

The Materiality and Environmental Impact of Digital Preservation



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Digital Content and the Environment

Storing and managing digital content impacts the environment through:

1. Greenhouse gas emissions
2. Depleting the Earth's natural resources (rare earth materials used in manufacturing hardware, data storage media, and chips; water used to cool data centers and manufacture devices & chips)

Greenhouse Gas Emissions (GHG)

Scope 1: Direct emissions from institutional facilities (e.g., on-premise servers, climate control systems).

Scope 2: Indirect emissions from purchased electricity.

Scope 3: Indirect supply chain emissions, including cloud data centers, embodied carbon in manufacturing of digital storage media, and logistics.

Scope 3 emissions can account to up to **90%** of an organization's GHG emissions.

For archives performing digital preservation activities, the list of potential sources of Scope 3 emissions is long:

- transportation of analog source media to digitization vendors
- vendors' own emissions
- shipping
- cloud storage and compute
- embodied carbon in data storage media
- staff travel
- and more

Greenhouse Gas Protocol. Scope 3 Frequently Asked Questions. <https://ghgprotocol.org/sites/default/files/2022-12/Scope%203%20Detailed%20FAQ.pdf>

Our archives intersect with ICT (Information and Communication Technology) through energy consumption and hardware use that are required to keep our digital files alive and usable.

Percent of ICT emissions

1. end-user devices [your computer]	(2011: 60%	2030: 47.2%)
2. telecommunication networks [streaming ISP]	(2011: 22%	2030: 24%)
3. data centers [Zoom, Facebook, YouTube]	(2011: 17%	2030: 28.8%)

It's expected that:

1. end-user devices emissions will **decrease** due to devices' reduced direct and indirect emission rates
2. Data centers will **increase** even with mitigations in efficiency and cooling.

#SMARTer2030: ICT Solutions for 21st Century Challenges. GeSI. 2015. http://smarter2030.gesi.org/downloads/Full_report.pdf

Data centers electricity use

2024:

US data centers accounted for 4% of total electricity use in the US. In 2028, expected to be 12%.

<https://www.theverge.com/2024/1/24/24049047/data-center-ai-crypto-bitcoin-mining-electricity-report-ia>

Ireland: electricity demand from data centers accounted for 21% of the total metered electricity.

Jackson, Amber. "Power-Hungry Data Centre Put Pressure on Ireland's Grid." Data Centre Magazine, 3 August 2024. <https://datacentremagazine.com/critical-environments/power-hungry-data-centres-put-pressure-on-irelands-grid>

Preserving digital content and making it accessible impacts the environment through:

Legacy media destruction: original audio and video magnetic media items will ultimately be **destroyed**. (e-waste)

Electricity use: data must be preserved and made accessible through storage and management, using **energy resources** that can be dirty or clean.

Hardware/media destruction: Media and hardware used to store and manage the data will be changed every 5-10 years, with the old media/hardware either **recycled, incinerated, or dumped in a landfill**.

There isn't enough data storage media to store all the data being generated in the next few years.

The planet doesn't have enough raw materials to manufacture traditional storage media *ad infinitum*.

Yet, 143 billion pounds of e-waste was generated globally in 2022.

Data storage media is shredded rather than undergo materials reclamation.

22 million hard disk drives age out at North American data centers every year. **The vast majority are shredded.**

Data storage materiality

Data storage devices don't last forever.

When their useful life is over, they're disposed of one way or another – usually as e-waste.

E-waste can contain:

- Heavy and rare earth metals
- Plastic

Consider the recycling potential of your storage media and devices.

Depleting the planet of its natural resources

Heavy and Rare earth metals

Heavy and rare earth metals: used in making phones, computers, TVs, servers, external hard drives, solid state drives, magnets, batteries – anything electronic. Rare earth metals are used in solar energy technology, lasers, automobiles....

Less than one percent of rare earth elements are currently recycled.

Heavy metals are toxic by their nature. They include: mercury, arsenic, copper, aluminum, lead, cadmium, chromium, cobalt, nickel, zinc, selenium, silver, antimony, and thallium.

Depleting the planet of its natural resources

Silica sand used to make electronics and glass is also a finite natural resource.

Helium to make hard drives spin cooler and use less energy.

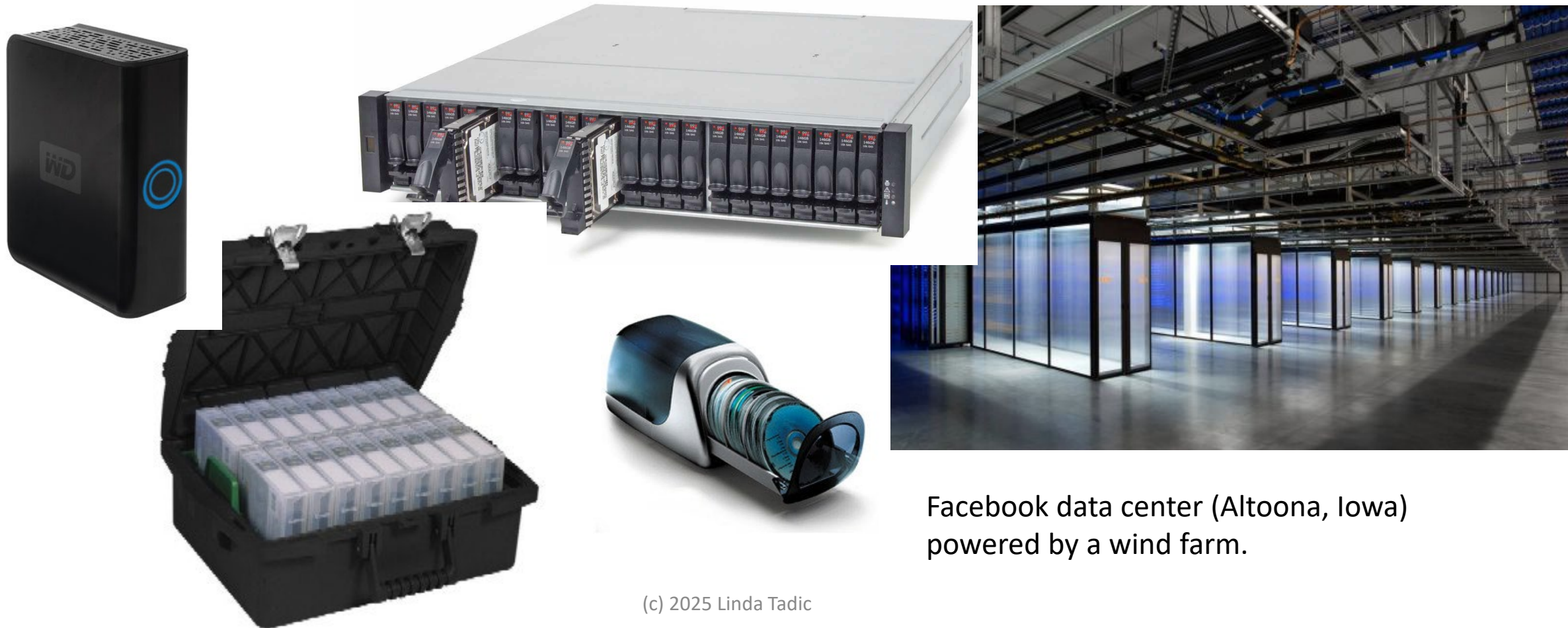
Purified water in making microchips.

Water is used to chill data centers: a mid-sized data center uses 300,000 gallons of water per day.

Climate change and stripping the Earth of its natural resources are each impacting the supply chain.

Data storage

Digital files must be stored and managed on storage media.



Facebook data center (Altoona, Iowa)
powered by a wind farm.

Data storage options

Physical carriers:

- Spinning disk (hard drives)
- NAND (Solid state/flash)
- Data tape (eg, LTO)

(the “cloud” sits on a mix of these three data storage carriers)

Alternative data storage media in various stages of development: DNA data storage, Project Silica (Microsoft), Cerabyte, Piql.

Most of the carbon emissions are from manufacturing, not from use (“embodied carbon”).

Consider the LCA (Life Cycle Assessment) of media.

What can be reclaimed?

How can you participate in a **Circular Economy**?

Data storage options: Spinning disk

Servers (single or networked; using HDDs / SSDs)

Electricity use: High

- Fans in enclosures; power to operate/process
- Environment must be maintained at constant temperature
- **Helium-filled hard drives reduce energy use by 23%** (but helium is a finite natural resource)

Life expectancy: Drives & parts replaced every 3-5 years (initial service life)

Potential recyclable parts: plastics, rare earth metals, magnetic material, heavy metals (copper, aluminum, steel). Server cases & motherboards have re-use potential (2nd life).



Manufacturers know there is a finite amount of material to keep making HDDs.

Material recovery if components are harvested:

- Aluminum substrate (largest raw material)
- Magnetic coating (rare earth material)

Promising recent efforts: Microsoft, Western Digital, Critical Materials Recycling, PedalPoint Recycling

Pilot program (2025). Over 50,000 lbs Western Digital HDDs in use at Microsoft data centers are shredded and sorted at PedalPoint Recycling before undergoing acid-free dissolution at CMR where rare earth oxides are extracted, then returned to the U.S. supply pool.

Recaptures essential rare earth elements but also extracts metals like gold (Au), copper (Cu), aluminum (Al) and steel. ~ 90% successful recovery.

<https://www.storagenewsletter.com/2025/04/18/at-scale-hdds-rare-earth-material-capture-program-successfully-launched-in-united-states/>

Promising recent efforts: Dell, Seagate, Teleplan

2019: Dell, Seagate, and Teleplan developed method to scrape rare earth metals and magnets from HDDs and recycle into new devices.

By October 2021, over 19,000 pounds of recovered and recycled magnets have been installed in Dell and competitor products. <https://www.dell.com/en-us/blog/circular-design-gives-e-waste-a-second-life/>

Seagate 2023 report: 1.16 million refurbished HDDs and SSDs in FY22 (540 metric tons e-waste) <https://www.seagate.com/esg/> <https://www.seagate.com/esg/planet/product-sustainability/>

<https://www.storagenewsletter.com/2023/05/02/seagate-report-on-transitions-more-operations-to-renewable-energy-and-ramps-circularity-program/>

Promising recent efforts: Seagate and Open Compute Project (OCP)

Holding discussions with hyperscalers to work on security protocols, so they feel secure to recycle the drives (not just shred).

22 million hard disk drives age out at North American data centers every year.

They are shredded. Companies fear litigation of client data on a drive is released on a decommissioned drive.

Open Compute Project (OCP): <https://www.opencompute.org/>

Promising recent efforts: Circular Drive Initiative (CDI)

“The Circular Drive Initiative (CDI) is a partnership of global leaders in digital storage, data centers, sustainability, and blockchain collaborating to reduce e-waste by enabling, driving, and promoting the secure reuse of storage hardware.”

<https://circulardrives.org/resources/> (*Data Sanitization Best Practices* guide)



Home Members FAQ Events News Blog LinkedIn Resources

McDONOUGH
INNOVATION
DESIGN FOR THE CIRCULAR ECONOMY™



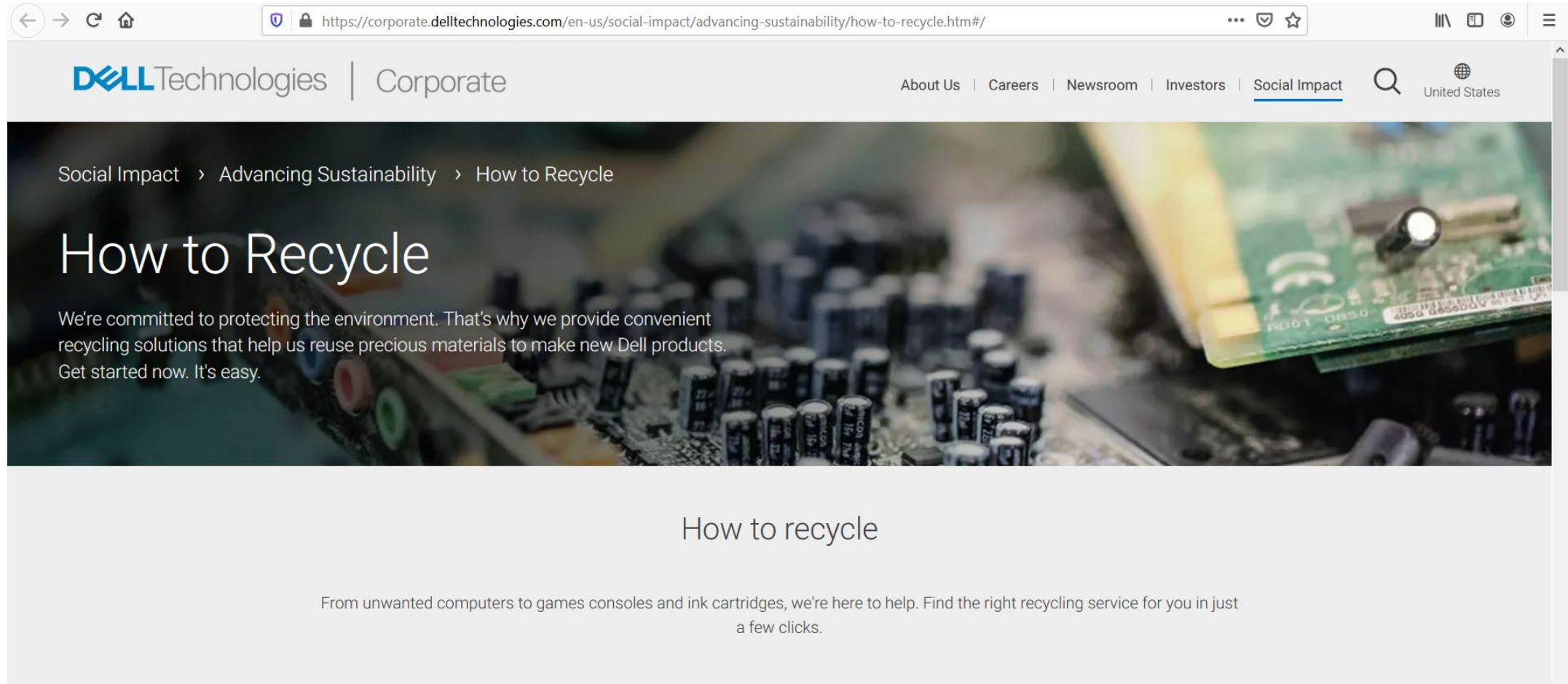
Promising recent efforts: Google and data centers

Google is developing technologies to reclaim magnets from data center HDDs. These are **enterprise HDDs**, not consumer HDDs.

Stone, Maddie. “Can you recycle a hard drive? Google is quietly trying to find out.” *Grist*. August 2021

<https://grist.org/technology/can-you-recycle-a-hard-drive-google-is-quietly-trying-to-find-out/>

<https://corporate.delltechnologies.com/en-us/social-impact/advancing-sustainability/how-to-recycle.htm#/> [This is an international program]



<https://www.hp.com/us-en/hp-information/sustainable-impact/planet-product-recycling.html> [this is an international program]

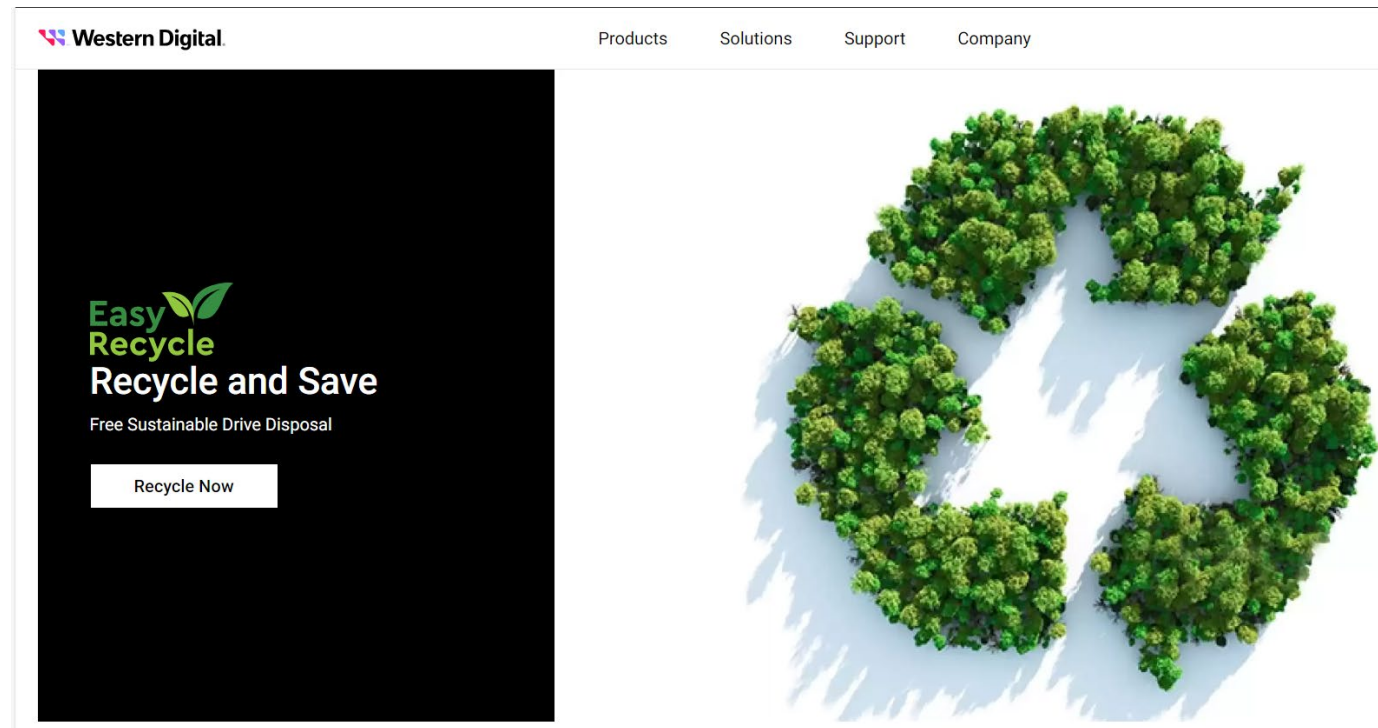
The screenshot shows the HP Planet Product Recycling website. At the top, there is a navigation bar with "Sustainable Impact" and links for "Planet", "People", "Community", and "Documents and Reports". A "DOWNLOAD REPORT" button is also present. The main heading is "RECYCLE". Below this, there are filters for "REGION" and "COUNTRY" (with a dropdown menu open showing options like Samoa, Saudi Arabia, Serbia, Singapore, Slovakia, Slovenia, South Africa, South Korea, and Spain). The page displays a grid of 12 items, each with an image and a description of the recycling program. The items include: ORIGINAL HP INK AND TONER CARTRIDGES, BUSINESS EQUIPMENT, ORIGINAL HP INK AND TONER CARTRIDGES, AND SAMSUNG TONER CARTRIDGES, HP 3D CONSUMABLES, SHOP FOR A REPLACEMENT, CONSUMER AND HOME OFFICE EQUIPMENT, and BUSINESS EQUIPMENT. The bottom of the page features a copyright notice: "(c) 2025 Linda Tadic".

HP has a global consumer and business recycling program.

Promising recent efforts

Western Digital recycling program for HDDs and SSDs. Drives from any manufacturer. Consumer-oriented (limit of 5 drives at any one time). (April 2020; US-only)

<https://www.westerndigital.com/company/programs/easy-recycle>



Data storage options: NAND Flash Memory on Solid State Drives (SSD)

- No moving parts (power down when not in use)
- Finite number of writes; infinite number of reads
- Fewer natural resources used in the final product



Electricity use: Low-medium

- Powered up only when used, but uses a lot of power when starting up
- Works in extreme environments (up to 85°C / 185° F)

Life expectancy: Depends on number of writes. Data “fades” (loses bits) over time; not a good archival storage medium. Can “fade” even when sitting inert on shelf.

Potential recyclable parts: silicon, copper

But SSDs emit more CO2 overall than HDDs

Taking into account the LCA over 5 years (comparing a 1TB SSD and 1TB HDD):

The SSD uses less energy while in use:

SSD: 56.9 kWh

HDD: 183.9 kWh

But the overall CO2 output:

SSD: 184 kg

HDD: 99.6 kg

<https://basic-tutorials.com/news/ssds-cause-more-co2-emissions-than-mechanical-hard-disks/>

<https://hotcarbon.org/> *Hot Carbon 2022: 1st Workshop on Sustainable Computer Systems Design and Implementation*

<https://arxiv.org/pdf/2207.10793.pdf> “The Dirty Secret of SSDs: Embodied Carbon.” Tannu, Swamit and Prashant J Nair. *arXiv*, 8 July 2022.

Co2 emitted by AI and machine learning tools

Using AI, ML, and autonomous cars requires extensive compute power in data centers.

ML CO2 impact calculator: <https://mlco2.github.io/impact/>

“Green Intelligence: Why Data And AI Must Become More Sustainable.” Bernard Marr. Forbes. March 22, 2023.

<https://www-forbes-com.cdn.ampproject.org/c/s/www.forbes.com/sites/bernardmarr/2023/03/22/green-intelligence-why-data-and-ai-must-become-more-sustainable/amp/>

2021 Global storage media & computing supply-chain shortage

1. **Microchip and semi-conductor shortage** (Spring 2021)

Manufacturing microchips is water-intensive. Pandemic plus drought in Taiwan contributed to a slow-down in production.

2. **Shortage of HDD and SSD from Chia cryptocurrency use**

<https://www.datacenterdynamics.com/en/news/chia-cryptocurrency-comes-for-the-hard-drive/> (12 May 2021)

Data storage options: Data storage tape

LTO has largest market share in data tape.

Electricity use: Low-Medium

- On shelf: no power. In drive or robotic system: low-medium
- Can be used as offline storage (used only when needed)
- Environment must be maintained at constant temperature (but higher than electronics)

Life expectancy: “30 years” but in reality, you replace every 2-3 generations (LTO-7 released Dec. 2015, LTO-8 Oct 2017, LTO-9 2021 Q4, LTO-10 2025 Q3).

Potential recyclable parts: plastics, screws (metal). No process yet to separate mylar ribbon (recyclable) from particles or other components. Generational obsolescence, finite number of “reads,” and WORM technology limits this medium’s re-usability.



Recycle your drives, LTOs, and media at certified e-waste facilities

R2:

<https://sustainableelectronics.org/find-an-r2-certified-facility/>

E-Stewards:

<https://e-stewards.org/>

SIMS Lifecycle Services:

<https://www.simslifecycle.com/locations/>

Data tape only:

Insurgo: <https://insurgo.co.uk/secure-disposal-solutions/>

Data storage options: “Cloud” (e.g., storing your files on other people’s servers)

“Cloud” **storage**: You pay for what you use, and don’t need to purchase hardware (no organizational storage e-waste).

Using the cloud **CAN** be helpful in its economies of scale. Cloud provider manages hardware, power, air conditioning.

You don’t need to keep buying the hardware which becomes e-waste.
Electricity use is optimized (*maybe*).

Collections’ access can be global, not just local.

Carbon neutral?

Archives, universities, and businesses incorporate cloud storage into a “carbon neutral” strategy –

But sometimes **“carbon neutral”** means **using someone else’s carbon.**

It’s still your data.

The “Cloud” has a heavy weight

Consider your vendor’s power source. Is it **dirty**?

In **2028 in the US**: expected to use **12%** of the country’s electricity demand.

- The major “cloud” service providers **were** moving towards using 100% renewable energy. **But developing and supporting AI put an end to that.**
- Facebook, Google, and Apple are investing in building wind and solar farms to power their dedicated-built data centers and to supply neighbors.
 - **BUT** most of their servers are in third-party data centers (renting space)

Global data center industry is expected to emit approximately 2.5 billion metric tons of carbon dioxide-equivalent through 2030.

This level of emissions represents about 40% of the total annual greenhouse gas emissions of the entire United States.

Morgan Stanley uses this data to encourage investment in decarbonization solutions.

Jenkins, Lisa Martine. "Will the Data Center Boom Boost Carbon Removal?" Latitude Media. 9 September 2024. <https://www.latitudemedia.com/news/will-the-data-center-boom-boost-carbon-removal/>

Data centers and water use

A mid-sized data center consumes around **300,000 gallons of water a day**, or about as much as 1,000 U.S. households. Their direct, on-site consumption ranks data centers among the top 10 water users in America's industrial and commercial sectors.

In the United States, there are about 2,600 data centers.

<https://www.npr.org/2022/08/30/1119938708/data-centers-backbone-of-the-digital-economy-face-water-scarcity-and-climate-ris>

Data centers keep cool by either using chilled water tanks (uses more electricity), or evaporative cooling (uses more water).

Data centers and water use

New data centers being designed to use recycled water, non-potable water, and chilled water tanks that use solar power to keep chilled.

Mini modular nuclear reactors are being developed to supply power to data centers. But the reactors need water to keep cool as well.

AI & ML tools and water use

Asking ChatGPT between 5-50 prompts or questions uses 500 milliliters of water (ca. 16 oz).

Microsoft's global water consumption spiked 34% from 2021 to 2022 (to nearly 1.7 billion gallons). Google's grew 20% in the same period. Both are attributed to AI research and computing.

<https://apnews.com/article/chatgpt-gpt4-iowa-ai-water-consumption-microsoft-f551fde98083d17a7e8d904f8be822c4>

Ren, Sholai, et al. "Making AI Less "Thirsty": Uncovering and Addressing the Secret Water Footprint of AI Models." arXiv.org. 29 Oct 2023. <https://arxiv.org/pdf/2304.03271.pdf>

Data centers and the circular economy

Google says 27 percent of the components it used in server upgrades in 2021 were refurbished inventory and that it overwrites data on its hard drives for reuse “where possible.”

Amazon: shreds all drives after 3-5 years of use.

Microsoft now operates several “circular centers” for refurbishing old servers and says more than 80 percent of its decommissioned assets will be repurposed by 2024. Several R&D projects using robots and AI to shred and sort rare earth materials and return to supply chain.

Signs that sustainability efforts are becoming normalized

- Organizations moving away from all-cloud to hybrid model.
- LTO is considered part of a “green” solution to data storage.

Keeping in mind energy use and e-waste:

What can archives do to mitigate their environmental impact?

Technology: Use less energy

Related to storage. Using less electricity and fewer spinning disks helps the environment plus saves money.

1. **Apply hierarchical storage management (HSM) policies:** Store large and infrequently accessed files offline on data tape. Only store frequently accessed files online (tier 1).

Spinning disk storage takes 26x more energy than storing and infrequently accessing data tapes.

HSM tiers

Tier 1 (Online): Immediate access from spinning disk or SSD

Tier 2 (Nearline): Can be (1) Stored on tape in a SAN; files accessed from the tape. OR (2) files on HDD with Tier1 on fast SSD

Tier 3 (Offline): Stored on tape or other media off the network

If applied thoughtfully, cloud storage can be part of HSM policies.

Technology: Use less energy

2. **If store on data tape (LTO):** Migrate to new media every two (or even three) generations LTO (~ every 5-10 years).

More files will be stored on the new generation tape (fewer media items).

Recycle the old data tape through destruction (not re-use) for security, but also since the tape format will be obsolete and overly-used. Data tape has a maximum number of “reads.”

- Recycle the plastic cartridge and metal screws if possible.

Technology: Use less energy

If you have a server room on-site running current hardware:

- 3. Set the server room temperature higher: 70-80° F**
(no more than 27° C / 81° F)

Rooms with data tape:

15 – 32° C / 59 - 89° F (rate of change less than 5° C per hour)

20 – 80% RH (rate of change less than 5% per hour)

ASHRAE, 2022. Thermal Guidelines for Data Processing Environments, Fifth Edition, ASHRAE.
<https://www.ashrae.org/technical-resources/bookstore/datacom-series>

Technology: Use less energy

4. Turn off unused servers.
5. Set servers to go to inactive mode when not in use.
6. Consolidate and virtualize several applications on one server.
 - This also results in fewer servers to replace/recycle.
7. Use the cloud for some applications (but verify the provider's "green" record).
8. Question your data/colocation center on its power source and "green" record.

Technology: Environmental planning

1. Purchase clean energy where possible, not coal-generated.
2. Purchase hardware that is energy efficient.
3. Purchase recycled devices (recycled materials or recycled by re-use).
4. Upgrade servers by upgrading drives (not the entire box)
5. Recycle by re-use when possible.
6. Recycle data tape and hard drives with vendors who strip out parts and recycle components where possible. If media is shredded and incinerated, verify the incineration process.

Preservation actions

Schedule infrequent fixity checks

This depends on storage medium and system. If the files and storage media are stable, no need to perform more than once a year.

Running fixity checks takes CPU, memory, storage --- all running on electricity.

Policies

Appraisal policies

Does all digital content acquired or created by the archive require **permanent retention**?

If retained for a specific period (not permanent), move files between storage tiers, and ultimately delete.

Policies

Appraisal policies

Does all content acquired or created by the archive need to be digitized/saved at the **highest possible resolution**?

High resolution = large files = large amount of storage to manage.

Store permanent large preservation masters offline.

Low resolution digital files are better than nothing.

If you have limited resources and budget, it's better to save the content than fetishize the file format.

Just be sure the format is sustainable (widely used and supported) and can be migrated in the future.

Set a carbon budget

Work from home as much as possible.

- Less transit use and automobile emissions
- Less oil/gas used, less demand = more investments in renewables

Hold remote conferences or hybrid events.

- Remote events widen the capability of people to participate who otherwise might not be able to travel.
- Online events more environmentally-friendly than in-person.

Set a carbon budget

Use local vendors and suppliers

Consolidate shipments



Photo: NASA

Thank you.

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