

The Ultimate Guide to Sustainable Manufacturing: Innovating Products for a Sustainable Future



No longer a buzzword or lofty aspiration, sustainability is now a critical concern for manufacturers globally. Consumers are hungry for more sustainable products. Public policy is creating greater incentives for investing in sustainable manufacturing capabilities. In addition to these incentives regulators will also employ increasingly powerful mandates investors and other stakeholders will come to expect established best practices for sustainability, and the imperative for manufacturing sector sustainability will increase. According to the [Carbon Reduction in Manufacturing Initiative of the World Economic Forum](#) **54% of the world's energy consumption comes from manufacturing**, and manufacturers will need to answer the call with an unprecedented commitment to tracking and reducing their negative environmental impacts.

Organizations that can establish leadership in sustainable product design will be well-positioned to earn long-term profits as pillars of a less carbon-intensive economy. Doing so will require not just reducing the first-order emissions of manufacturing processes, but thinking more holistically about how products will be used and valued throughout the value chain in a [true circular economy](#), where planned obsolescence gives way to recycling and reuse. **In this guide, we explain how to get started.**

01.

What is Sustainable Manufacturing?



Sustainable manufacturing is a range of practices for designing, sourcing, and delivering products with an optimal combination of value and reduced environmental impact. In the context of global warming, the chief variable for measuring this impact today is the Carbon Dioxide equivalent (CO_2e). CO_2e equates the global warming potential of different greenhouse emissions to metric tons of CO_2 allowing for apples-to-apples comparisons.

As a foundation for the emerging circular economy, sustainable manufacturing practices will be of critical importance for every industry on earth. Yet public discussion on sustainability is often dominated by misconceptions (we debunk some of the most common in our blog post on [sustainability myths](#)).

Manufacturers must recognize that sustainability and cost efficiency are not “either-or” propositions. Public incentives and consumer demand will continue to push sustainability toward becoming a core attribute of a competitive product. We explain why in our blog post [Forgoing Manufacturing Sustainability Does Not Equate to Profitability](#). Rather than hamper competitiveness, sustainability will instead become a key driver for long-term success. [In a survey of S&P 500 firms conducted by CDP](#), firms estimated that the aggregate financial benefits of the opportunities are almost 15 times higher than the potential impact of the risks associated with sustainability.

Net-Zero Emissions Versus Carbon Neutrality

The distinction between two common terms associated with sustainable manufacturing—carbon neutrality and net zero emissions—is helpful for understanding different avenues for reducing environmental impact.

- **Carbon neutral** describes an organization, operation, or product which balances its carbon emissions through the purchase of offsets from an external organization.
- **Net-zero** refers to an organization, operation, or product which targets internal abatement of emissions without financing external offsets. Consequently, a net-zero target creates greater pressure for an organization to reduce emissions directly, within its own supply chain. Different standards and regulations may refer to either “net zero carbon” or “net zero emissions” (which includes a broader spectrum of emissions in addition to CO₂).

Both of these concepts will be important as manufacturers work to reduce their environmental impact. Regulations focused on carbon neutrality create broad economic incentives for emissions reduction, rewarding companies that can sell excess carbon permits ([we explore the price of carbon under the EU's cap-and-trade policy in our blog here](#)). As regulators seek to reduce emissions within specific sectors, industries, or geographies, net-zero targets will provide a more direct lever.

“Across industries, the great cleanup is underway. Driven by tightening regulations, pressure from investors, and shifting customer preferences, companies are striving to reduce the burden of their activities on the planet. This quest for sustainability requires action on many fronts, with changes to supply networks, manufacturing processes, and business models. Companies are also rethinking how their products are designed, engineered, and used, looking for ways to meet performance and quality requirements while using fewer resources across the full life cycle of everything they make.”

– [McKinsey & Company Report on Product Sustainability](#)



23% of greenhouse gas emissions come from industrial emissions.



66% of consumers prefer sustainably responsible companies.



99% of CXOs say environmental programs drive shareholder value.

Where should I start? What elements does an effective sustainable manufacturing strategy need to include?

Improved sustainability will require a holistic strategic commitment that extends to the entirety of the product development process. Given the global, complex, and interrelated nature of sustainable manufacturing, it can be difficult to know where to begin. That's why [Gartner's Sustainability Survey](#) reports that while 92% of companies say sustainability spending is increasing at their organization, only 40% believe that they have the knowledge and capabilities to achieve their targets.

We recommend approaching this challenge by considering how sustainability can be incorporated through each phase of the product development lifecycle. The three elements below are a great place to start.

1. Sustainable Design and Manufacturing

Many product attributes are baked in at the design stage, which is why, [according to McKinsey](#), a product's design determines 80% of its environmental impact. Engineering teams will need to incorporate sustainability analysis into methodologies such as Design to Value (DTV) and Design for Manufacturability (DFM) to deliver competitive products.

2. Sustainable Sourcing

Supply chains can be responsible for 80% of a company's overall environmental impact and supplier collaboration is instrumental to sustainable manufacturing. Sourcing teams need the right tools and methodologies to evaluate sustainability when sourcing components, evaluating bids, and negotiating prices (without slowing down urgent product development timelines).

3. Sustainability Reporting and Assessment

Detailed reporting on the carbon intensity of manufacturing activities is foundational for continued improvement and often required by law. Developing a robust baseline assessment of both internal activities and the supply chain is a critical initial challenge for manufacturers seeking to enhance sustainability.

We explore each of these elements in greater detail in this guide.



02.

Sustainable Design and Manufacturing: How to Embrace Green Design Without Sacrificing Profitability

As we explore in our blog post [Striking a Balance Between Green Design and Cost Efficiency](#), green design practices can help achieve key sustainability goals including:

1. Reducing CO₂e emissions.
2. Improving environmental, social, and governance (ESG) performance for better customer satisfaction.
3. Eliminating waste while conserving energy.
4. Enhancing corporate social responsibility (CSR) programs through environmentally conscious manufacturing processes and material selection.

For manufacturers, the challenge is realizing these benefits while maintaining an optimal balance between cost, carbon mitigation, and end-user value.





Why Design to Cost and Sustainability Go Hand-in-Hand

80% of a product's cost is determined during the design phase, which is precisely why manufacturers have increasingly adopted Design to Cost (DTC) as a core pillar of design. Learn more about [DTC](#). In short, DTC tools and methods rationalize cost management by providing detailed insight into a product's cost structure.

A robust DTC strategy needs to account for the impact of design choices on cost drivers such as:



Material
specifications




Shape and geometry
of the product



Manufacturing
processes



Supplier
location



An effective design for sustainability strategy needs to account for the emissions impact of these same factors—all of which exhibit complex interactivity. Today, many design and cost engineering teams rely on [should cost models](#) to establish benchmarks for product cost if efficient design and sourcing practices are followed. Extending these models to incorporate comprehensive “should carbon” calculations requires insight into critical variables such as:

- Material selection, including recycled content, the impact of rough mass, regrind/remelt, and waste materials on CO₂e emissions.
- Manufacturing process, including the emission impacts of cycle time, energy use, and electricity generation mix.
- Carbon intensity of component suppliers. We explore sourcing in more detail below, but it is important to note that sourcing data will be critical for weighing make-buy decisions even in the earliest phases of design.

Like cost, sustainability can never be analyzed in isolation. Manufacturing brands are acutely aware of their customers’ unyielding demands for new features, dependability, fast service, and delivery.

As sustainability becomes a core requirement for new product development, manufacturers will need an established method for incorporating it into the design process. We provide a deeper look at Design for Sustainability, including three best practices for implementing it in your organization, in our blog post [Three Essentials for Design for Sustainability](#).

03.

Sustainable Sourcing: Why Green Products Need Green Supply Chains

Manufacturing sustainability is rarely just a matter of one organization improving its internal design practices. The carbon impact of purchased materials and components is ultimately just as important as the intensity of specific end products. [According to McKinsey](#), supply chains can account for 80% of a typical manufacturer's greenhouse gas emissions.

Emissions may be categorized into three different levels of analysis, as provided by the Greenhouse Gas (GHG) Protocol.

- **Scope 1:** direct emissions from owned or controlled sources.
- **Scope 2:** indirect emissions from the generation of purchased energy.
- **Scope 3:** upstream and downstream emissions.

[Sustainability reporting regulations](#) are now extending to Scope 3, and consequently, manufacturers will need to find opportunities to improve sustainability for not only their own production facilities, but supply and distribution chains which may spread across multiple countries and hundreds, if not thousands of vendors.



A selection of recent examples from leading manufacturers illustrates some potential avenues for reducing this impact.

- Scania, a sustainable truck maker (including EV and hybrid solutions) uses aPriori to integrate cost and CO₂ calculations with the design process without slowing down time-to-market. [Watch the Scania Video Case Study](#).
- Arrival, a UK electric vehicle maker employs “Microfactories,” a new supply chain and manufacturing model that allows for localized, highly scalable manufacturing. Learn More: [Arrival Case Study](#).
- BMW is taking a “[secondary first](#)” approach to sourcing materials (with nearly 30% of their cars today made from reused materials) while [proactively collaborating with suppliers](#) to bring down carbonization levels.
- Collins Aerospace is working to source [alternative thermoplastic materials](#) for use in aircraft—materials that can reduce cost, improve reusability, and help reduce aircraft weight.
- Ørsted, a Danish renewable energy firm, recognizes that prioritization is essential when seeking to reduce emissions across 1000’s suppliers. [Their approach to mapping emission “hot spots”](#) helps focus their efforts where they can have the greatest possible impact.



7 Steps to Addressing Sustainable Sourcing Goals

Every manufacturer's supply chain looks different, but the seven steps below are a great place to start thinking more systematically about establishing a low-carbon procurement model.

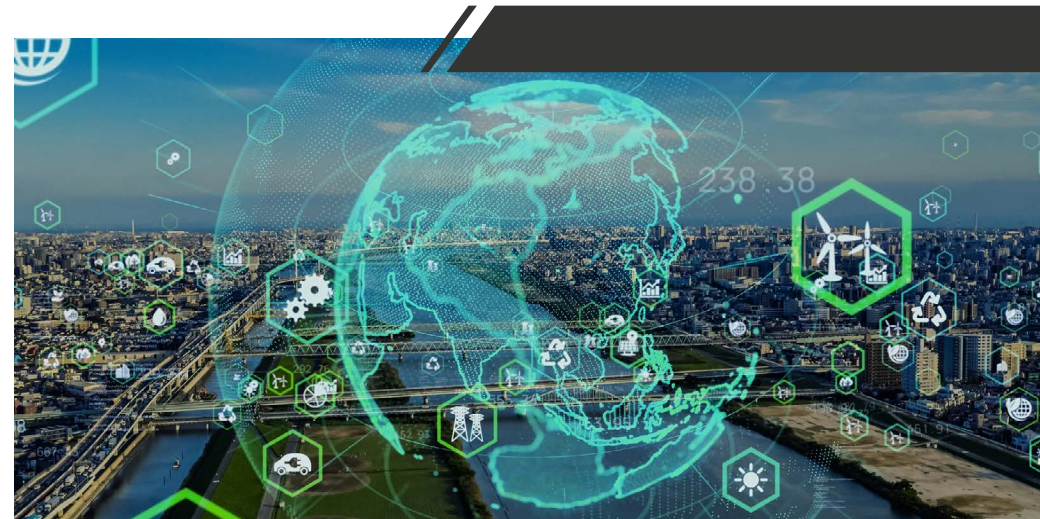
- 1. Make sustainability fully traceable.** Robust traceability will be instrumental to demonstrating progress to investors, consumers, and regulators alike (and will only become more important as re-used materials proliferate).
- 2. Use sustainability reporting to guide action.** Emerging regulatory frameworks in the EU and elsewhere establish non-financial reporting requirements. These reporting standards will be a strong foundation for establishing overall sustainability objectives for supply chains.
- 3. Expand supplier collaboration.** More sustainable supply chains will require more transparency, more cooperation, and ultimately deeper relationships with suppliers.
- 4. Establish a baseline for current supply chain emissions.** Developing a robust understanding of current emissions (both upstream and downstream) is critical to establishing standards for continuous improvement.

5. Establish a supply chain sustainability plan. While it may be long-term, a clear-cut goal (e.g. net-zero by 2050) is an important anchor for efforts to improve supply chain sustainability.

6. Develop Key Performance Indicators (KPIs). Once a plan is in place, quantifiable metrics are essential to tracking progress and prioritizing investments.

7. Develop the capability to generate real-time insights into cost, sustainability, and manufacturability tradeoffs. Advanced digital capabilities such as should cost modeling and must be extended to include sustainability insights for new products.

Take a deeper look at each of these seven steps: [Sustainable Sourcing Strategies that also Improve the Bottom Line](#)



04.

Sustainability Reporting and Assessment: New Requirements for Public Transparency

Global momentum for mandatory corporate reporting of climate-related risks is growing with each passing year, with 75% of the G20 nations currently instituting at least some form of mandatory corporate climate reporting. For more and more manufacturers across the globe, sustainability reporting will be not just a matter of good corporate citizenship, but regulatory compliance. Recent frameworks from the European Union provide a leading example.



SEC Climate Disclosure Mandates

The [SEC climate disclosure plan](#), issued in March 2022, would require certain publicly traded companies in the US to report upstream and downstream emissions. Activities would be categorized using the [GHG Protocol system](#) outlined above. This rule was opened for public comment after its initial issuance, and is expected to be issued in its final form in Q1-Q2 2023.

The plan would require reporting of both Scope 1 and Scope 2 emissions. Scope 3 reporting may also be required if these emissions have a material impact on investors. SEC regulations will also require manufacturers to substantiate stated ESG goals with specific plans, a requirement designed to prevent “greenwashing” through false sustainability claims.

Learn more by reading [How to Prepare for SEC Climate Disclosure Mandates](#).

EU Taxonomy Sustainability Reporting Requirements

As part of an effort to become the first GHG-neutral continent by 2050, the [EU's "Green Deal" policy measures](#) includes mandated sustainability reporting for corporations. Businesses will be required to disclose when activities and investments are environmentally sustainable according to a new classification system and corporate scorecard, the [EU Taxonomy](#). The Taxonomy is part of a suite of EU regulations to mandate corporate sustainability reporting on financial and operational activities. Specifically, the EU Taxonomy is aligned with the current [Sustainable Finance Disclosure Regulation \(SFDR\)](#), which focuses on financial reporting. The Taxonomy also supports the [Corporate Sustainability Reporting Directive \(CSRD\)](#), which will replace the SFDR.

Public companies that meet EU disclosure thresholds are required to institute internal controls to identify and report on climate-related risks that may have a material impact. The companies are also mandated to provide their carbon footprint and plans to support the EU's GHG reduction efforts in their financial statements. To help protect EU companies from being undercut on cost from higher-emission products, the EU has also introduced the [world's largest carbon border tax program](#).

We cover the EU taxonomy in greater detail in our blog post [Manufacturers: Are you Prepared for New EU Taxonomy Sustainability Reporting Requirements?](#) and our podcast [Sustainability Reporting: the EU Taxonomy](#).

05.

Sustainable Manufacturing in Action: Industry Examples

Every industry will face different challenges in instituting more sustainable design, sourcing, and manufacturing practices (and the reporting capabilities needed to track, assess, and verify them).

The resources below provide a deeper look at how some specific industries below are working toward a more sustainable future.

[Podcast: Sustainability Design in Housing](#) | CEO Paolo Tiramini discusses Boxabl's tiny house concept and how it relates to the future of sustainable construction.

[Podcast: EV Supply Chain Sustainability](#) | Craig McLeod, former Director of Advance Planning for GM, discusses how automakers can build more sustainable supply chains.

[Webinar: Balancing CO2 and Cost](#) | Watch three real-world examples of manufacturers making product design trade-offs in cost, sustainability, and manufacturability in real time.





[Podcast: Aerospace's Secret Sustainability Solution](#) | John Pilla, former CTO for Spirit AeroSystems, explains why reducing weight is the biggest key to aerospace sustainability.

[Podcast: Sustainable Plastic Manufacturing](#) | Bahruz Mammadov, CEO of BERKM and an expert on the life and afterlife of plastic, looks at some of the most important challenges for plastic recycling.

[Blog: How Additive Manufacturing Can Help Design Engineers Meet Manufacturability, Sustainability, and Cost Initiatives](#) | The additive manufacturing industry has the potential to create unique opportunities for more sustainable manufacturing benefits such as lighter parts, less carbon-intensive tooling, and leaner inventories enabled via on-demand parts.

06.

How to Incorporate Real-Time Sustainability Insights into Product Design and Production

As we have explored throughout this guide, the business case for prioritizing sustainability across every phase of the product development process is stronger than ever. For most manufacturers, the central challenge is to provide the accurate, granular sustainability insights needed to support this new priority. Manufacturers with the insights needed to evaluate cost, carbon footprint, and manufacturability in real-time are well-positioned to leverage sustainability as a competitive advantage.



Integrating sustainability into manufacturing operations can be a complex and time-consuming endeavor, and the right digital tools are an important foundation for helping engineers and sourcing teams:

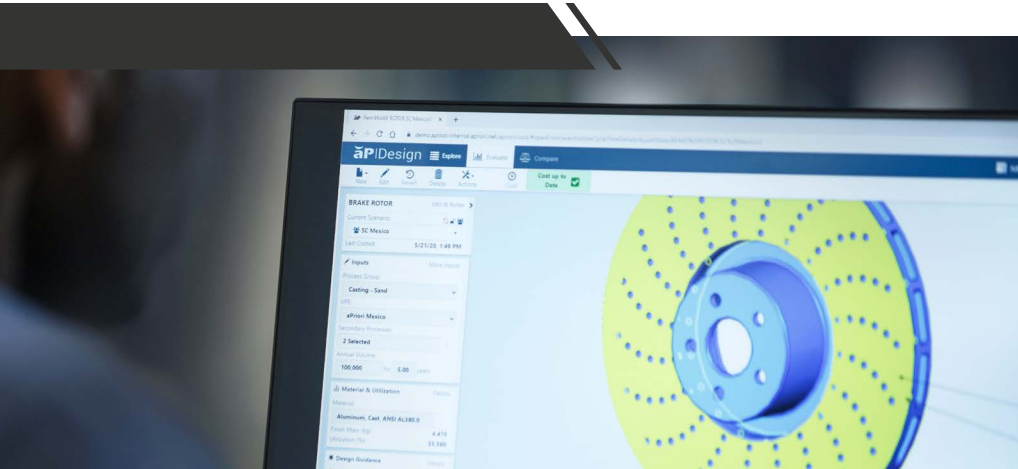
1. Establish a Carbon Emissions Baseline: quantifying current emissions according to the levels established by the GHG Protocol is a foundational capability for measuring emissions across the entire supply chain.

Traditionally, manufacturers have made use of product life cycle assessment (LCA) software to collect sustainability information only once a design is complete. But this manual process is cumbersome, sustainability information isn't integrated into other systems, and it doesn't drive insights when they are needed most—during the design phase. For most manufacturers, developing a robust baseline will require securing carbon emissions data from their suppliers (and even their suppliers' suppliers).

2. Evaluate Sustainability, Cost, and Manufacturability: with a baseline in place, cross-functional teams can precisely evaluate design sustainability while simultaneously working to meet other core product requirements. Teams need the ability to analyze complex tradeoffs related to sustainability priorities. Examples include:

- Identifying the biggest contributors to CO₂e emissions and product cost.
- Running trade-off analysis to compare CO₂e emissions with cost and identify outliers.
- Evaluating different manufacturing processes to compare CO₂e with cost.
- Finding material substitutes that emit less CO₂e with full transparency or visibility into their cost impact.
- Assessing alternate regions of the world to determine how they impact production costs and the carbon footprint of a product design.

Using aPriori, manufacturers can put all of these analytical capabilities at engineering and sourcing teams' fingertips—all while a product is still in the design phase.





“CIMdata believes aPriori has demonstrated a solid approach to helping manufacturers who are struggling to manufacture ‘green’ products by merging CO₂e emissions data with should cost and design for manufacturing. This enables a company to see both cost and CO₂e data in a PLM solution as well as aPriori’s Manufacturing Insights Platform. This provides companies with the ability to evaluate trade-offs, optimize product design and production for cost, and help enable more resilient supply chains.”

–CIM Data Analysis of aPriori’s Sustainability Capabilities

How aPriori Helps Integrate Sustainability with Every Phase of Product Development

aPriori’s Sustainability Insights help manufacturers integrate detailed data on sustainability with product design, sourcing, and manufacturing. The aPriori platform can provide detailed cost and manufacturability insights through the analysis of 3D CAD files, employing simulated manufacturing in digital factories, which can be customized to reflect real-life production variables—including labor rates, machinery, materials, and manufacturing processes. Learn more about our approach to [digital manufacturing](#).

Now fully integrated with ecoinvent’s* life cycle inventory database, aPriori provides real-time, fine-grained analysis of sustainability tradeoffs using [the digital factory](#)—a digital representation of a physical factory with all of the key elements you would find if you walked into any production facility.

Simulated manufacturing analyzes the interaction of emissions with four key levers: geometry/shape, materials, manufacturing processes, and location/electricity mix. Simply by uploading the relevant CAD file, manufacturing professionals can use aPriori to calculate both should-cost and should-carbon models, providing critical insights for measuring, reducing, and reporting on product emissions (including the broader Scope 3 emissions of the supply chain).

aPriori helps manufacturers understand and communicate carbon impact both up and down the supply chain, providing insight into the carbon intensity of purchased parts and components, while making it easier for suppliers to share carbon footprint information with their customers.

*ecoinvent is a not-for-profit association based in Zurich, Switzerland, dedicated to the availability of high-quality data for sustainability assessments worldwide.

Learn more about how to
create innovative, sustainable
products with aPriori.

VISIT [APRIORI.COM/SUSTAINABILITY](https://apriori.com/sustainability)



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