WHITE PAPER

SEAGATE

Working Toward the Future of Circularity

Learn about Seagate's sustainable data storage solutions and what Seagate is doing to reduce its environmental impact through circularity practices.

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Seagate Green Design: Working Toward the Future of Circularity

Seagate enables the data economy through data storage and management solutions. From breakthrough cloud services and systems to precision-engineered hard and solid-state drives, we're responsible for over four billion terabytes of global data capacity, creating a foundation for the digital innovations of tomorrow.

We're committed to engineering products that deliver hyperscale storage efficiency and frictionless data mobility—and since 2010, we've also been committed to driving continuous sustainability improvements across every terabyte (TB) of storage we design, produce, and ship. In that time, we've reduced impacts by up to 93% per TB across key sustainability indicators, including use-phase energy consumption, greenhouse gas (GHG) emissions, and water and metal depletion. While significant, we believe these accomplishments represent just the first steps in a more comprehensive approach that supports the accelerating digital economy by ensuring long-term sustainability for its supply chain and infrastructure.

The key to bringing this future to life is unlocking circular business models to decouple growth from the consumption of finite resources.

This white paper is the first of a series in which we'll highlight some of the key opportunities and challenges we face in pursuing product circularity for the data storage industry. To give clarity around the science, we also provide an overview of the life cycle assessment (LCA) methodology through which we measure, promote, and report our product impacts.

Changing the Game on Product Circularity

Interest in circular business models has risen in recent years as organizations seek solutions to help reverse the drivers of climate change without putting brakes on economic growth. Through systems of planned reuse, remanufacturing, and recycling, these models extend energy and materials efficiencies and innovation across the product life cycle:

- Designing for durability and regeneration
- Using feedstocks from reused or recycled sources
- Keeping products in use longer through reuse, remanufacture, and resale
- Making more intensive use of products (e.g., via service or performance models)
- Reusing components or recycling product materials
- Ending reliance on finite, non-renewable resources

Adopting circularity in the data storage industry promises enormous benefits to both businesses and the environment:

- Designing products for multiple economic life stages reduces the need for new, energy-intensive resource extraction, resulting in reduced GHG emissions, conservation of natural resources, and minimization of waste.
- Though energy efficiency and renewability, customers reap cost savings during and after the product use-life, contributing to achievement of their own sustainability goals.
- A circular design mindset leads to greater innovation and competitive advantage in the market.
- Ultimately, circularity contributes to the recovery of planetary health by moving from a linear ‘take-make-waste’ economy to one that supports natural processes and gives natural systems room to thrive.

Seagate was one of the first companies to measure the circularity of our products using a Material Circularity Indicator (MCI), a metric we adopted from the Ellen MacArthur Foundation to measure the restorative potential of our products’ material flows and act as a benchmark for further improving material efficiencies. To measure the evolving sustainability performance of our products, we also partnered with sustainability consultancy Anthesis and software platform Footprinter™ to establish the Seagate Green Design tool, which allows us to perform LCAs measuring the complete impacts of our data storage products across four key priorities: global warming, mineral resource scarcity, human toxicity, and water consumption.

We share summary results of our product LCAs publicly through our Product Sustainability Reports, which help us support our customers with detailed sustainability data (which can inform their own sustainability calculations) and aid communication with our stakeholders around identifying priorities, challenges, and solutions.

Flipping the Risk-Reward Balance of Data Storage Circularity

Over the past several years, Seagate has been exploring product circularity strategies with customers and partners, with the aim of returning materials, components, and entire products to productive use through regeneration, recovery, remanufacture, and reuse.

To extend a product's life in the field without taking it out of service, we've introduced Autonomous Drive Regeneration (ADR), which reconfigures drives at customer sites to bypass errant components and restore dependability. We're also able to take back, renew, re-warranty, and repurpose drives to be used again in secondary markets. Finally, we can reuse product components to build new drives, or recycle product materials to create new raw material stock for the supply chain.

All these outcomes support circularity's goals of eliminating waste and deriving full benefit from resources, but our efforts have faced resistance from customers whose data security policies require drives' physical destruction at end-of-use. To promote greater acceptance of circular approaches for our products, we are continually advancing solutions to ensure total data sanitization on used drives. Communicating the efficacy of these solutions will be key to increasing buy-in to our circularity ambitions, along with designing simple processes for getting drives back into our hands.

One more key strategy? Changing the incentive structure.

Today, every corporation has goals to reduce their carbon footprint or achieve net zero, but they also struggle with the reality that hard drives account for a large part of that footprint. Even if a company is running its data centers on 100% renewable energy, today's carbon accounting rules require that company, as the product's first user, to absorb 100% of the embodied carbon[1] that went into its manufacture. So what's the incentive to support a reuse strategy?

How about this: A new accounting methodology that allocates a product's embodied carbon between the first and the second user, rewarding the original owner with carbon credits upon refurbishment and resale to reduce their carbon footprint and further their net zero goals?

That's where Seagate wants to take the fight, helping build a circular economy while also satisfying the growing demand for data storage in secondary markets. In the pages that follow, we'll describe the methodology we use to calculate our products' carbon impacts. As our circularity ambitions evolve, the methodology could also evolve to capture circular end-of-life pathways and inform new carbon accounting paradigms.

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[1] Embodied carbon includes emissions generated during raw material extraction, product manufacturing/assembly, and all transportation of materials from extraction through manufacturing and from manufacturing to customers.

Calculating Our Impacts: Metrics and Methodology

The Seagate Green Design tool produces life cycle assessments of new and existing Seagate hard disk drives (HDDs) and solid-state drives (SSDs) and their associated packaging. The results provide benchmarks to track the impacts of Seagate's product portfolio over time, identify hotspots for further improvement, help customers understand the life cycle carbon footprint of their purchased Seagate products, and begin considering the sustainability impacts and savings from circularity models.

System Boundary: To model the impacts of Seagate products, our assessments use a cradle-to-grave system boundary that encompasses life cycle stages from extraction and processing of raw materials to manufacturing, transportation, product use, and end-of-life handling, including recycling. Future evolution of the model will extend the boundary to better capture the full scope of circularity interactions and feedback loops (product takeback, repair, remanufacturing, reuse) that enable continuous cycling of resources back into the value chain.

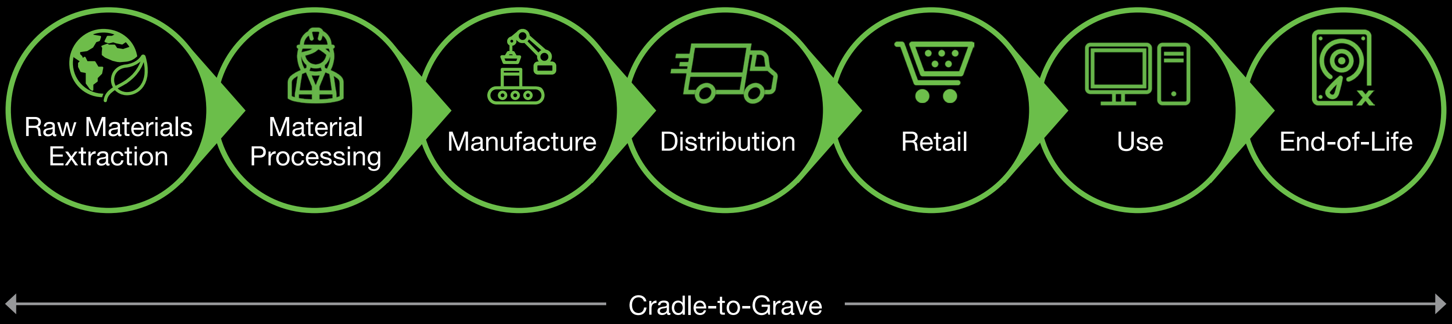

Figure 1: Life cycle stages included in Seagate product LCA

Life Cycle Inventory and Impact Assessment Methodology: To evaluate the impacts of material and energy inputs, our LCAs use product specifications, supply chain information, and comprehensive Full Material Declarations[2] (FMDs) that inventory types and quantities of all raw materials and components in a product. Use-phase energy consumption is calculated using product-family electricity consumption profiles. Energy consumed in manufacturing, distribution, and end-of-life pathways is calculated annually.

Where primary data is unavailable, we leverage secondary data from the Ecoinvent life cycle inventory (LCI) database. The database includes energy and material inputs required for material extraction, processing, manufacture, transportation, and end-of-life treatment for a wide range of industry sectors. Component and material entries in the FMD are mapped to representative processes in Ecoinvent via part category and substance/material composition and entered into our Seagate Green Design library, ensuring consistency across our internal systems and alignment of future FMDs.

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[2] Product FMDs used for life cycle assessments are Bills of Materials (BOMs) augmented with supplier-provided information on the material content of components and parts.

The combination of Seagate and Ecoinvent LCI data allows us to catalog a robust inventory of exchanges with the environment, or elementary flows. We then assess these flows using the ReCiPe 2016 life cycle impact assessment (LCIA) method, which measures environmental impact on a continuum that shows the causal relationship between an environmental intervention (e.g., emission of specific chemicals contributing to global warming) and its potential impacts to human health, ecosystems, and resource availability. Our assessments characterize our products' impacts using 2016 Midpoint Hierarchical indicators for global warming, mineral resource scarcity, and water consumption, and ReCiPe 2016 Endpoint Hierarchical indicators for human toxicity.[3]

The Seagate Green Design tool aligns with the requirements and principles of LCA methodologies defined by the Greenhouse Gas Protocol Product Life Cycle Accounting and Reporting Standard (GHGP) and the ISO 14040 and ISO 14044 Environmental management–life cycle assessment series and has been third-party reviewed and verified.

Method Overview: Information specific to each product, such as the FMD and electricity consumption for product testing and use, are combined with average values for inbound transportation, distribution to market, and end-of-life pathways.

Product Life Cycle Processes: The Greenhouse Gas Protocol Product Standard stipulates the scope of emissions sources that must be included in a product assessment:

Emissions from purchased electricity for own use.

Seagate in-house part manufacturing, on-site energy consumption, and materials processing.

UPSTREAM: Raw material extraction, processing, and transport, third-party part manufacturing, and transport of materials and parts between Seagate facilities.

DOWNSTREAM: Distribution to market, use-phase electricity consumption, and end-of-life pathways.

Figure 2: Product life cycle processes

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[3] Due to changes between the 2008 and 2016 versions of ReCiPe, which split human toxicity midpoint indicators into carcinogenic and non-carcinogenic, we chose to employ endpoint characterization models for human toxicity to align the two categories under a single impact, simplifying communication and aligning with our current report formatting.

Digging down, Figure 3 shows the elements that make up Seagate's production system, from raw materials extraction through end-of-life pathways. Elements included in the LCA model appear in blue boxes, and several inputs deemed immaterial to results are displayed in gray boxes. There is potential for double counting in some elements, but this also is considered immaterial to results.

Functional Units: The reference flow for Seagate Green Design LCAs is one drive, either hard drive or SSD. Seagate Green Design provides for three functional units applicable to our products:

- **Unit:** Each product/drive is considered one unit.
- **Terabyte:** Each drive has a specified capacity of data storage measured in bytes. (1Terabyte = $1e^{12}$ Bytes)
- **Terabyte-year:** This functional unit highlights cases where efforts have been made to extend the product's lifespan so that the same service (data storage) is provided for longer, with the same manufacturing and disposal impacts. Terabyte-year is calculated as capacity multiplied by the product's warrantied lifespan.

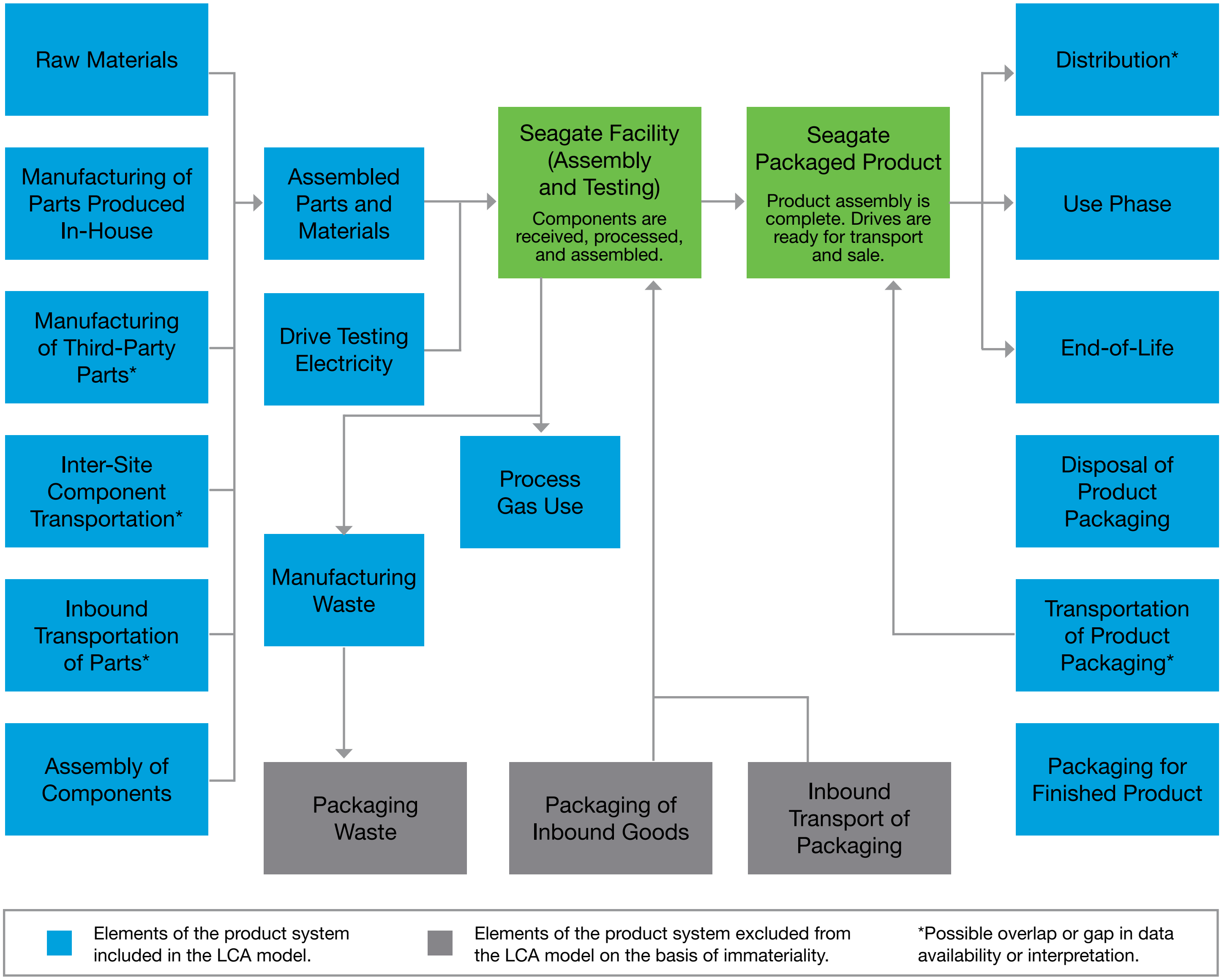
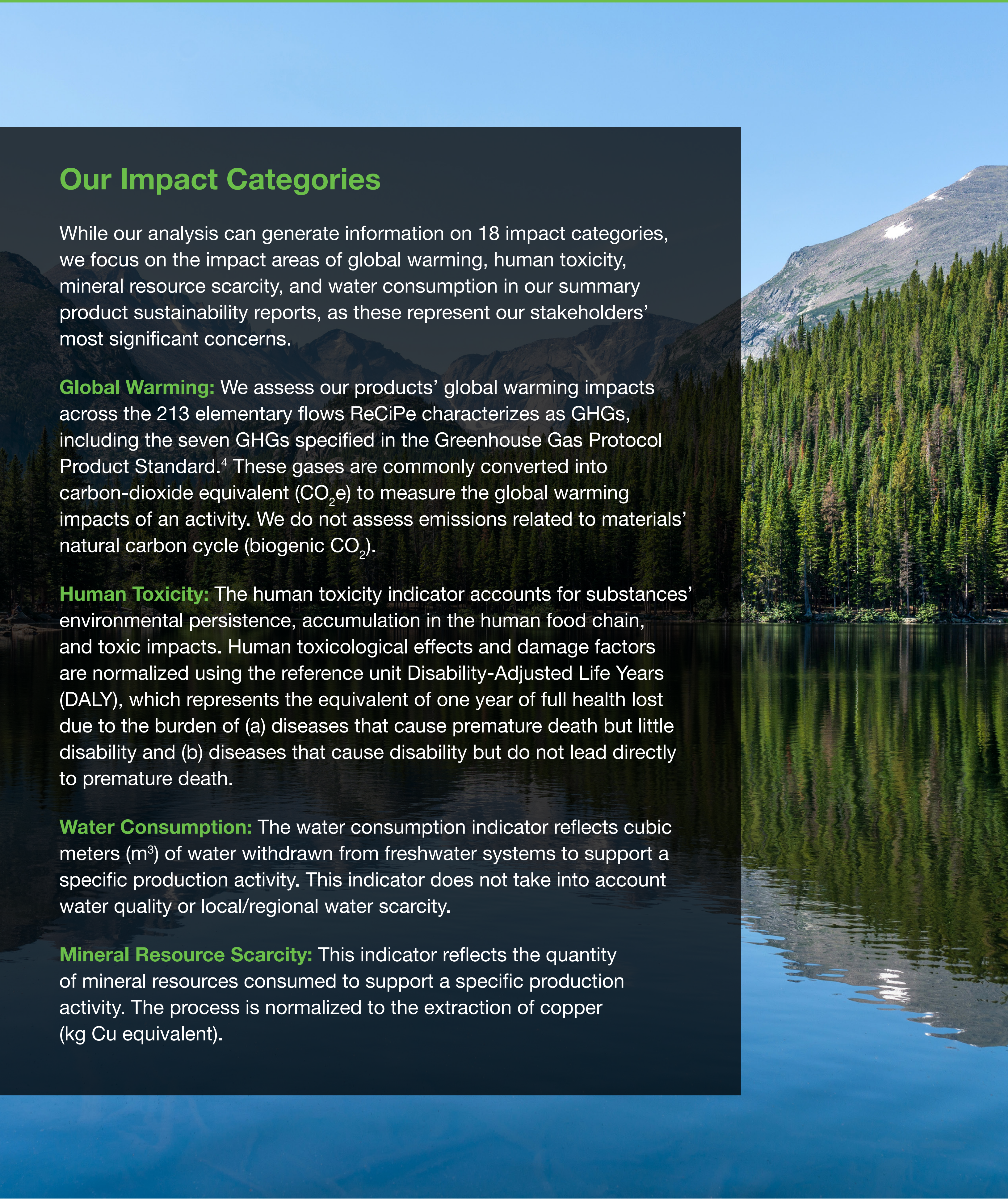


Figure 3: Seagate drive manufacturing process map



Our Impact Categories

While our analysis can generate information on 18 impact categories, we focus on the impact areas of global warming, human toxicity, mineral resource scarcity, and water consumption in our summary product sustainability reports, as these represent our stakeholders' most significant concerns.

Global Warming: We assess our products' global warming impacts across the 213 elementary flows ReCiPe characterizes as GHGs, including the seven GHGs specified in the Greenhouse Gas Protocol Product Standard.[4] These gases are commonly converted into carbon-dioxide equivalent (CO_2e) to measure the global warming impacts of an activity. We do not assess emissions related to materials' natural carbon cycle (biogenic CO_2).

Human Toxicity: The human toxicity indicator accounts for substances' environmental persistence, accumulation in the human food chain, and toxic impacts. Human toxicological effects and damage factors are normalized using the reference unit Disability-Adjusted Life Years (DALY), which represents the equivalent of one year of full health lost due to the burden of (a) diseases that cause premature death but little disability and (b) diseases that cause disability but do not lead directly to premature death.

Water Consumption: The water consumption indicator reflects cubic meters (m^3) of water withdrawn from freshwater systems to support a specific production activity. This indicator does not take into account water quality or local/regional water scarcity.

Mineral Resource Scarcity: This indicator reflects the quantity of mineral resources consumed to support a specific production activity. The process is normalized to the extraction of copper (kg Cu equivalent).

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[4] Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), and nitrogen trifluoride (NF_3).

Life Cycle Stages

We collect primary and secondary data across five key life cycle stages.

1 Raw Materials Extraction and Processing

As described under “Life Cycle Inventory and Impact Assessment Methodology,” above, our LCAs use both primary and secondary sources to inventory the upstream impacts of materials used in our products, including those associated with raw material extraction and processing.

2 Manufacturing

Seagate’s manufacturing impacts comprise three major elements: Seagate in-house manufacturing and assembly, third-party manufacturing, and product testing. Seagate uses primary data for in-house manufacturing and assembly and product testing, and assumptions for third-party manufacturing based on information contained in the FMD. Manufacturing scrap and defects associated with part manufacturing are represented in either the processes selected from the Ecoinvent LCI database or by increasing input quantities of materials to account for scrap/defect rates.

See figure 4 for a visualization of hard drive parts described below.

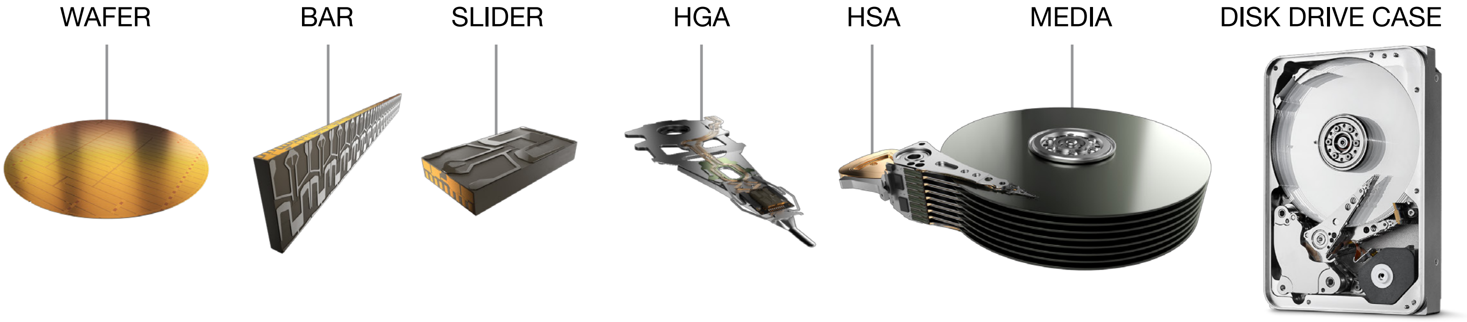

Figure 4: Breakdown of hard drive components and assemblies

Seagate In-House Manufacturing and Assembly: Our own fabrication/manufacturing operations provide energy inputs for the following processes:

- Fabrication of silicon wafers used for sliders in head gimbal assemblies (HGAs) (allocated per slider)
- Slicing of HGA sliders from silicon wafers (allocated per slider)
- Fabrication of aluminum substrate used in disks/media (allocated per disk)
- Application of magnetic film to all substrates used in disks/media (allocated per disk)

We also provide energy inputs for:

- Assembly of all HGA elements (allocated per HGA)
- Assembly of all head stack assembly (HSA) elements (allocated per HSA)
- All other final assembly steps (allocated per drive)

Part quantities produced by these fabrication, manufacturing, and assembly processes scale with drive capacity and are provided by Seagate for each drive. Quantities of HGAs scale with drive capacity—some drive families have two, but most others have one.

Seagate Third-Party Manufacturing: Seagate receives the majority of our parts from third-party manufacturers specialized in producing small metal and plastic parts in complex shapes. In the absence of third-party manufacturing data, we use the Ecoinvent LCI database to map each substance to a representative manufacturing process: average metalworking processes for metal substances and injection molding processes for plastics. When it's unclear whether a substance is used in a metal or a plastic, the substance is mapped to a general manufacturing process comprised of equal parts average metalworking and injection molding.

Seagate Product Testing: Seagate drives are tested for quality control purposes to ensure they function properly. Testing processes require all data storage media to be checked; therefore, testing time scales with the drive's storage capacity. Seagate testing of electricity consumption and drive capacity data was used to develop a linear equation for use in calculating drive test time.

SSD Manufacturing and Assembly: Seagate's SSDs use parts produced at third-party manufacturers and are assembled by a subcontractor. Methodologies for calculating their impacts match those described above. The energy required for assembly of SSDs is provided by the subcontractor and allocated per drive. Unlike hard drives, the physical mass of SSDs changes only slightly when adding more capacity, so it is assumed that manufacturing energy doesn't vary significantly between SSDs of different capacities.

Packaging: Packaging materials and production processes account for less than 1% of cradle-to-grave impacts across all impact categories assessed. For this reason, we base our impact calculations on product packaging LCAs last updated in 2019. We plan to update packaging models only when our packaging solutions change significantly.

3 Distribution

Using Eco Transit, we model distribution impacts per kilogram based on weighted average distances for each mode of freight transport (sea, land, air), as recorded in Seagate sales and logistics data. See figure 4 for a visualization of hard drive parts described below.

4 Use-Phase Electricity Consumption

We calculate a product's use-phase electricity consumption based on typical patterns for the drive's intended use scenario, and power consumption as detailed in the product's spec sheet. These are scaled across a lifetime equal to the product's warranty period, which is generally five years.

Since differences in energy mix during the use phase can result in varying impacts, we model consumption impacts using two scenarios: a global average electricity mix and a global average renewable electricity mix. Considering our customers' renewable energy mix is important, as many power their cloud-based services and hyperscale data centers using renewable electricity, which significantly reduces the use-phase impacts of our products.

5 End-of-Life Pathways

End-of-life impacts are currently modeled based on shipped weight and assumptions for recycling and landfill rates for electronics products by geography, published in the 2020 Global E-waste Monitor. We then use Seagate sales data for each geography to calculate a single set of weighed average end-of-life impacts. Recycling allocations are calculated using the cutoff method, where impacts of recycling are assigned to the user of the recycled material.

Additional Considerations

In addition to the above, our LCAs also currently calculate impacts for:

- Inbound transport of parts and substances, using Seagate data on the number of suppliers in each region, paired with distance and transport mode assumptions
- Operational waste and process gas usage from operational data
- Transport of components between Seagate sites and by external suppliers to our manufacturing sites for final drive assembly

The Seagate Green Design model is reviewed and updated annually to reflect changes to industry standard databases and Seagate's production and operating practices. These updates are incorporated into the new product life cycle assessments. Existing published studies are not changed.

The Numbers Tell Our Sustainability Story and Point to the Future

Circular business models have the potential to transform the Information and Communication Technology supply chain, driving both environmental and economic benefits. By prioritizing circular design principles, resource efficiency, waste reduction, and extending product life through reuse, Seagate can help reduce the embodied carbon and Scope 3 emissions of our hyperscale customers.

This white paper is the first in a series exploring these changes. In a follow-up paper, we'll go deeper into the ecosystem changes that will help unlock product returns and accelerate circularity in our industry. We'll also examine potential changes to our LCA methodology to capture end-of-life pathways such as product takeback, repair, remanufacturing, and reuse.

We look forward to engaging with our stakeholders on how changes like these would work in practice.

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