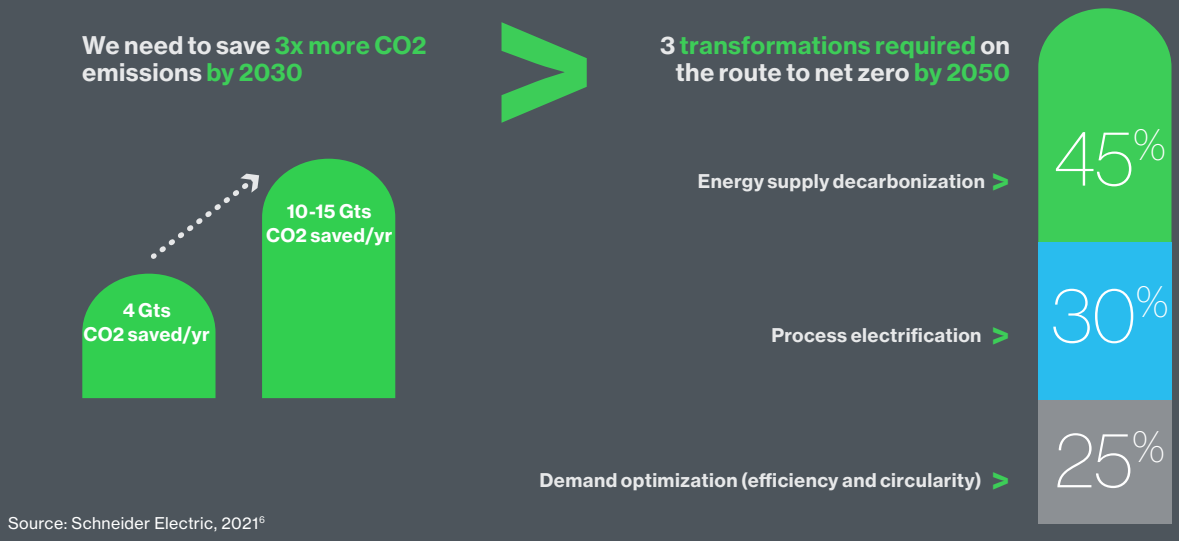
> "Internet-connected controllers can be used to increase process electrification, and IoT-delivered data can deliver insight that enables the next step of visibility as firms increase their efficiency and work towards circularity."
>
> Pierre Sagrafena, Circularity Program Leader, Schneider Electric

can deliver increased visibility on additional efficiency and circularity potential," says Sagrafena.

Circularity principles involve making manufacturing tools more efficient and the entire production design less carbon intensive. Analytics tools transmit better information about the condition and energy use of equipment used in production lines, as well as the usage of raw materials and components across the supply chain. "Analytics are quite important – internally, we share tooling, through a searchable database of tools that allows us to reuse them across different facilities," explains Bruno Chazalette, head of circular solutions at Renault Trucks in France. "Externally, in order to assess and to measure precisely all our products, and the carbon composition from the components, we need to precisely measure everything. We have had all our trucks connected for years, and we use data collected on our trucks in service to support customers in their own optimization journey." Such efforts complement Renault's longer-term transition toward complete circularity, which includes the repurposing of existing product lines and efforts to accelerate the introduction of low-carbon electric vehicles (see "The circular economy of parts adds value").

Figure 3: Three key transformations large corporations need to undergo to achieve carbon neutrality

According to a 2021 report by Schneider Electric, large corporations can contribute to limiting global warming by 1.5° compared to pre-industrial levels with three key transformations.



Source: Schneider Electric, 2021[6]



"If we really want to decarbonize, we need a core design that will involve tremendous efficiency from our factories. This means less energy and water consumption, and we are asking all our suppliers to present their carbon footprint plans."

Bruno Chazalette, Head of Circular Solutions, Renault Trucks

The circular economy of parts adds value

In a bid to increase the reuse, refurbishment, and remanufacturing of all its products, French automaker Renault Trucks is building a new factory dedicated to dismantling ageing trucks to extract parts that can be reused elsewhere. "We are trying to push the maximum durability of our solutions," says the company's head of circular solutions, Bruno Chazalette. "We have decided to build a completely new factory to dismantle our product in order to reuse parts – the first OEM (original equipment manufacturer) to do so – and will start production early next year."

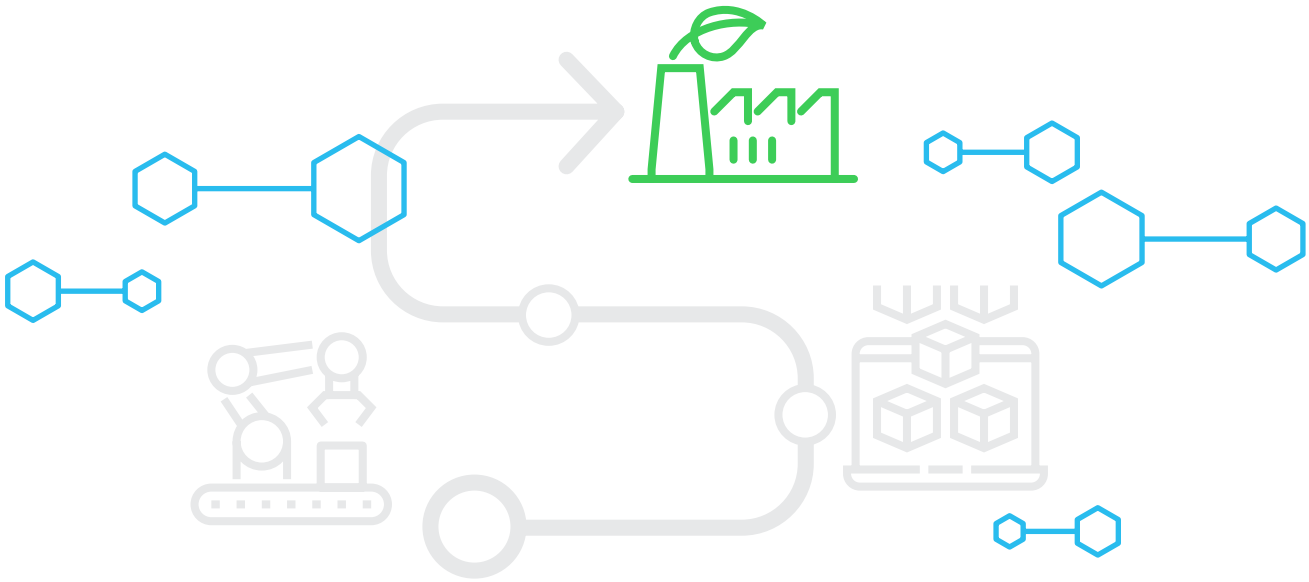
Reinventing Renault's production process to incorporate repurposed components creates additional value streams and sets Renault on a path toward a circular economy-based business. Chazalette notes that some of its older combustion-engine trucks in service have lower values than that of their combined component parts. This has a large impact on its spare parts business, which accounts for 14% of Renault's total turnover. Refurbishing allows Renault to "create better value for the customer, as well as create a longer life for our products in service through regeneration of trucks," says Chazalette.

However, he is quick to add that this is only the first step in the journey Renault is taking toward their circularity platform and their goal to be carbon neutral by 2040. This will involve transitioning the firm toward electric vehicles: in less than 10 years, 50% of its sales will be made up of fully electric vehicles. "If we really want to decarbonize, we need to have a core design that will really protect our future. This will involve tremendous efficiency from our factories around less energy and water consumption, and we are asking all our suppliers to present to us their carbon footprint plans," Chazalette adds.

Flexible and fungible: modularity as the future of sustainable manufacturing

As in any other operational improvement process, the goal of decarbonizing a factory or production line involves a reassessment of the overall efficiency of these facilities, with an eye to design them in climate-friendly ways. Moreover, as sustainable manufacturing increasingly takes into account the carbon impact of products after they leave the assembly line, such design principles must also be implemented in ways that increase the energy- and material-efficiency of each product's lifecycle, as well as that of the operational infrastructure that builds it.

Digital technologies and analytics improve predictive processes that producers can use to design more sustainable manufacturing capabilities from the start. J&J's John Perrigue describes how his company works with virtualization technology and analytics to develop digital models of manufacturing processes for various consumer goods, which use predictive tools to stress-test sustainably optimal production models in virtual reality before committing them to actual carbon-intensive manufacturing lines.



"By modeling the mixing processes, we can look at heating and cooling times, and use computational fluid dynamics and simulation to predict cycle operations before we try it in a full-scale environment," says the senior director of digital process design. "We are thus able to deliver products faster, and validate the materials required to create the product right the first time." Perrigue sees digital twinning as a core element in J&J's design for manufacturability R&D processes, which also creates decarbonization gains. "We are able to improve our quality and improve our equipment functionality, which gives us good cycle-time performance, which means less heating, cooling, and electricity consumption."

Ultimately, accelerating decarbonization in manufacturing processes requires leaner processes and more modular manufacturing facilities, both of which help producers consume fewer materials and less energy. By making components more modular – segmenting them into smaller, more flexible components – producers can more precisely calibrate assembly lines, processes, and material inputs so that they can provide on-demand and customized manufacturing. Flexible manufacturing can also be developed into part of a circularity-oriented business solution for producers. "Our CEO wants us to move into an 'equipment-as-a-service' business model," explains Renault Trucks' head of circular solutions, Bruno Chazalette. "The more we do this, the more we need to understand our customers' business, and the more we will customize our production. But to customize, we need modularity in our facilities."

Digitizing manufacturing processes enables J&J to take an aggregated view across its global operations and to benchmark across its facilities so that it can make greater carbon reductions globally, says Perrigue. "Digital is fundamentally transforming the way we approach sustainable manufacturing design and how we approach manufacturing process-planning. Failure mode and effects (FMEA)-type analysis within our facilities and management groups determines a total cost lifecycle ownership over most of our products. This primarily looks at efficiency improvements in production, but there are also elements of fixed- and variable-cost reduction in the overall bottom line, and all this rolls up into our broader mission to promote a healthy planet." He notes that this involves encoding sustainability principles into the design facilities of critical utilities and assessments of the sustainable practices of manufacturing and business partners.

Many of these efforts include modernizations such as increased use of automation and robotics, but Perrigue believes that, ultimately, a more systemic approach to sustainable manufacturing is needed. "In an age of increasingly personalized medicine or consumer goods, we are going to have to start thinking about ways to build products on a mass scale that are customized for individuals, not for markets. This will require a flexible, modular, and mobile approach to manufacturing, enabling the ability to wheel equipment in and wheel it out." Such a shift to respond to changing consumer dynamics, he believes, will quickly accrue sustainability benefits. "Such

an approach will require less fixed equipment, less energy to run and operate, and it will take less energy to build such facilities for multiple product lines, as more rapid turnover will require smaller and fewer components. If we are making a body cleanser today and a lotion tomorrow, we'll just swap out the elements of the packaging line or swap out elements of the upstream process," says Perrigue.

Sustainability for the long haul

Leading firms are integrating production-specific sustainability practices into their overall sustainability objectives at an organizational level. Increasingly, firms are looking to create viable sustainable supply chains as well, extending their carbon-footprint targets to the materials and services provided by ecosystem partners. As this report has discussed, the long-term goal of manufacturers working toward carbon neutrality requires achieving two cojoined goals: increasing visibility of the carbon content across a firm's entire supply chain and reorienting their business model based on circular economy principles.

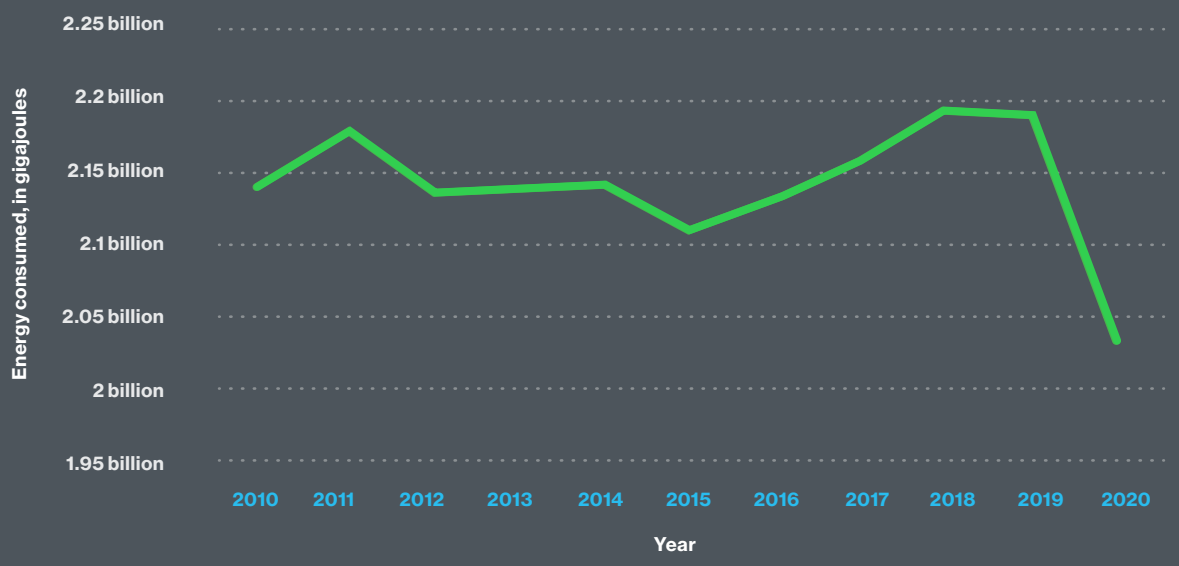
Measuring and management are key strategies for maximizing the lifespan of products and equipment used in operations. Up until recently, equipment and asset management (upgrading equipment, use of automation, more responsive repair processes, and performance-based maintenance) has largely been used to increase operational performance and contain costs, with sustainability goals a happy coincidence.

Now, however, with investors and customers increasingly evaluating firms on their environmental, social, and governmental (ESG) objectives and sustainable development goals, sustainability is becoming the goal of process improvements. Industry 4.0 tools such as IoT sensors and performance management software increase the availability and precision of production data, and now includes sustainability-relevant data such as energy consumption and the carbon content of materials.

Managing these inputs downward has proved challenging for the world's manufacturing industries, even in mature economies: in Canada, for instance, average energy

Figure 4: Canada: manufacturing energy consumed, in gigajoules

Energy consumption in manufacturing industries has remained relatively constant over the last decade and even increased in recent years, dropping only significantly in 2020 as the impact of covid-19 took hold.



Source: Compiled by MIT Technology Review Insights based on data from Statistics Canada, 2021[7]

"As we focus on getting our carbon footprint smaller, we have to look at the usage of our products and the eventual end of lifecycle so that we can determine how we can manufacture in a way that increases each machine's recyclability and fewer pounds of material go to landfill."

Scott Park, CEO, Doosan Bobcat

consumption in manufacturing industries has remained relatively constant over the last decade and even increased in recent years, dropping only significantly in 2020 as the impact of covid-19 took hold (see Figure 4). This reality means firms must actively look at managing their entire sustainability impact. "We try to capture the impact we generate per unit of product that we make, to get metrics in place, and them obviously try to reduce our energy and material consumption. We're really getting a handle on our factories carbon footprint, and trying get to the same insight with waste and the water," says Scott Park, the Seoul-based CEO of global construction manufacturer Doosan Bobcat, noting that the company must seek this visibility outside of the production facility too. "As we focus on getting the carbon footprint smaller on our products, we have to look at the usage of our products and the eventual end of lifecycle so we can determine how we can manufacture them to increase each machine's recyclability so that fewer pounds of material go into landfills," adds Park.

Circular economy principles are allowing firms to build in end-to-end decarbonization practices, in addition to addressing raw material scarcity – but this is a long-term objective. The quest for sustainability through better analytics is highly correlated with the broader objectives of digital transformation and continuous improvement processes.

"We are trying to eliminate carbon within our four walls, but we mostly run assembly facilities that have a modest footprint compared to steel-making or chemicals, so our aspirations need to be inclusive of our supply chain partners," says a chief sustainability officer (CSO) of a major industrial conglomerate. Only 5% to 10% of the overall carbon emissions associated with its products is directly attributed to factory activity, while the conglomerate's supply chain probably has five to six times its own footprint, says the CSO. "The steel, plastics, and electronics that we buy from a lot of different firms with different ESG viewpoints, so to get the really big impact, our factories need to constructively engage with suppliers to get them to produce greener over time." The firm is beginning to work with companies that supply completely recycled polypropylene and other materials.

For many leading manufacturers, the factory floor thus serves as an important "command-and-control" point in a larger decarbonization journey, particularly now as their sustainability emphasis expands to include Scope 1, 2, and 3 emissions. The production facilities of a firm may not account for a large percentage of its direct carbon footprint, but the material inputs that flow through its facilities, and the up- and downstream supply-chain relationships that connect through them, all have their own carbon journeys that must be accounted for and managed.

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We drive digital transformation by integrating world-leading process and energy technologies to realise the full efficiency and sustainability opportunities for your business. We provide end-point to cloud integration connecting products, controls, software and services. We enable lifecycle solutions from design and build to operate and maintain phases through a digital twin. We deliver capabilities to transform from site-to-site to an integrated company management. Our integrated solutions are built with safety, reliability and cybersecurity for your homes, buildings, data centres, infrastructure, and industries.

Footnotes

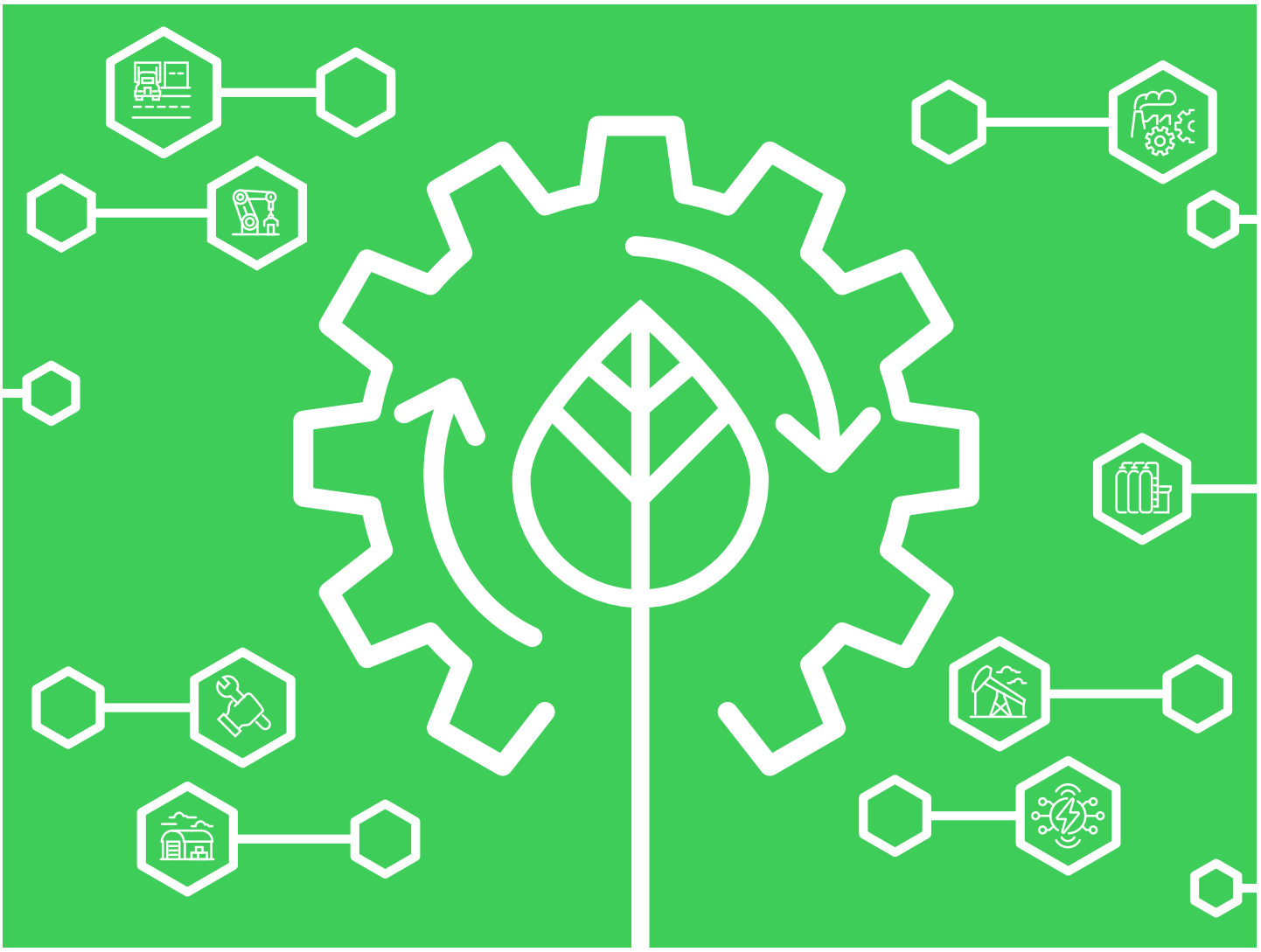
1. United States Environmental Protection Agency, "Summary of the Clean Air Act", September 2021, https://www.epa.gov/laws-regulations/summary-clean-air-act
2. Nicole Goodkind, "There's a disappointing gap between companies' promises about climate change and the actual results, study says," Fortune, February 8, 2022, https://fortune.com/2022/02/07/climate-change-companies-study-meeting-goals/
3. New Climate Institute, "Corporate Climate Responsibility Monitor 2022," February 2022, p. 5, https://newclimate.org/wp-content/uploads/2022/02/CorporateClimateResponsibilityMonitor2022.pdf
4. New Climate Institute, "Corporate Climate Responsibility Monitor 2022," February 2022, p. 5, https://newclimate.org/wp-content/uploads/2022/02/CorporateClimateResponsibilityMonitor2022.pdf
5. Wal Blejde, Frank Fisher, Mike Schueren, and Gary McQuillis, "The Latest Developments With the Castrip Process," Castrip and Nucor Steel, 2011, p. 7, https://docplayer.net/76172244-Faster-smarter-thinner-better-the-latest-developments-with-the-castrip-process.html
6. Compiled by Schneider Electric based on data from the Schneider Research Institute "Back to 2050" report, 2021, https://go.schneider-electric.com/HKEN_202201_Back-to-2050_SF-LP.html?source=Content&sDetail=Back-to-2050_HK&#:~:text=To%20keep%20global%20warming%20limited,energy%20transition%20of%20momentous%20proportions
7. Statistics Canada, "Manufacturing industries, total annual energy fuel consumption in gigajoules, 31-33," 27 October 2021, https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2510002501&pickMembers%5B0%5D=2.1&cubeTimeFrame.startYear=2010&cubeTimeFrame.endYear=2020&referencePeriods=20100101%2C20200101

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