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Recycled Materials Guide

g.co/hardware/MaterialsGuide

Google

At Google, operating in an environmentally sustainable way has been a core value from the beginning.

As our business has evolved to include consumer devices, we've expanded our efforts to improve each product's environmental performance.

Reflecting on our work and why we do it, we've realized that progress in sustainability should be a journey we all make together.

In that spirit, we are sharing our insights to be helpful to other companies with sustainability aspirations, and we encourage them to share what they learn too.

For additional insights into other areas of our work, check out these resources:

Plastic-Free Packaging Design Guide →

Consumer Hardware Carbon Reduction Guide →

Assessing Biological Ecosystems in Consumer Electronics Supply Chains →

`sustainability.google/reports`

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01
Introduction

At Google, our mission is to organize the world's information and make it universally accessible and useful.

We believe in the power of knowledge and are committed to sharing it in ways that positively impact people and the planet. Many companies have engineered sustainable solutions with impressive results, and it's imperative that we all pursue this. Recognizing the numerous and difficult challenges in building a sustainable future, we believe innovation in sustainability should be a collaborative endeavor, not a competitive one. We also believe that sustainable product solutions should not compromise the product experience and encourage customers to embrace them without reservation.

This guide shares how we've approached recycled materials and the solutions we've used in our products. Our goal is to empower others with helpful insights, inspire further progress, and accelerate the transition to a sustainable future.

Collaborative development

Designing products with recycled materials is not an individual endeavor. It demands a symphony of expertise, with art and science working in harmony.

Collaboration is the engine driving innovation. Designers and product engineers advance the product vision while navigating a web of technical constraints and circularity goals to create viable and delightful products.

Concurrently, material engineers select, test, and validate recycled materials with suppliers, ensuring rigorous quality and performance standards are met. Alongside that, procurement, supplier development, and operations teams cultivate a network of supply chain partners and commercial engagements capable of producing the envisioned product. As concepts solidify, reliability engineers test prototypes for durability, safety, and long-term performance while manufacturing and process engineers optimize production for quality and efficiency.

This interplay – design vision shaped by material reality, validated by testing, and refined by manufacturing – is essential for unlocking sustainable solutions.

Successfully embedding recycled materials extends beyond technical execution – it requires folding this progress into the brand experience, marketing the innovation, and articulating a commitment to sustainability. This, in turn, builds momentum and helps scale opportunities to future generations of products. This end-to-end collaborative process is fundamental to delivering environmentally conscious products that resonate with consumers.

02

Why we focus on recycled content

- Reducing waste
- Reducing pollution
- Reducing carbon
- Our public commitments
- Our perspective on bio-based plastics

Reducing waste

Google products are built with many different recycled materials, including plastics and metals, to reduce our environmental impact. This guide details our approach to designing, engineering, and validating their uses in mechanical parts without compromising product quality.

Our sustainability strategy for all these materials is the same. We believe that creating strong demand for recycled materials in new product manufacturing drives the infrastructure and marketplace improvements needed to expand the circular economy.

Waste generated from all material types poses a challenge, and plastic pollution in particular is a growing concern. Only about 9% of all plastic ever created has been recycled, with the majority ending up in landfills, polluting natural environments, or being incinerated.[1]

Global recycling infrastructure faces difficulties in handling contaminants ranging from small items like stickers and food waste to heterogeneous materials within plastic waste streams. Varying consumer services, limitations in sorting technology, and differing recycler capabilities create a complex challenge in designing effective solutions. At the same time, many consumers want to recycle their waste. Research has shown that 85% of Americans believe strongly in recycling.[2]

Recycling is a business, so it requires both supply and demand to function effectively. We hope that by creating demand for recycled materials and enabling others to do the same, we can expand the supply chain for these materials and reduce waste.

1 The world's plastic pollution crisis, explained
National Geographic, 2024

2 Americans Strongly Believe in Recycling
The Recycling Partnership, 2020

Reducing pollution

Using recycled material avoids many mining and refining processes involved in creating primary materials. These often involve the use of industrial chemicals that can harm biologically diverse ecosystems and human communities that often lack the ability to effectively advocate for better environmental controls.

Mining operations are sometimes situated in areas designated as protected or recognized for their biological diversity.[3] Mining processes generate byproducts, which can contaminate groundwater and nearby waterways. That contamination can affect wild aquatic species, migratory animal populations, commercial fisheries, livestock, and water sources for nearby communities.[4] Additionally, airborne particulates from mining activities potentially increase human health risks for mine workers and people in adjacent communities.

In some instances, the drive to increase mining production and access ore-rich sites has resulted in community displacement.[5] Deep-sea mining is being considered to potentially lessen impact on the land. However, the full scope of its ecosystem impact remains unclear, particularly as ocean site surveys continue to reveal species previously unknown to science.[6]

One example of where primary material refining processes creating health issues is the petrochemical plants and oil refineries in an 85-mile stretch of Louisiana along the Mississippi River known as "Cancer Alley." The EPA determined in a study that near one manufacturing plant in this area, chloroprene emissions have made the risk of developing cancer from air pollution about 50 times greater than the national average.

The study also found that significant numbers of people within 1.5 kilometers of the plant also experienced chronic symptoms including chest pain, heart palpitations, difficulty breathing, headaches and dizziness, eye pain, coughing, sore throat, skin rashes, and fatigue.[7]

Recycling involves a variety of technologies and processes. However, formalized supply chains for most recycled materials will likely have a lower environmental impact compared to what's required to create primary materials. Beyond manufacturing primary materials, landfilling waste or improperly discarding it in the open environment poses additional risks that can generally be mitigated through recycling. All of these reasons make recycled materials a better choice for our products and make the circular economy a better system for people and our planet.

3 Mining Is Increasingly Pushing into Critical Rainforests and Protected Areas *World Resources Institute, 2024*

4 Mining Conflict in Madagascar *Climate Diplomacy, 2025*

5 Mining-induced displacement and livelihood restoration: A data-driven approach *School of Biological Sciences, 2025*

6 State of the Science Fact Sheet: Deep Sea Mining *National Oceanic and Atmospheric Administration, 2025*

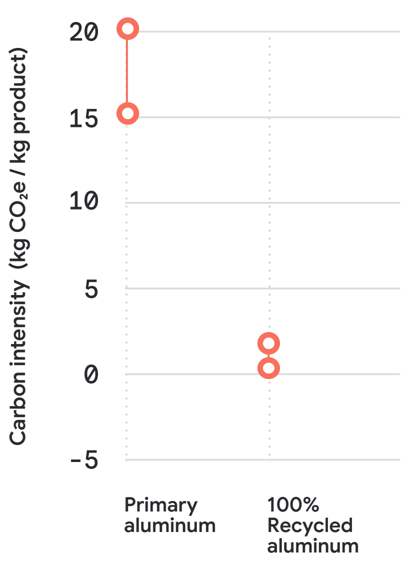
7 Waiting to Die: Toxic Emissions and Disease Near the Louisiana Denka / DuPont Petrochemical Plant *University Network for Human Rights, 2019*

Reducing carbon

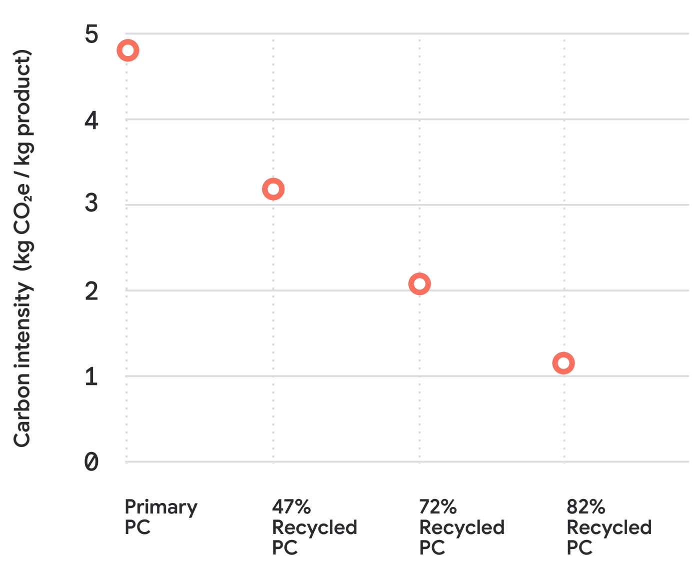
Recycled materials often have a lower carbon footprint than primary materials.

Mining raw materials and refining them to produce metals such as aluminum, stainless steel, titanium, and magnesium incurs a substantial carbon footprint. While plastics have a much lower carbon footprint compared to metals, recycled versions also realize a notable carbon reduction compared to primary plastics.

Comparing primary and post consumer aluminum



Post consumer recycled polycarbonate (PC) plastic resins



We set a goal to include recycled materials in 100% of Google consumer hardware products launching in 2022 and every year after.[9]

We first achieved this goal in 2020 for our Nest, Pixel, and Chromecast devices, and have maintained it for these products launched each year since.[10]

Our public commitments

We see the opportunities recycled materials offer, and we've made a public commitment to use recycled materials throughout our product portfolio.[8] We've achieved this and also maintained high standards for material quality and design.

But there is more do. Extending product lifespans and increasing participation in recycling programs are also important. Beyond that, circular supply chains still have the potential for environmental and social impacts that are important to understand and address. Respecting the health and safety of workers and communities everywhere is essential, and we encourage active participation in industry collaborations to improve it.

[8] Our hardware sustainability commitments, *Keyword Blog, 2019*

[9] Doesn't include third-party products such as the Nest x Yale Lock.

[10] For products launched in 2020 and 2021: Nest, Pixel, and Chromecast devices are made with recycled plastic ranging between 9% and 68% based on weight of plastic used in each respective product launched during this timeframe. The following items are excluded: plastics in printed circuit boards, labels, cables, connectors, electronic components and modules, optical components, electrostatic discharge (ESD) components, electromagnetic interference (EMI) components, films, coatings, and adhesive

Our perspective on bio-based plastics

In Google's material selection process for plastic parts, we consider post consumer recycled (PCR) plastic to have the highest sustainability value. We also prioritize the use of post industrial recycled (PIR) plastic sourced from manufacturing waste streams.

If an appropriate recycled plastic cannot be sourced, the preferred alternate material is bio-based plastic made from renewable agricultural feedstocks instead of fossil fuels. When using a bio-based material, we pay careful attention to where the feedstock comes from to ensure it is responsibly sourced. However, we still consider it environmentally preferable to use recycled plastics instead of bio-plastics to reduce waste. Even if it uses renewable, sustainably grown material, bio-plastic manufacturing doesn't stimulate demand to draw more waste plastic material into recycling systems and circular supply chains.

Some bio-plastics, but not all, are designed to be compostable. But we do not consider these be circular in the context of consumer electronics. Compostable plastic does little to enrich compost. Its main benefit is capturing more residual food waste into the composting system that might be left in a compostable food package. That is why compostable certifications aren't offered for electronics or other products not associated with food or green yard waste.[11]

"Biodegradable plastic" is another category that we do not consider to be circular. It's created by applying an additive to a fossil fuel-based plastic to help it break down into smaller pieces. This process actually creates microplastics that can contaminate the ecosystems we depend on to source food and water. In some places like California, laws are in effect restricting the use of the term "biodegradable" as a sustainability claim.[12]

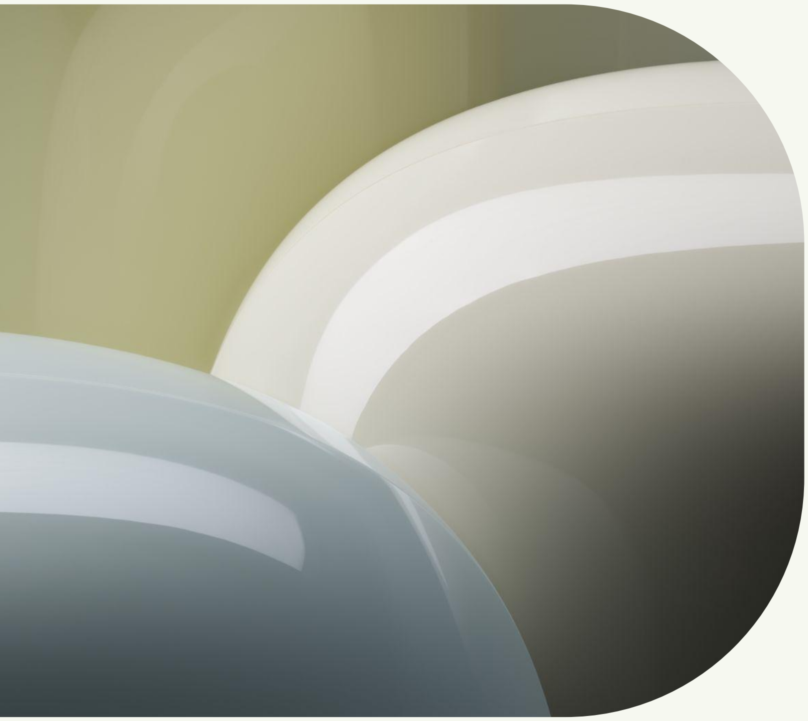
[11] BPI Compostability Certification

[12] Truth-in-Labeling Laws Protecting California Consumers from False Marketing Claims *CalRecycle, State of California*

03

Post consumer, mechanically recycled

Polycarbonate PC



Defined

For the recycled polycarbonate (PC) used widely across our product portfolio, we typically use post consumer recycled (PCR) plastic taken from clear scrap parts such as car headlamp covers, plastic water bottles, and safety glasses.

Transparent plastics are intentionally chosen to ensure our high cosmetics standards are met. These plastics are shredded, washed, and sorted into different grades of clarity and color. Then our suppliers add our desired colors as well as reinforcing fillers and performance additives as needed. The recycled plastic is then extruded into pellets for injection molding using the same process as non-recycled, primary plastic.

Note that the certified PCR plastic is not the same as plastic made from “regrind.” Regrind is made from unused plastic parts created during manufacturing that are ground up and reintroduced into the molding process. PCR plastics have several additional cleaning and control steps to ensure quality before becoming a material used in product manufacturing.

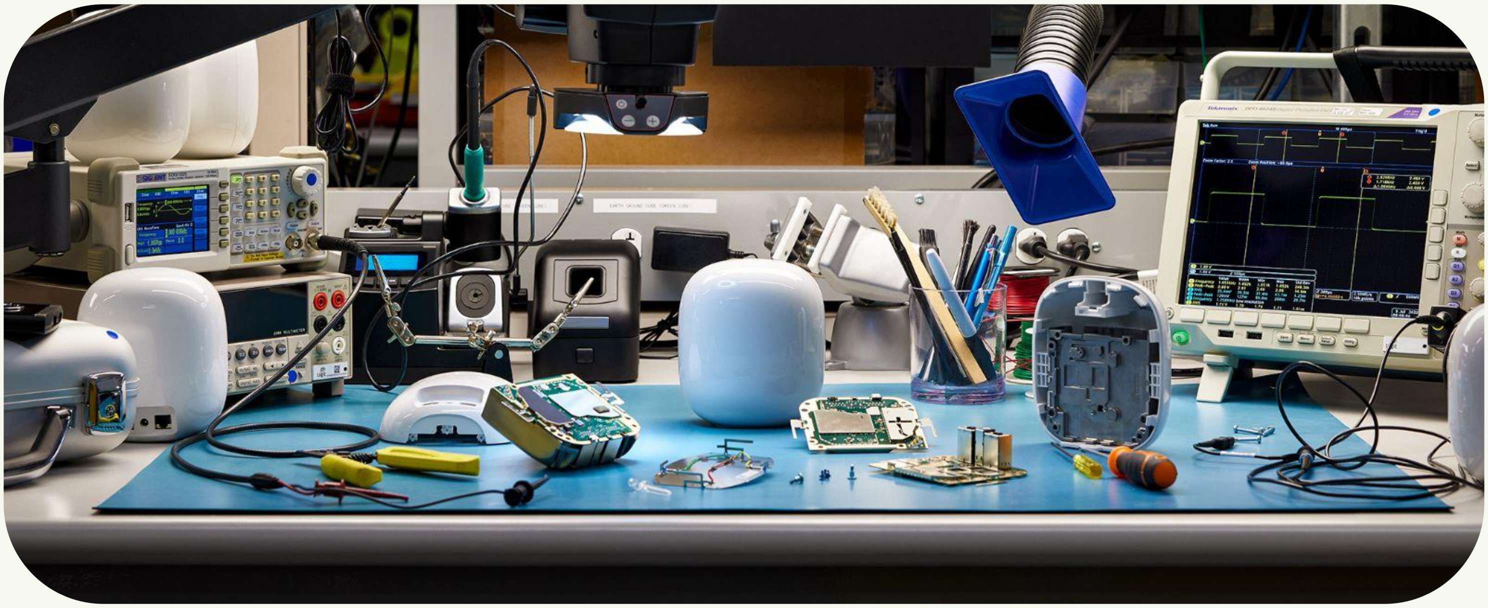
Calculating recycled content for mechanically recycled plastics

When calculating the recycled content percentage of a mechanically recycled resin, we typically divide the recycled polymer mass by the overall mass of the resin, which may include a non-recycled, primary polymer and additives such as flame retardants, colorants (dyes, pigments, etc), and UV stabilizers, as well as fillers like glass fiber. Some resins contain 100% recycled polymer mass, but are only 95% recycled content as a resin due to additives and fillers that make up the remaining 5% of the resin mass. Some additives and fillers are available from a recycled source and would count towards the recycled content mass of the resin. For example, for some resins we have sourced recycled glass fiber which can be a significant recycled mass contributor.

Mass balance recycled content calculation

Another type of recycled content calculation is called "mass balance." This is often used with chemically recycled or bio-based materials when physical segregation of primary plastics is not feasible. For example, a company may combine chemically recycled or bio-based plastic feedstock with primary material. Once mixed, it is impossible to distinguish the materials from each other.

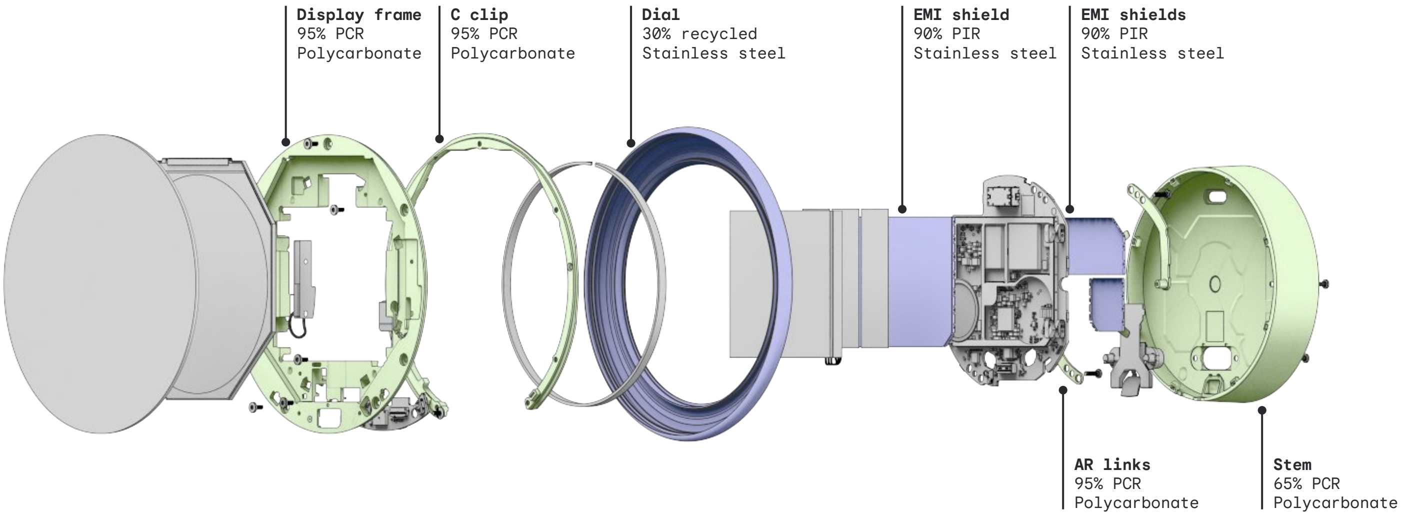
In order to claim an accurate recycled or bio-based content percentage, the supplier needs to carefully track the mass of each input material that enters the process and the mass of the output per standard methods. A qualified third party, such as UL, SCS Global, or SGS, should verify any such claims following the standards in ISO 14021.



Where we use recycled PC in our products

Polycarbonate (PC) is the main cosmetic enclosure material for our cameras, doorbells, speakers, thermostats, earbuds, Wi-Fi routers, and most phones, as well as internal structural parts and power adapters across the portfolio. PC is commonly used because of its impact resistance, colorability, recyclability, and combinability with other plastics such as acrylonitrile butadiene styrene (ABS) for more flow and polybutylene terephthalate (PBT) for added chemical resistance.

One of our early successes launching recycled plastic in a product was a 50% PCR PC for the internal frame of the Nest Thermostat E in 2017. In our newest thermostat, the 4th-generation Nest Learning Thermostat, we have been able to achieve between 65% and 95% recycled content in individual PC parts, including all cosmetic plastic parts.



For many of our products, we spent significant time demonstrating that transitioning from primary PC to 50% PCR PC was feasible.

After that, it was much easier to start to use higher PCR content materials (e.g., 85% or 95%) once commercially available. Also, demonstrating feasibility with one part in one product simplifies adoption across the portfolio and year-over-year improvements, making a much bigger impact over time.

To reduce manufacturing yield loss, complexity, and material footprint in our outdoor camera and doorbell, we investigated a solution to eliminate coatings on the enclosures that we had historically needed to mitigate degradation from UV exposure and address cosmetic flaws in the plastic parts.

Our material science, reliability, and product design teams collaborated with our resin supplier to develop a resin that could inherently handle outdoor environments, meet our cosmetic and other reliability specifications, and still include a high level of recycled content. This required tuning the additives in the resin and qualifying the estimated part color change over time in outdoor conditions. In 2025, after extensive experimentation and testing, the broader Google team including our operations and procurement teams came together to launch the Google Nest Cam Outdoor (wired, 2nd gen) and Google Nest Doorbell (wired, 3rd gen) with this new 75% PCR resin addressing long-term UV exposure without a coating.

Recycled PC: Development and testing

On a high level, when creating a product, we need to ensure all components fit together and that the product will survive the expected wear and tear of everyday use for years.

Our design specifications do not change when we use recycled materials, but a recycled plastic resin cannot always be substituted without some manufacturing process changes. Therefore, we must validate that the assembly and functionality of the product meet our original specification. This requires collaboration across hardware teams and the active engagement of suppliers from the beginning of product development and material integration. Perceived risks are real risks, and addressing concerns from all teams with performance data is important to ensuring successful product outcomes.

In this section we'll share what we've learned from using PCR PC as it relates to product integration, part-level design, material qualification, and molding considerations.

Product integration and part design considerations

Product-level integration considerations

- PCR plastic may have different mechanical properties compared to primary plastic, requiring adjustments to the processing window to achieve the desired part performance. Design and tool validations are crucial to understand if more margin is needed to accommodate recycled resins.
- Rigorous product-level reliability testing remains critical whether you are using a primary material resin or one with recycled content. Environmental testing combined with drop and impact testing from multiple angles can identify potential failure modes that the product could encounter during use.

Part-level design considerations

- Ensure minimum wall thickness requirements are understood in the part design to avoid risks, since the PCR material has slightly tighter molding tolerances.
- Engage design teams to define cosmetic specifications and limit samples. Because maximizing manufacturing yield is a major sustainability goal, teams should monitor how these decisions affect your yields.
- Coatings applied to plastic parts may affect reliability performance. For example, we have observed stress cracking due to a coating, which was consistent with both recycled and primary plastics.
- Both recycled and primary plastics age with time, including in their cosmetic appearance. Careful consideration of resin properties can help the product age gracefully. These can include color selection, UV additives, and coatings.

Material qualification and molding considerations

- **Low-quality recycled material carries risk.** Ensure the material comes from a reliable and high quality supplier, and track incoming resin cosmetic quality and performance over time.

- **Molecular weight (MW)** may be lower in a recycled resin than a primary material, but a good resin supplier will typically offset this by adding higher MW primary material and impact modifier additives to balance the overall formulation. The resulting resin should have almost equivalent MW to a comparable primary material resin.

- **Melt mass flow rate (MFR)** and **melt volume-flow rate (MVR)** shifts can occur, but small adjustments to molding parameters such as melt temperature, mold temperature, injection speed, injection pressure, and holding time can achieve the intended results.

- **Technical datasheet (TDS)** properties should be verified across multiple lots of the material for consistency, like impact resistance and tensile / flexural properties, even with high-quality primary material.

- **Recycled resin grades** may have a tighter processing window depending on their heat history. The cumulative heat exposure of a plastic over its lifetime can degrade polymer chains, resulting in reduced mechanical properties and changes to a resin's MFR. These risks can be mitigated by choosing a resin vendor that carefully minimizes heat exposure during recycling, adding stabilizers into the resin, and controlling processing temperatures while molding.

- **Shrink rates** may change when introducing recycled plastic material, requiring parameter and part design adjustments.

- **Black dots from contamination** are common in mechanically recycled PCR material. Because of this, light-colored cosmetic parts may require a specification or limit sample specifically for black dots. A root cause analysis of the source may be necessary if this issue causes significant yield loss in part manufacturing. Source material sorting, extrusion mesh filtration, and injection molding are all points where we have observed opportunities to reduce contamination.

  Not all suppliers use optical sorting in the initial source material sorting process, so we advise understanding how they sort out contaminated material.

- **Chemical resistance** may be reduced and require additives such as stabilizers or antioxidants. Depending on the plastic part's reliability requirements, chemically recycled material may be a better feedstock choice.

- **Color and finish** could be impacted. For example, a potential milky tint or slight gray shade could be visible in the final part. Understanding material limitations early will allow design and engineering teams to adapt their approach and achieve the desired cosmetic outcome.

- **Cycle times** do not generally change when using recycled plastics in our experience, especially after an injection molding supplier gains confidence in working with the new material.

- **Moldability** can always differ between resins, whether they are primary or recycled. While variations may be small, minor molding or tooling adjustments are always expected with any change in material.

Building supplier confidence

Injection molding suppliers may require additional time and resources to get comfortable with processing recycled plastics. Some suppliers may prefer to use primary material resins that they already understand well.

01. We had some suppliers start with an internal or non-cosmetic part and run several designs of experiment (DOEs) with both primary material and PCR material to compare dimensional stability, cosmetics, and reliability testing results (e.g., temperature cycling, impact, and chemical testing appropriate for the product).

02. Then we had them inject several parts from multiple lots (suggested: at least 3 parts from 3 lots) of the PCR resin and test them to ensure lot-to-lot consistency. Giving them time to run this testing and analyze the data will build their confidence.

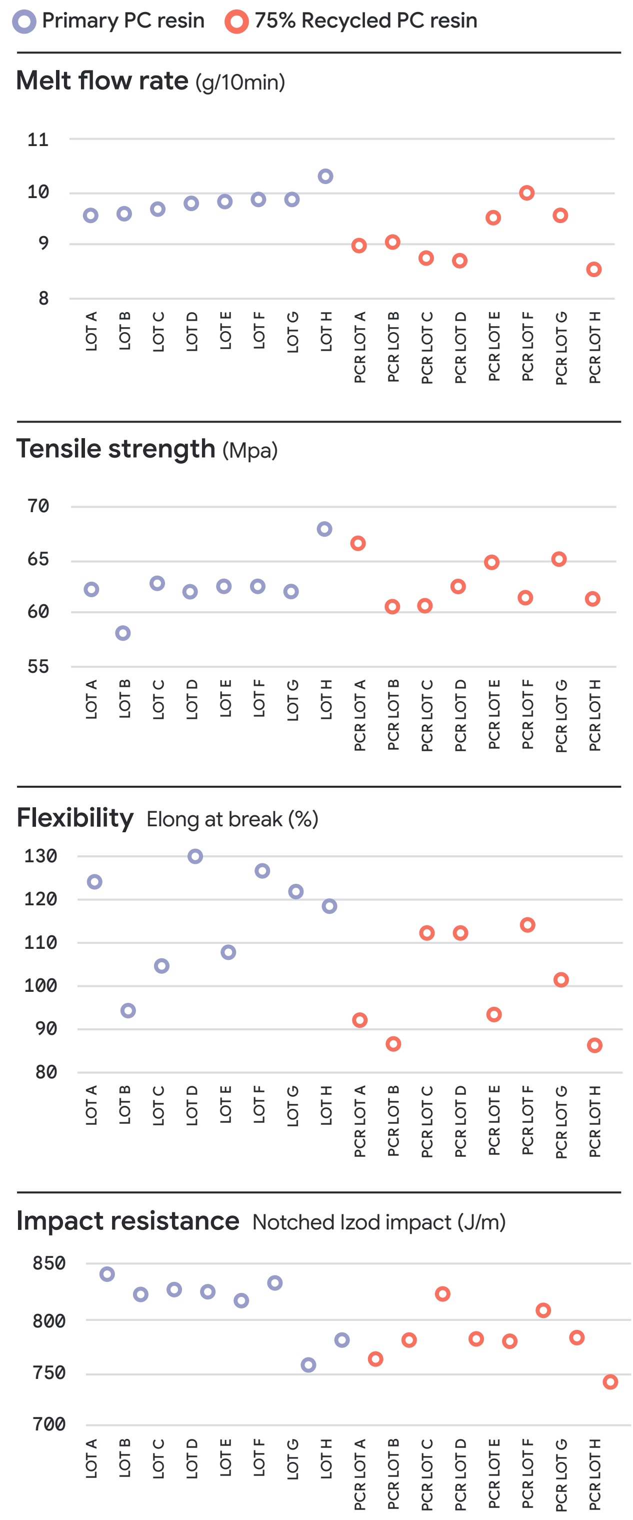
03. Once the risks had been addressed, the supplier ran the same trials with cosmetic parts.

Case study
Nest Thermostat

For the Charcoal version of the Nest Thermostat, we reached a new milestone, using a 75% PCR PC resin for the first time.

To validate the performance of the new material, we evaluated the properties of the resin itself and conducted extensive testing on parts manufactured with it. While recycled resins may have different characteristics and mechanical properties from primary material resins, manufacturers can adjust for these differences to ensure product quality. The charts below compare several lots of a primary material resin with the 75% recycled content resin used in the Charcoal Nest Thermostat, showing both differences and similarities between them.

Comparison of resin attributes by lot number



Case study

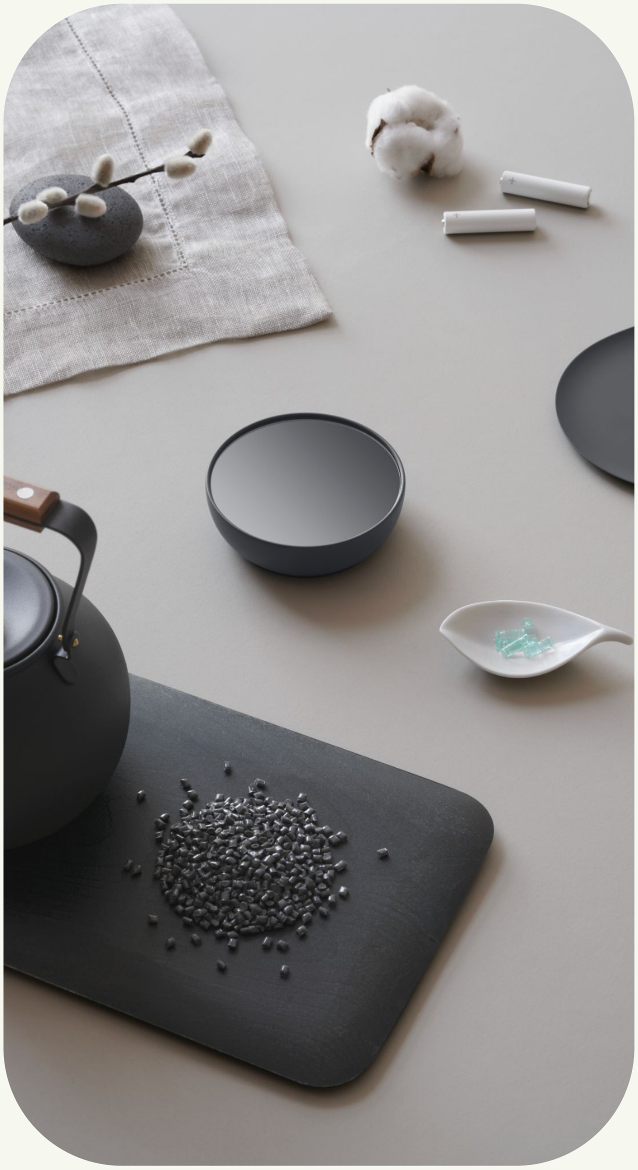
Nest Thermostat

(continued)

During part level testing we evaluated the following criteria:

- Dimensions (including flatness)
- Cosmetics: stress marks, color match, surface quality, yield (note: this is for a black part, so “black dots” weren’t observed)
- Ultrasonic welding capability
- Accessory fit (including a check after a heat soak test)
- Reliability: 6-point push, 3-point bend, temperature cycling, high temperature with high humidity, drop, ball impact, micro-drop, abrasion, salt mist, chemical

This extensive part validation found no significant difference between the 50% and 75% PCR resins. After launching this product, we quickly introduced the 75% PCR polycarbonate into other products in the Google Nest portfolio. We continued to validate even higher content PCR plastics, such as a 95% PCR content resin in the internal display frame of the Nest Learning Thermostat (4th generation).

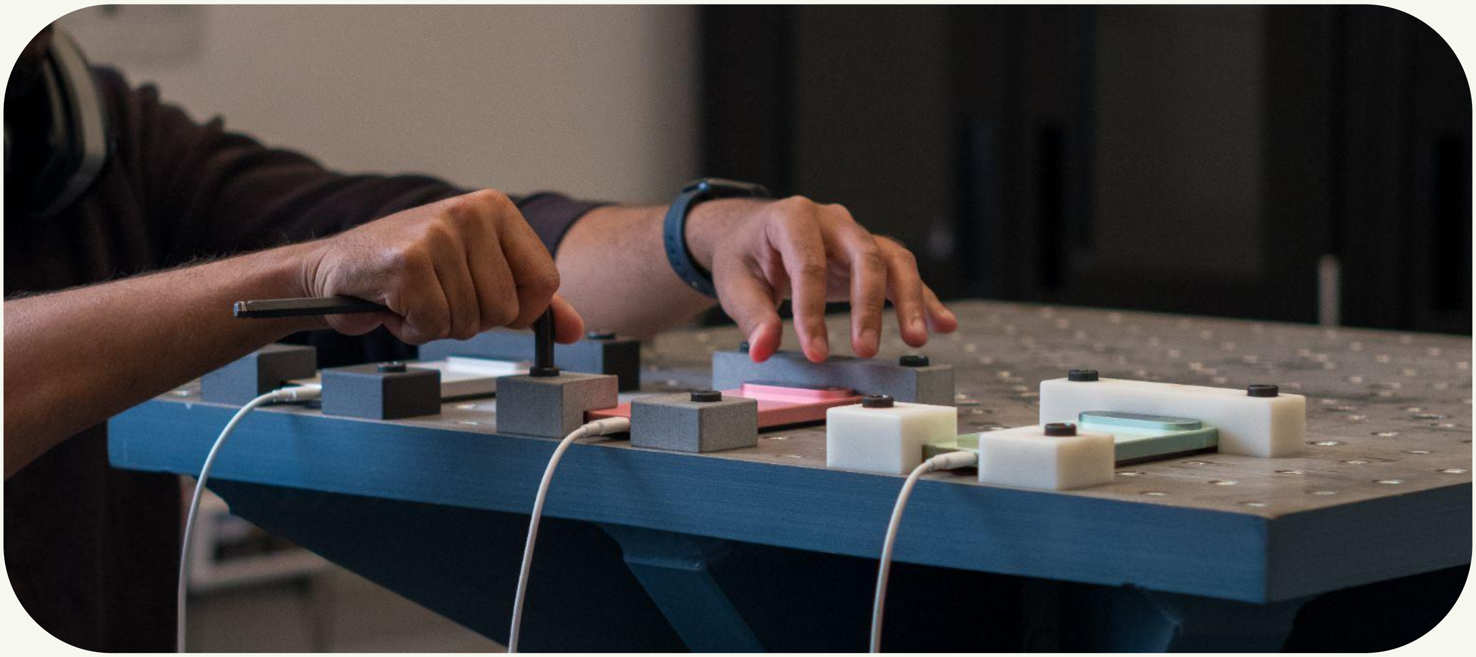


04

Post industrial, chemically recycled

Polybutylene terephthalate PBT

- → Defined
- → Where we use recycled PBT resin in our products
- → Recycled PBT: Development and testing
- → Case study: Pixel 10 series



Defined

We have validated a chemically recycled polybutylene terephthalate (PBT) resin which has two major recycling process differences from the recycled polycarbonate resins we use:

- The PBT resin grade we use in our products contains post industrial recycled (PIR) material.

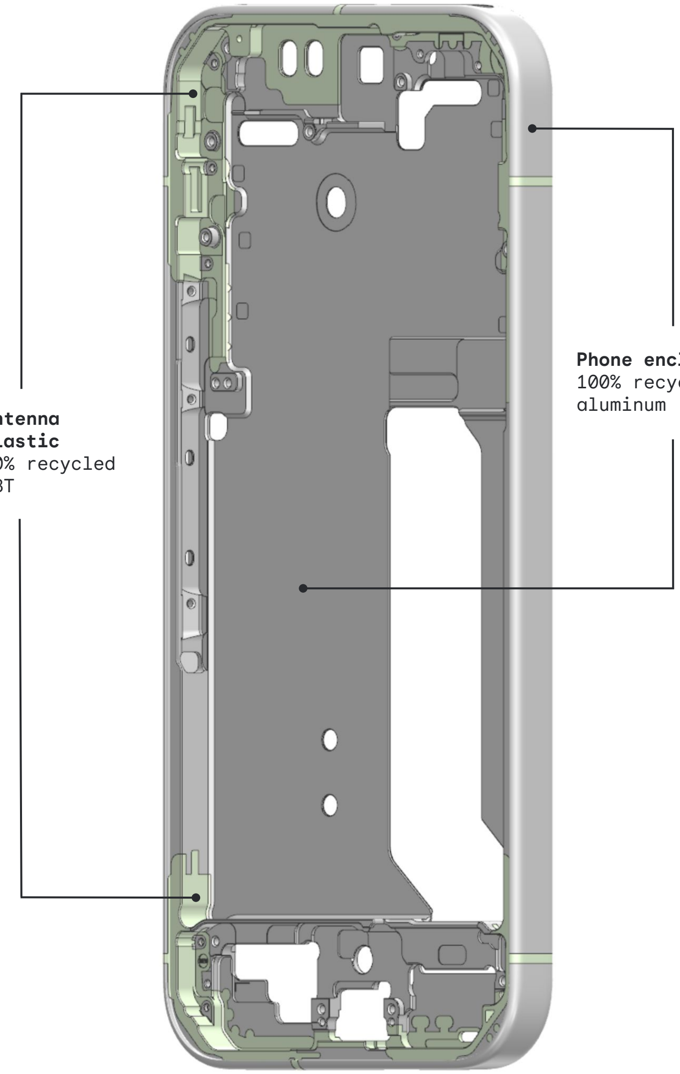
- The PBT is also chemically recycled, rather than mechanically. Scrap PBT plastic is de-polymerized into its chemical building blocks, filtered for impurities, and then re-polymerized to make recycled PBT.

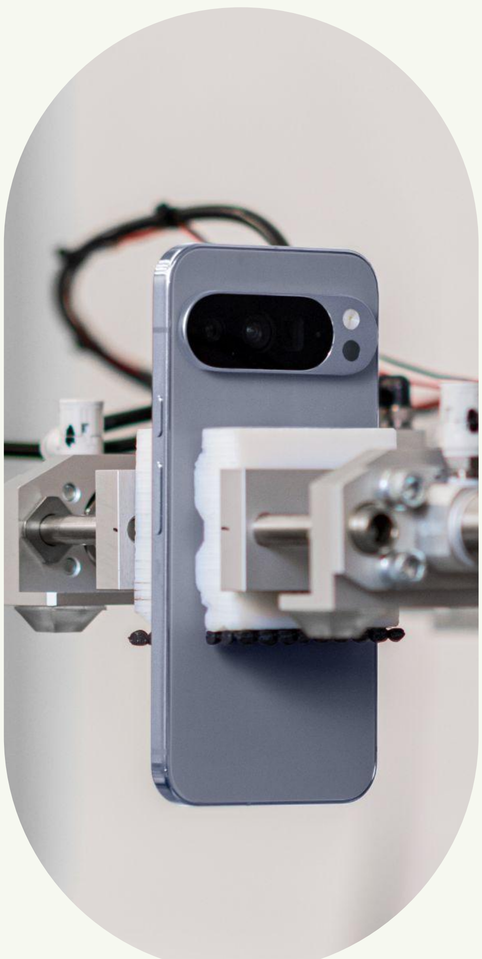
PBT resin is widely available in PIR and PCR forms. We selected a PIR resin that achieved the maximum recycled content with the material performance properties we needed.

Where we use recycled PBT resin in our products

Recycled PBT for enclosure parts is one of the largest uses of plastic in our Pixel products.

Some of the characteristics of PBT that make it work well for antennas include its dielectric properties, resistance to heat and chemicals, high mechanical strength, colorability, and dimensional stability.





Recycled PBT: Development and testing

Development and use of a chemically recycled PBT required deep technical expertise, robust testing, and close partnership with our suppliers.

Our product teams collaborated with our supplier to ensure consistency of viscosity, dielectric properties, colorability, and mechanical strength specifications. We also validated lot-to-lot consistency, and refined manufacturing processes.

Key insights

- Enclosure parts require significant post-processing, such as CNC machining. To ensure recycled materials wouldn't affect performance or quality, we tested both primary and recycled PBT throughout the manufacturing process, including CNC machining and other post-processing steps.
- While material suppliers provide test results during initial qualification, we performed independent testing and quality control screening to verify the material would work in our application.
- Batch-to-batch variability of any raw material could result in inconsistent performance. We conducted extensive qualification testing across multiple batches of resin, hundreds of subassemblies, and full product units to ensure consistent reliability and cosmetic performance and found low variability with our selected resin.

PBT **Post industrial, chemically recycled polybutylene terephthalate**

Case study

Pixel 10 series

Testing the dielectric and mechanical properties of a product when using PBT resin that has been treated with pigment packages is important.

We also know that cosmetic color inconsistency can arise from glass fiber and other additives after post-processing of finished enclosures. All of these issues had the potential to lower part yields and generate more waste.

To prevent that, we validated all colors of PBT resin for Pixel 10 series phones with both primary and recycled PBT resin to ensure there was no impact to performance or cosmetic outcomes due to recycled content.

We also performed a variety of tests on the enclosures with recycled PBT including drop, heat soak, tumble, 3-point bend, chemical, hardness, UV weatherability, wet denim abrasion, and metal bonding strength. That data showed that the chemically recycled PBT performed the same as a primary PBT resin for our application.

Our system-level reliability test results also showed strong performance. We tested fully assembled phones for air leaks, antenna performance, bonding strength, and color matching. In all instances, the devices showed no performance loss.

05

Recycled Polyester PET in softgoods

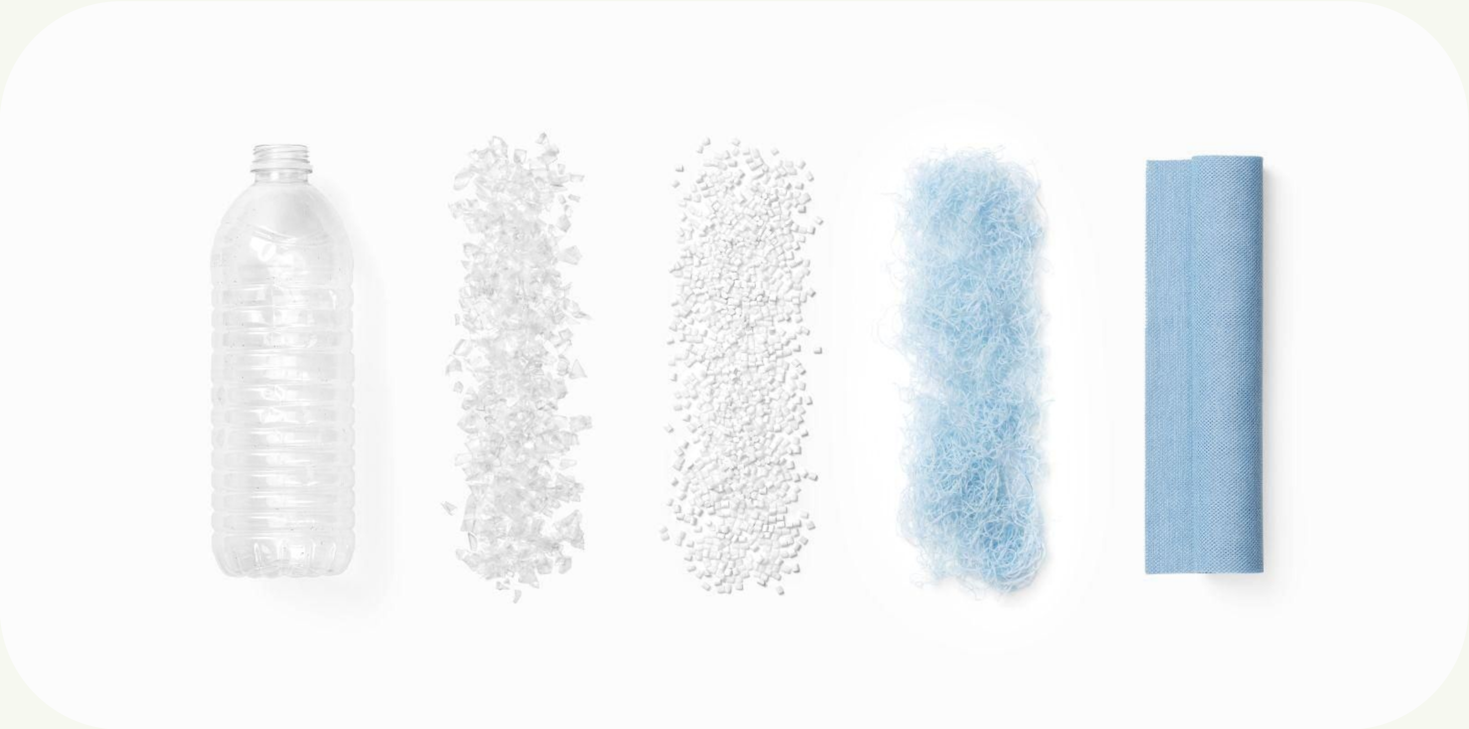
Defined

Recycled polyester (PET) is now a very accessible and mature material for yarn suppliers to work with, and can come from PCR content, PIR content, or a combination of both.

Some PCR content can come from recycled water bottles, and PIR content tends to come from yarn or textile factory scrap. The source material is crushed, washed, sifted, dried, melted into resin pellets, and then drawn, spun, and textured into yarn before being woven or knit into a textile.

Our partially recycled microfiber is made from a combination of PCR, PIR, and primary polyurethane which we customize with our color choices. Across all the products we have developed with recycled polyester yarn, there have been only negligible material property differences compared to a primary PET yarn, with no impact to the durability of our finished product.

Recycled polyester in softgoods

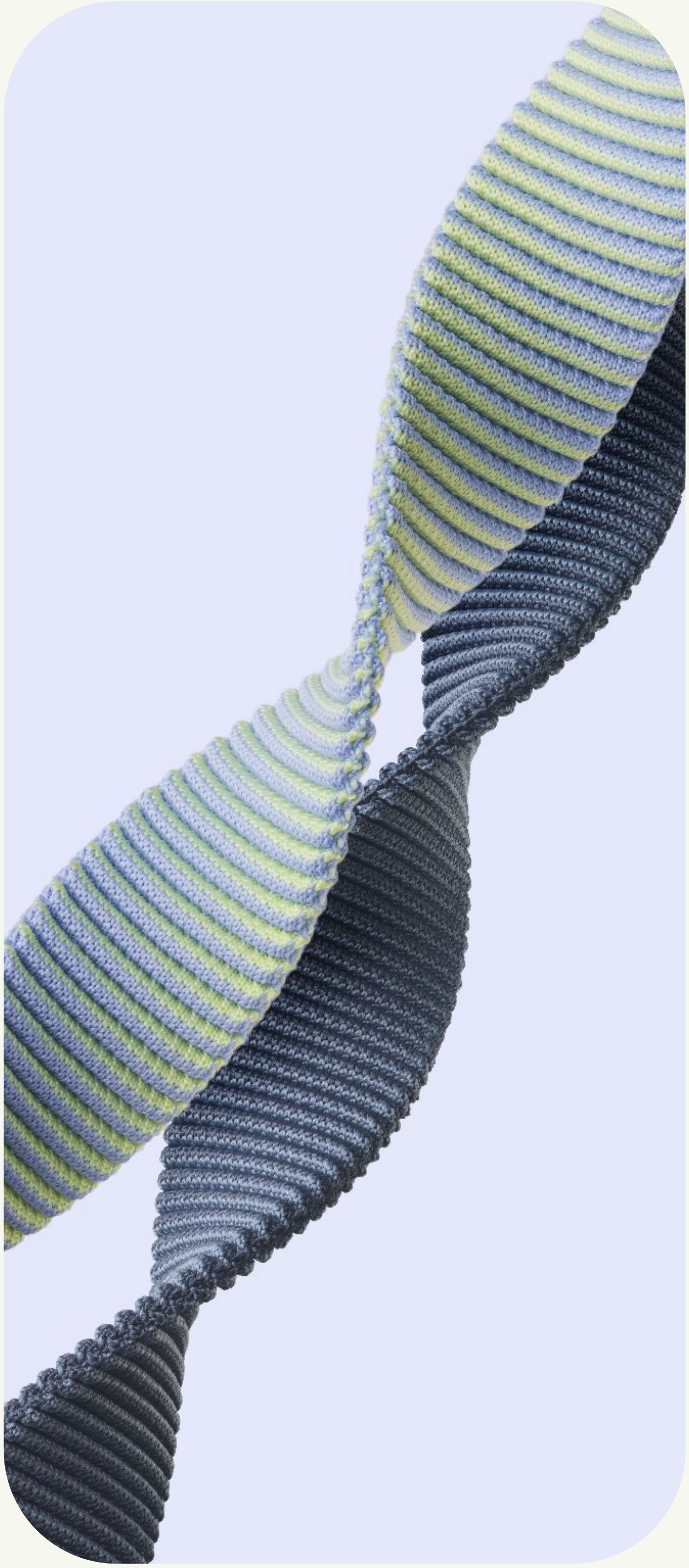


Where we use recycled PET in our products

We use recycled PET in the yarn of our speaker product fabrics and textile-based watch accessory bands (including the Pixel Watch Performance Loop Band, Woven Band, and Stretch Band). We designed the fabric to provide an enhanced texture on our speaker products and achieve the added benefit of veiling cosmetic variances that would otherwise create additional manufacturing yield waste.

The recycled PET microfiber on the inside surface of the Pixelsnap Case for Pixel 10 is also made with 92% PCR and PIR recycled content. It has a premium feel and reduces scratching risk between the product and the case.

Recycled yarn: Development and testing



Key insights

- In developing Pixel Watch textile bands, we specifically looked for recycled PET yarns with mechanical properties that would meet our product specifications and support different design needs. We validated that these recycled materials performed the same as primary PET yarn for our applications and maintained durability without compromise.

- Some trade-offs do exist with some recycled materials. In developing our Pixel Watch Performance Loop Band, we observed premature fuzz from recycled nylon in our testing and concluded that the recycled content benefit did not justify a shorter useful life for the band. Despite that, we achieved 48% recycled content in this band with recycled PET alone, and continue to evaluate options for more recycled content without a performance or longevity impact.

- We also evaluated recycled elastane for the Pixel Watch Stretch Band, but discovered non-recoverable lengthening of the material in our testing, so we've opted for primary elastane to avoid performance degradation. However, using primary elastane only resulted in a minimal reduction of 4–5% in total recycled content since the band is primarily made with recycled PET.

Recycled polyester in softgoods

Case study
Google Home Speaker

Textiles have become a key design element in smart home products for many years.

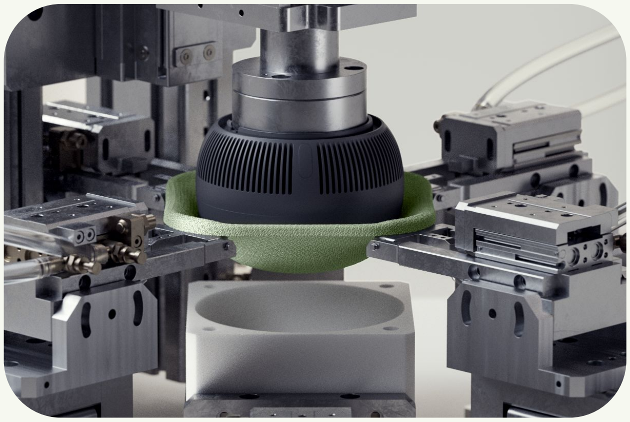
For ours, we've engineered recycled PET into an acoustically transparent fabric that preserves audio quality. We created many different colored yarns and twisted and knitted them together into a triple-pique 2D fabric.

In our previous-generation products, such as Nest Mini, fabric was bonded to the speaker enclosure with significant adhesive and then tested for rub and buzz, audio quality, and mic performance impact.

Our latest Google Home Speaker is crafted with 39% recycled materials, including an innovative 3D-knit enclosure fabric.[13] The fabric is robust, with improved yarn twisting and tension control compared to previous products. Knitting yarn into a 3D part also reduces material waste from offcuts traditionally generated from a 2D fabric design. This technique uses approximately 63% less material and requires no adhesive to wrap it over the product housing.[14]

This design also enables manufacturing rework processes. If a defect is found during assembly in either the 3D fabric or the plastic housing, the other part can still be used, reducing both material yield waste and cost.

The 2D fabric in Nest Mini was bonded to the enclosure with adhesive.



The Google Home Speaker features a tensioned 3D-knit enclosure fabric wrapped over a plastic housing without any adhesive. This means if one part has a defect, it can be easily replaced without damaging the other one.

[13] The recycled materials are at least 39% of product based on weight.

[14] Fabric usage measured by fabric utilization.

06

Recycled

Aluminum & stainless steel

Al SUS

- Defined
- Where we use recycled aluminum & stainless steel in our products
- Recycled aluminum enclosures: Development and testing
- Stainless steel certification challenges
- Case study: Pixel 5

Defined

We strive to maximize the recycled content of our metals to reduce waste and carbon intensity.

For more information on how we address the carbon footprint of our products, see our **Consumer Hardware Carbon Reduction Guide**.

In many cases, metals used in the manufacturing industry already have some level of recycled content, but it isn't always certified by a third party. For Google products, we ensure that suppliers provide a third-party certification for every metal alloy used where we make a recycled content claim. This certification may be for PIR or PCR content, or a combination of both. This is required for all parts where we have specified recycled material in our product designs.

Recycled aluminum & stainless steel

Where we use recycled aluminum & stainless steel in our products

We use recycled extruded aluminum for the enclosures of our phones, tablets, and watches, and recycled diecast aluminum for heat sinks in some camera and phone products.

We also use recycled stainless steel in the dial for the Nest Learning Thermostat (4th gen) as well as many electromagnetic interference (EMI) shields for printed circuit boards across our portfolio, including in the Pixel Watch 4.

Recycled aluminum enclosures: Development and testing

Achieving 100% recycled aluminum for Pixel phone enclosures required extensive validation and a dedicated certification effort. While recycled content is common in aluminum, consistency and certification are not.

When we first started evaluating 100% PIR aluminum, the largest concern was cosmetic part quality with a new raw material stream, including anodizing quality, metal porosity, and impurity levels. Our team created a alloy specification with identical mechanical properties between recycled and primary aluminum grades. We defined iron and zinc impurity limits in the specification to prevent anodizing quality issues, and created limit samples to ensure cosmetic consistency.

We successfully validated the functional and cosmetic outcomes for our recycled aluminum alloy and then worked with our suppliers to adopt this lower carbon footprint material across a wide range of products.

Recycled aluminum & stainless steel

Stainless steel certification challenges

The Nest Learning Thermostat (4th gen) includes a stainless steel dial, and like all product parts, we wanted to explore opportunities for using recycled content. We discovered, however, that while the stainless steel supply chain often uses some level of recycled content, it is not typically tracked or certified in the manufacturing of parts or material batches.

Certification for recycled content is essential for us both to verify the material being used as well as to track our progress in circularity over time. To achieve this for the Nest Learning Thermostat dial, we collaborated with our suppliers to measure and track the recycled content of our chosen alloy. While the actual recycled content in stainless steel can vary, our supplier was able to guarantee and certify a minimum percentage. As a result, the 30% recycled content level certified for our material is conservative and potentially lower than the actual amount used in the final part.

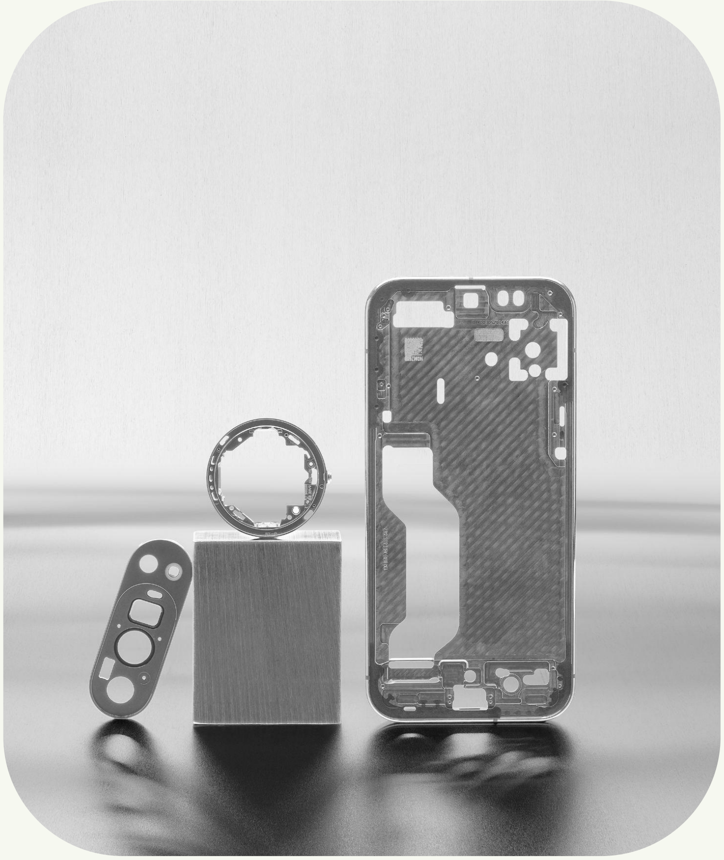
We hope recycled content certification for stainless steel becomes a standard industry practice to broaden the options brands have, lower the environmental footprint of their materials, and enable more circular options for supply chains in general.

Recycled aluminum & stainless steel

Case study
Pixel 5

For Pixel 5, we eliminated primary aluminum in the enclosure to reduce waste, which also lowered the carbon footprint of manufacturing the enclosure by 35%.[15]

Since then, we have expanded the use of recycled aluminum across the portfolio, including 100% recycled aluminum in the enclosures of all Pixel phones since Pixel 6, Pixel Watches since the Pixel Watch 2, and the Pixel Tablet.[16]



[15] Carbon footprint reduction claim based on third-party verified life cycle assessment.

You can read more about this journey on our **sustainability website**.

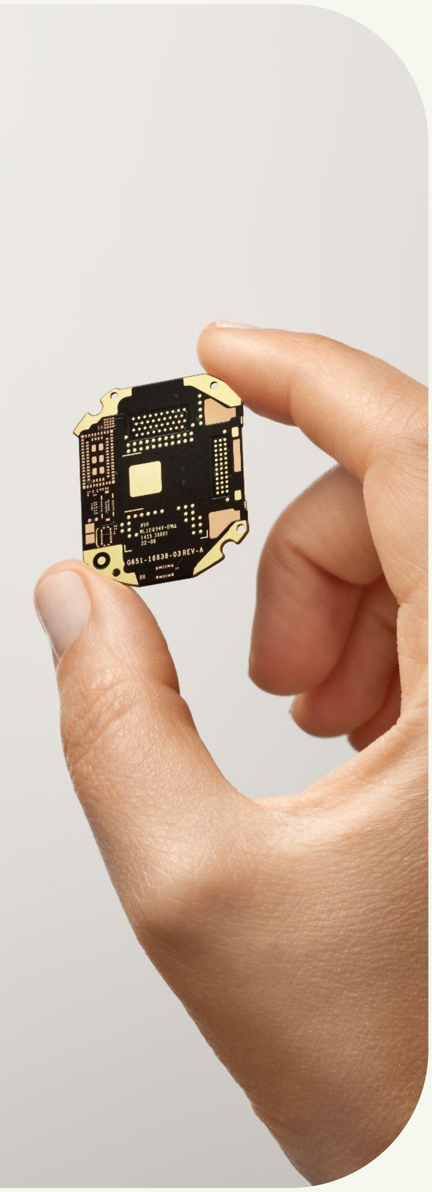
[16] Recycled aluminum in the enclosures is at least 3% of Pixel Watch, 9% of applicable Pixel phones, and 25% of Pixel Tablet product based on weight. This 100% recycled content claim excludes Pixel 5a.

07

Recycled critical minerals

Copper, gold, tin, cobalt, tungsten & rare earths

Defined



Pick up a Google device, and you'll know right away that we take pride in design. But it's the intricate components hidden inside that truly define a consumer electronics product.

Built with a complex suite of critical minerals, electronics rely on metals such as copper, gold, tin, cobalt, and tungsten, and rare earth elements including praseodymium and neodymium, to perform a number of key functions. These materials require energy-intensive mining and refining processes with significant environmental footprints and complex social implications.

When we set out to incorporate recycled critical minerals into our products, we had the fundamental engineering goal of making no specification changes at the material, component, or product design level. As discussed earlier in this guide, the plastic recycling process can affect properties like impact strength and color consistency, requiring engineering teams to account for these differences. For metals purified to the molecular or alloy level, however, the distinction between primary and recycled material is less relevant. Whether copper comes from a mine or is reclaimed from a discarded industrial cable, its conductive properties, thermal characteristics, and ductility can remain functionally identical at a specified purity level.

We did not ask our electrical and mechanical engineering teams to design around recycled metals, or to modify performance standards to accommodate them. Instead, we engaged our supply chain partners to find recycled alternatives that met our existing technical specifications for mined materials, often requiring 99.9% purity or more.

By proving that recycled gold, tin, copper, cobalt, and tungsten could be dropped into existing manufacturing processes like plating baths, solder paste printing, and battery cathode formation, we removed the need to redesign and re-engineer parts. We demonstrated that sustainability does not require a compromise in performance. It simply requires more refined criteria in material sourcing.

Engineering the supply chain, not the part

Because material specifications remain constant, the burden of innovation shifts from product design to supplier development. Success in integrating recycled critical minerals requires partnering with suppliers who can guarantee the integrity of their materials and processes. This is crucial to reaching recycled content targets. Our process followed a multi-stage validation path:

Material survey and partner selection

We looked for component suppliers that were capable of integrating high-purity recycled minerals into their material sourcing operations.

Third-party certification

For each material, we required verification from a qualified third party, such as UL, SCS Global, or SGS, that it was truly post-industrial or post-consumer recycled content following the standards in ISO 14021.

Material verification

We reviewed technical data sheets as well as testing data to ensure the recycled materials matched the performance of mined materials.

Product and manufacturing verification

We integrated these materials into hardware builds in our product development process to verify manufacturability and quality at scale.

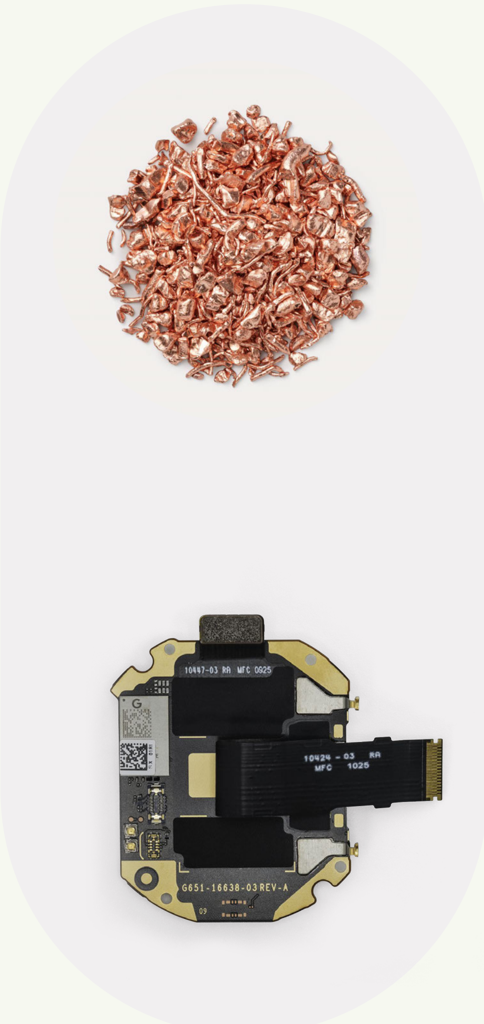
Documentation

Finally, we added these requirements into our component documentation and supplier agreements, formalizing their use for mass production.

Other consumer electronics brands have also been instrumental in developing these supply chains. Demand for high-purity recycled copper, gold, tin, cobalt, tungsten, and rare earths from industry has prompted suppliers to expand their material sourcing capabilities and convert more waste streams to useful recycled material.

Recycled critical minerals

Recycled copper



Copper is essential for electronic devices. It's used in the foundational structure of rigid printed circuit boards, foils for flexible printed circuits, and thermal management components.

Our transition to recycled copper necessitated evaluating the availability of recycled content in different forms.

In the manufacturing of printed circuits, two types of copper foil are generally used: rolled annealed (RA), made by mechanically rolling copper ingots into thin sheets, and electro-deposited (ED), created using electrolysis to deposit copper from a solution onto a rotating drum. Due to supply limitations, it can be difficult to source 100% recycled RA copper at scale. However, recycled ED copper foil was available through our main logic board suppliers.

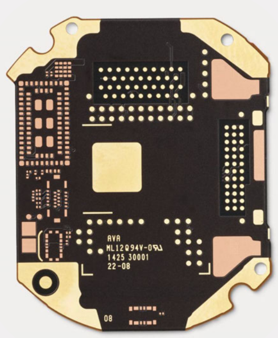
This made integration into our part specifications straightforward. But in addition to the foil, a significant amount of copper is added to a phone during the plating process that builds up conductive traces on a circuit board. Switching this use of copper to recycled content in Pixel phones required changing how the chemicals that contain copper in this process are sourced. Our suppliers successfully qualified and integrated recycled copper oxide powder, copper anode balls, and copper sulfate for use in plating baths.

By using 100% recycled copper in the main logic boards for Pixel 10 series phones and the Pixel Watch 4, we are reducing our environmental impact. Producing copper from 100% recycled sources reduces the carbon footprint of the copper by approximately 90% compared to mining and refining ore.[17] Furthermore, recycled copper reduces reliance on copper mines, many of which are in water-stressed regions and areas of high ecological value.

[17] A Recycling Champion
International Copper Association, 2018

Recycled critical minerals

Recycled gold



Gold's corrosion resistance makes it essential for high-reliability connectors.

Artisanal and small-scale gold mining often relies on mercury amalgamation, in which miners mix liquid mercury with crushed gold ore. This dangerous process separates the gold from surrounding rock and dirt, but it releases mercury vapor into the air. It also leaves mercury in the waste rock, generating massive amounts of toxic tailings.[18]

In an effort to end our reliance on mined gold, we revised our part specification to use 100% recycled gold in our main logic board plating processes without compromising the "hard gold" durability required for connectors.

Technical performance

As we did with copper, we partnered with suppliers who could source recycled gold with the same 99.99% purity specification we traditionally used.

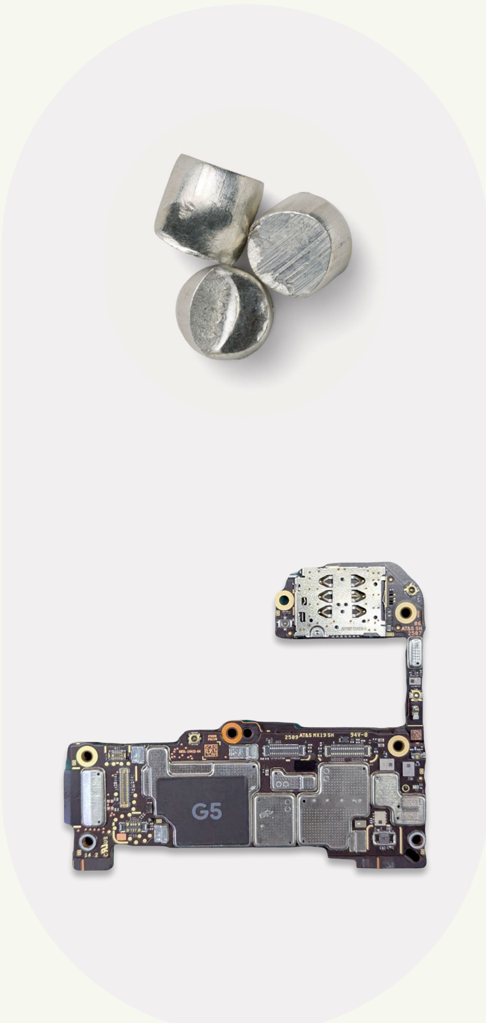
During validation, we paid close attention to contact resistance and found contacts plated with recycled gold to be indistinguishable from those plated with mined gold. This allowed us to reduce the carbon footprint of the gold in the main logic boards of our Pixel 10 series by over 90%.[19]

18 Artisanal and Small-Scale Gold Mining (ASGM)
Global Mercury Partnership

19 Environmental impact of high-value gold scrap recycling
The International Journal of Life Cycle Assessment, 2020

Recycled critical minerals

Recycled tin



Tin is a key component of the solder paste used in printed circuit boards.

Our transition to 100% recycled tin in the solder of multiple printed circuit boards, including the main logic boards of Pixel 10 series phones and the Pixel Watch 4, has reduced our reliance on mined sources. Expired solder paste often ends up as hazardous waste, and its manufacture generates additional waste. Our solder paste vendor developed a process to recover tin from this waste and recycle it.

Manufacturing scrap and expired solder paste are collected, tin is separated from the waste and purified to its elemental state, and the metal powder is combined with new flux to manufacture solder paste with 100% recycled tin.

Technical performance

Solder paste is a highly sensitive material. Variations in particle size or oxygen content can lead to “cold” solder joints, voiding, or brittle failures during drop events. In order to mitigate these issues, we conducted a validation of solder paste made with recycled tin. Scanning electron microscopy, cross-sectioning, and other tests allowed us to evaluate the physical composition and purity of the solder paste, the strength of solder joints, and the formation of the intermetallic compound layer after reflow.

In every case, the recycled tin solder paste exhibited the same performance properties as standard paste, including wetting, reflow characteristics, and shear strength. As a result, our contract manufacturers were able to switch to recycled tin paste without altering their reflow oven profiles or surface mount technology parameters.

Recycled critical minerals

Recycled cobalt

Cobalt is another critical ingredient in electronics, providing the thermal stability and high energy density needed for the cathode of lithium-ion batteries.

The journey of cobalt in a battery is complex. In lithium cobalt oxide batteries, the cathode material is synthesized from a precursor, typically cobalt chloride. We worked with battery cell suppliers to validate a supply chain where the cobalt chloride is derived entirely from recycled batteries and manufacturing scrap.

Battery cell performance validation

Because this is a chemical purification process, the resulting cobalt chloride meets the same specifications as what's produced from mined ore.

Extensive testing of cells made from recycled metal confirmed their voltage profile, cycle life, and high-temperature stability to be equivalent to those of traditional lithium cobalt oxide batteries.

Recycled tungsten

With its high density, tungsten is able to generate powerful vibrations in a compact space, so we chose it for the rotating mass in our haptic engines.

Our suppliers source recycled tungsten from a variety of sources including post-industrial scrap, allowing us to integrate 100% recycled tungsten into the haptic engines of Pixel 10 series phones and the Pixel Watch 4.

Validation

The primary technical specification for the haptic mass is density. If the material is not sufficiently dense, the vibration feedback will feel weak. We validated that the recycled tungsten sintered parts met our density requirements for primary tungsten.

We also performed reliability tests including salt fog and temperature humidity cycling testing in addition to cosmetic and welding quality inspection on the haptic modules to ensure that the recycled tungsten did not negatively impact any specifications.

Recycled critical minerals

Recycled rare earths

Rare earth elements (REEs) are a group of 17 metals with a wide variety of uses.

We rely primarily on two of them, neodymium and praseodymium, for the high-performance magnets used in our speakers, camera modules, and haptic motors, with some magnets also incorporating small quantities of terbium and dysprosium.

Although relatively common in the earth's crust, rare earths are always found mixed with other elements. This makes economical extraction and chemical separation difficult, requiring environmentally harmful mining techniques and processes. Some mining methods render land unsuitable for agriculture by removing topsoil to uncover ore deposits. Others pump chemicals into the earth to dissolve the minerals, potentially causing soil erosion and groundwater pollution. Our transition to 100% recycled rare earths in some magnets allows us to reduce our reliance on sources associated with these issues.

Building a circular supply chain

Thanks to the commendable work of companies that nurtured supply chains for some of the minerals covered in this chapter, a good supply of recycled materials was available through qualified suppliers when we began our journey.

The supply chain for recycled rare earth elements in magnets, however, was not yet fully established, and availability of high-quality, certified recycled feedstock was very limited.

Our speaker and haptic suppliers had already integrated some recycled material, but because of a lack of demand, they had no roadmap for qualifying new sources of recycled rare earth elements. To address this, our global supply chain and sustainability teams engaged directly with upstream manufacturers to develop sourcing options with verifiable recycled content claims. They identified a magnet supplier that wasn't using recycled rare earths, but was willing to partner with us to develop that capability.

Having secured a magnet supplier and sufficient volume commitments, our vendors were able to integrate this new supply source into their manufacturing process for our speaker and haptic modules.

We qualified the recycled rare earths' performance at the magnet, module, and product levels to ensure parity with mined material options. Both the raw material and the magnets produced from it underwent thorough testing before being used in products. We assessed the purity of the input metal, ensured that it met our corrosion resistance standards, and measured its magnetic strength and resistance to becoming demagnetized. We then evaluated final magnets within a component, such as a speaker or a haptic engine. Environmental stress tests validated the durability of the magnets, and functional testing confirmed their acoustic or haptic performance.

This rigorous testing confirmed that 100% recycled rare earth magnets sourced from qualified vendors introduce no discernible risk. In our validations for Pixel products, the components with recycled material consistently showed no statistical difference in performance compared to ones made with the equivalent mined material option.

Recycled critical minerals

Case study
Pixel 10 Pro Fold

With our latest foldable phone, we endeavored to use recycled rare earth elements across a variety of magnets.

Achieving that required approaching our custom parts and commodity parts differently. Pixel 10 Pro Fold uses magnets in a wide range of applications including Qi2 wireless charging, speakers, cameras, the haptics engine, and the housing. Modules custom-designed for Google, like our haptics engine, could be redesigned with both 100% recycled tungsten and 100% recycled rare earths relatively quickly, just by updating our specifications. Commodity parts such as speaker drivers, however, are designed for a wide range of brands without recycled content requirements, making a transition more complex.

Many speaker vendors had no plans to use recycled magnets in standard parts, but by committing to higher volume purchases across multiple Pixel models, we incentivized our suppliers to qualify recycled magnets for their standard driver lines. This approach increased the supply of recycled rare earths available for a wide variety of products.

08

Key takeaways

Our work with recycled materials has taught us that compromises in performance, design, or quality can be avoided with clear technical specifications and strong supplier partnerships.

Beyond that, creative thinking about product and manufacturing design can unlock new sustainable material opportunities that weren't possible before.

As we continue to expand this work, we are not alone. Many companies agree that the future of materials is circular. Just as Google benefited from supply chains built by other brands, we hope other companies benefit from the work we've done and that it accelerates industry progress.

- Engage early with internal cross-functional teams, understand their concerns, and gather data to demonstrate that rigorous product specifications can be met.
- Integrate sustainable material goals into your company's product development process and your expectations for supply chain partners. Grassroots initiatives are helpful, but process integration is needed to succeed.
- Partner with experienced suppliers who have worked with recycled materials before.
- When working with suppliers who have less experience with recycled materials, give them time to tune their manufacturing processes and parameters to achieve the part-level quality you need.
- Demonstrate recycled material viability in a single part for one product, building confidence to adopt it in more parts across more products.
- Insist on third-party certified recycled content to ensure you get the material you expect. Certifying a new material takes time and will need to be aligned to your product development schedule.

Glossary of terms

Chemical recycling
A process where scrap polymer is broken down into smaller molecules (monomers) or a liquid/gaseous feedstock which are then used to create a recycled material.

Cosmetic parts
Parts with aesthetic value that are visible to the user in the final product.

Cycle time
The total time elapsed from the start of one injection molding cycle to the start of the next.

Design of experiments (DOE)
A set of controlled tests to better understand a variable change and how it affects the cosmetic or functional performance of a product.

Mass balance
A calculation method used to determine the percentage of recycled or bio-based material, typically when physical segregation of recycled and primary feedstocks is not feasible. The method tracks the mass of input recycled material entering a process and the mass of the output.

Mechanical recycling
A process where plastic is sorted, shredded, washed, and re-extruded into pellets for use in new products.

Melange
A yarn or fabric created by mixing fibers of different colors to produce a speckled or heathered effect.

Melt flow rate (MFR)
A measure of the flowability of a thermoplastic polymer that indicates the ease of processing the plastic.

Molding parameters
A set of process variables – such as melt temperature, mold temperature, injection speed, injection pressure, and holding time – that are adjusted during injection molding to achieve the desired part quality.

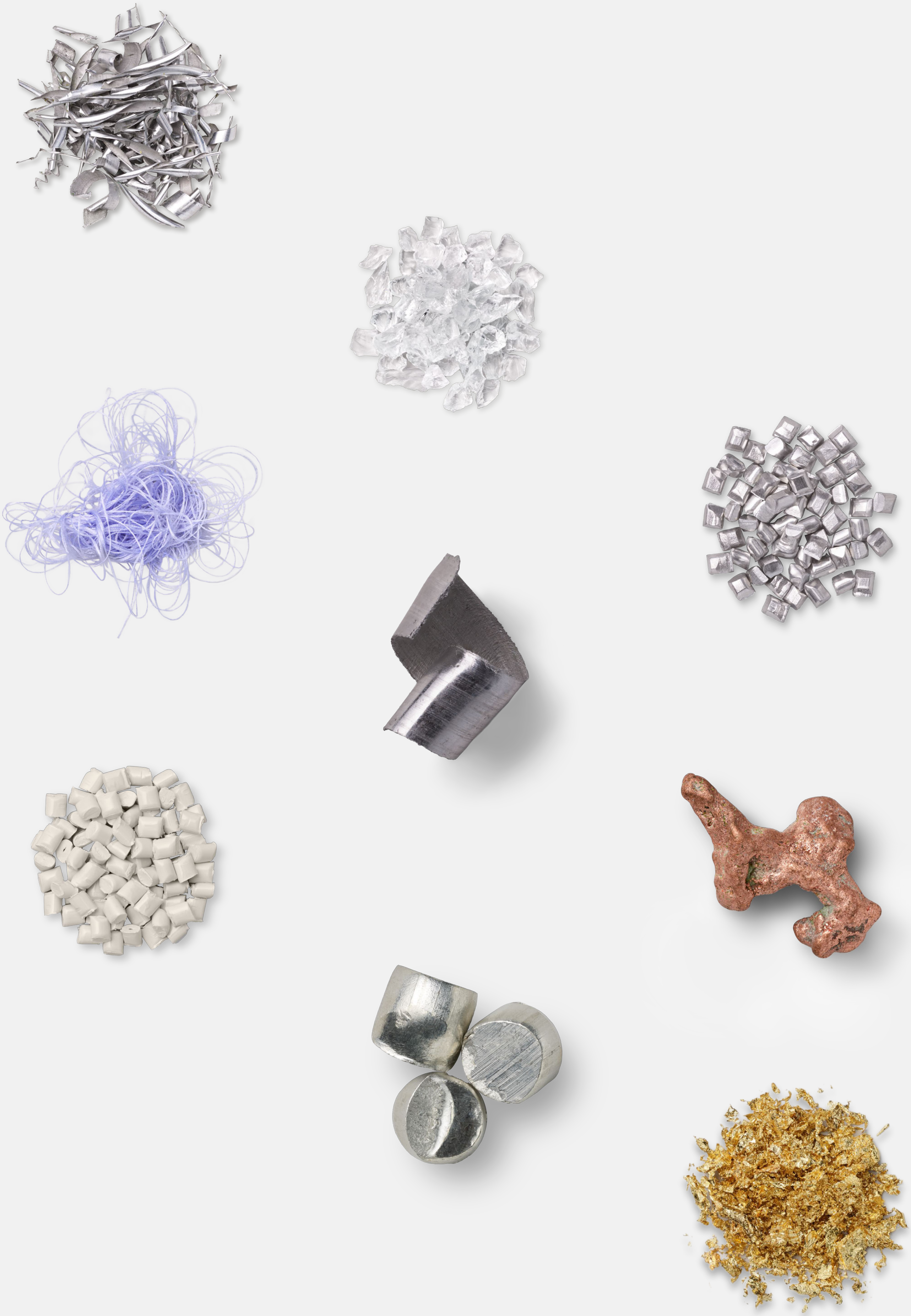
Moldability
The effectiveness with which a material can be formed into the intended part during injection molding.

Non-cosmetic parts
Internal and structural components of a product that are not visible to the user.

Post consumer recycled (PCR)
Material generated by households or by commercial, industrial and institutional facilities in their role as end users of the product which is no longer used for its intended purpose and is reprocessed into a recycled material.

Post industrial recycled (PIR)
Post industrial recycled material, also known as pre-consumer recycled content, describes waste generated during the manufacturing process that is collected and recycled before it ever reaches a consumer. This includes things like excess trim, scraps, rejected parts, and other by-products.

Primary material
Raw material that has not been previously used or processed. It is extracted directly from nature, such as timber, crude oil, metal ores, or natural gas, and has not been recycled or repurposed from a waste stream. This is also sometimes called first-use or virgin material.



Acknowledgements

Our work on recycled materials has been made possible by the talent, creativity, and dedication of Google's engineering, design, operations, sustainability, and supplier partner teams.

Resources and disclaimers

1. **The world's plastic pollution crisis, explained.** *National Geographic, 2024*
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2. **Americans Strongly Believe in Recycling.** *The Recycling Partnership, 2020*
   Page 8

3. **Mining Is Increasingly Pushing into Critical Rainforests and Protected Areas.** *World Resources Institute, 2024*
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4. **Mining Conflict in Madagascar** *Climate Diplomacy, 2025*
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5. **Mining-induced displacement and livelihood restoration: A data-driven approach** *School of Biological Sciences, 2025*
   Page 9

6. **State of the Science Fact Sheet: Deep Sea Mining** *National Oceanic and Atmospheric Administration, 2025*
   Page 9

7. **Waiting to Die: Toxic Emissions and Disease Near the Louisiana Denka / DuPont Petrochemical Plant.** *University Network for Human Rights, 2019*
   Page 9

8. **Our hardware sustainability commitments** *Google Blog, 2019*
   Page 11

9. Doesn't include third-party products such as the Nest x Yale Lock
   Page 11

10. For products launched in 2020 and 2021: Nest, Pixel, and Chromecast devices are made with recycled plastic ranging between 9% and 68% based on weight of plastic used in each respective product launched during this timeframe. The following items are excluded: plastics in printed circuit boards, labels, cables, connectors, electronic components and modules, optical components, electrostatic discharge (ESD) components, electromagnetic interference (EMI) components, films, coatings, and adhesive.
    Page 11

11. **Commercial Compostability Certification**
    Page 12

12. **Truth-in-Labeling Laws Protecting California Consumers from False Marketing Claims** *CalRecycle, State of California*
    Page 12

13. The recycled materials are at least 39% of product based on weight.
    Page 34

14. Fabric usage measured by fabric utilization
    Page 34

15. Carbon footprint reduction claim based on third-party verified life cycle assessment. You can read more about this journey on our **sustainability website**
    Page 40

16. Recycled aluminum in the enclosures is at least 3% of Pixel Watch, 9% of applicable Pixel phones, and 25% of Pixel Tablet product based on weight. This 100% recycled content claim excludes Pixel 5a.
    Page 40

17. **A Recycling Champion** *International Copper Association, 2018*
    Page 44

18. **Environmental impact of high-value gold scrap recycling** *The International Journal of Life Cycle Assessment, 2020*
    Page 45

19. **Artisanal and Small-Scale Gold Mining (ASGM)** *Global Mercury Partnership*
    Page 45

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Recycled Materials Guide

We’d love to hear about ways you’ve found this guide helpful, technical questions you have, or suggestions to improve it. Let us know at **recycled-materials@google.com**

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