Circular Economy for Microelectronics: Economic and Environmental Benefits

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Recent research themes

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FULBRIGHT

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WHERE DISCOVERIES BEGIN

National Science Foundation

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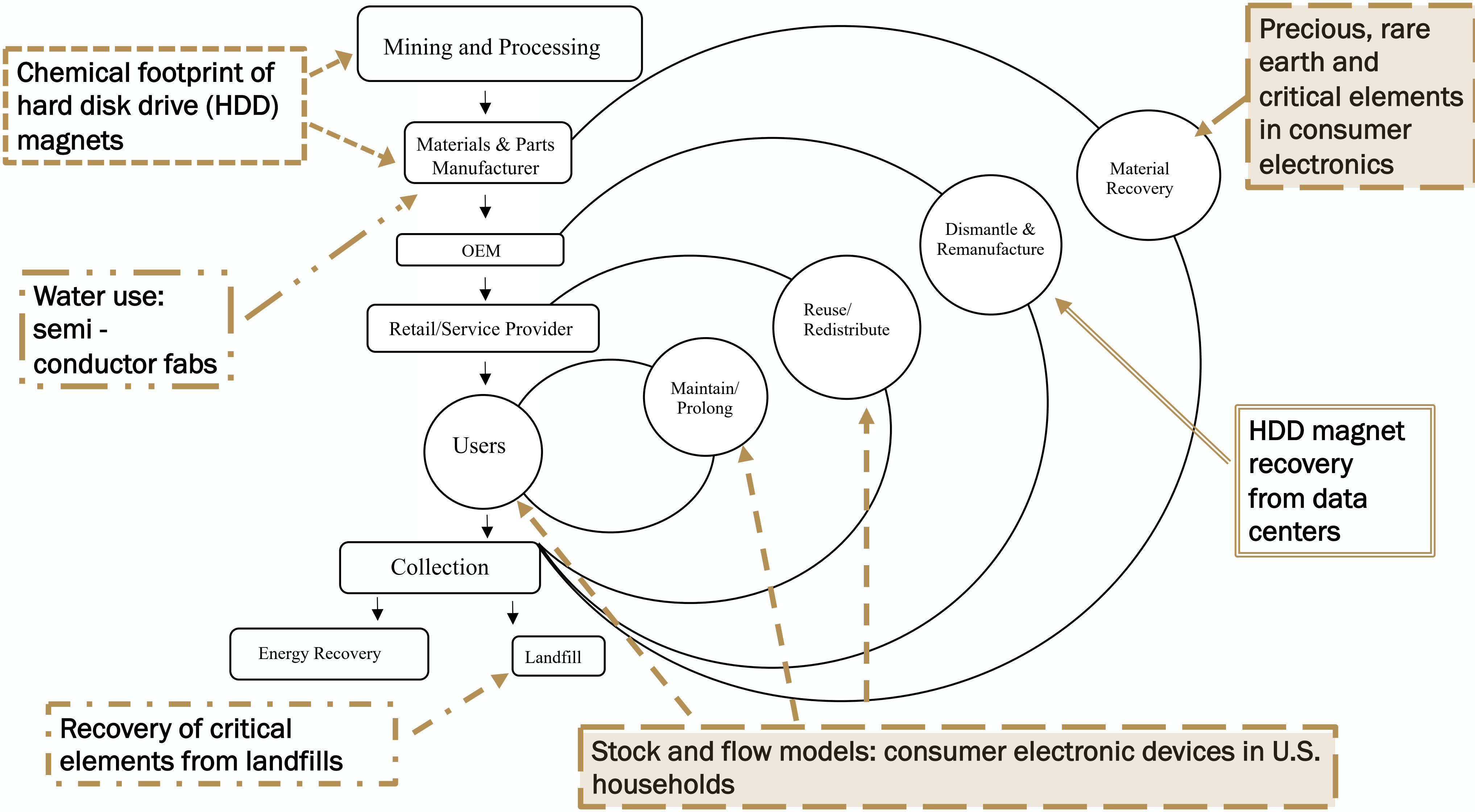


Mining and Processing
Materials & Parts Manufacturer
OEM
Retail/Service Provider
Users
Collection
Energy Recovery
Landfill
Maintain/ Prolong
Reuse/ Redistribute
Dismantle & Remanufacture
Material Recovery
Chemical footprint of hard disk drive (HDD) magnets
Water use: semi - conductor fabs
Recovery of critical elements from landfills
Stock and flow models: consumer electronic devices in U.S. households
HDD magnet recovery from data centers
Precious, rare earth and critical elements in consumer electronics

Precious, rare earth and critical elements in consumer electronics

- Electronic devices of all kinds, and especially consumer electronics, have evolved in function and composition, in parallel to increasing manufacture and use.
- Historical focus on recycling and recovery of commodities such as aluminum, iron, glass, etc.
- More recent studies related to rare earth, precious, critical elements in electronics (*environmental impact and supply constraints*)
- What is the potential for recovering valuable elements from consumer electronics?

End-of-Life (EoL) Devices and Methodology Summary

Collected 10 EoL samples: hard drives, ethernet hubs, portable media players, printers, answering machines, mobile phones, Digital Versatile Disc (DVD) players, computer wiring, printed circuit boards (PCBs) and electronic waste (commercial recycling facility).

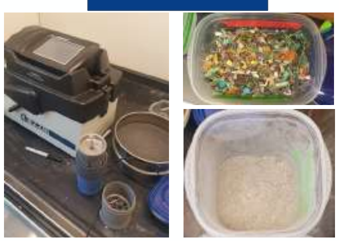
Methodology and Work Flow Example

Desktop

Disassembly & Sorting

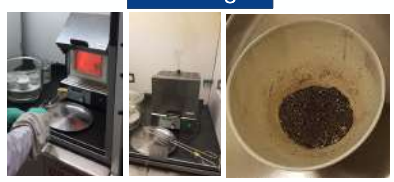
Ten EoL electronics samples collected. Shown here are the PCBs taken from one desktop computer. Samples were sorted based on device or component.

Size Reduction



Disassembled devices were sent to an industrial shredder. Shredded material *(top right)* was further size reduced to 1.18 mm powder *(bottom right)* using an IKA blender, freezer mill, and liquid nitrogen *(left)*.

Ashing



Ashing was completed in a Ney Vulcan D-130 muffle furnace *(left and center)* for two hours at temperatures ranging from 500° C to 1000° C. The sample shown *(right)* was ashed at 800° C for two hours.

Microwave Assisted Digestion

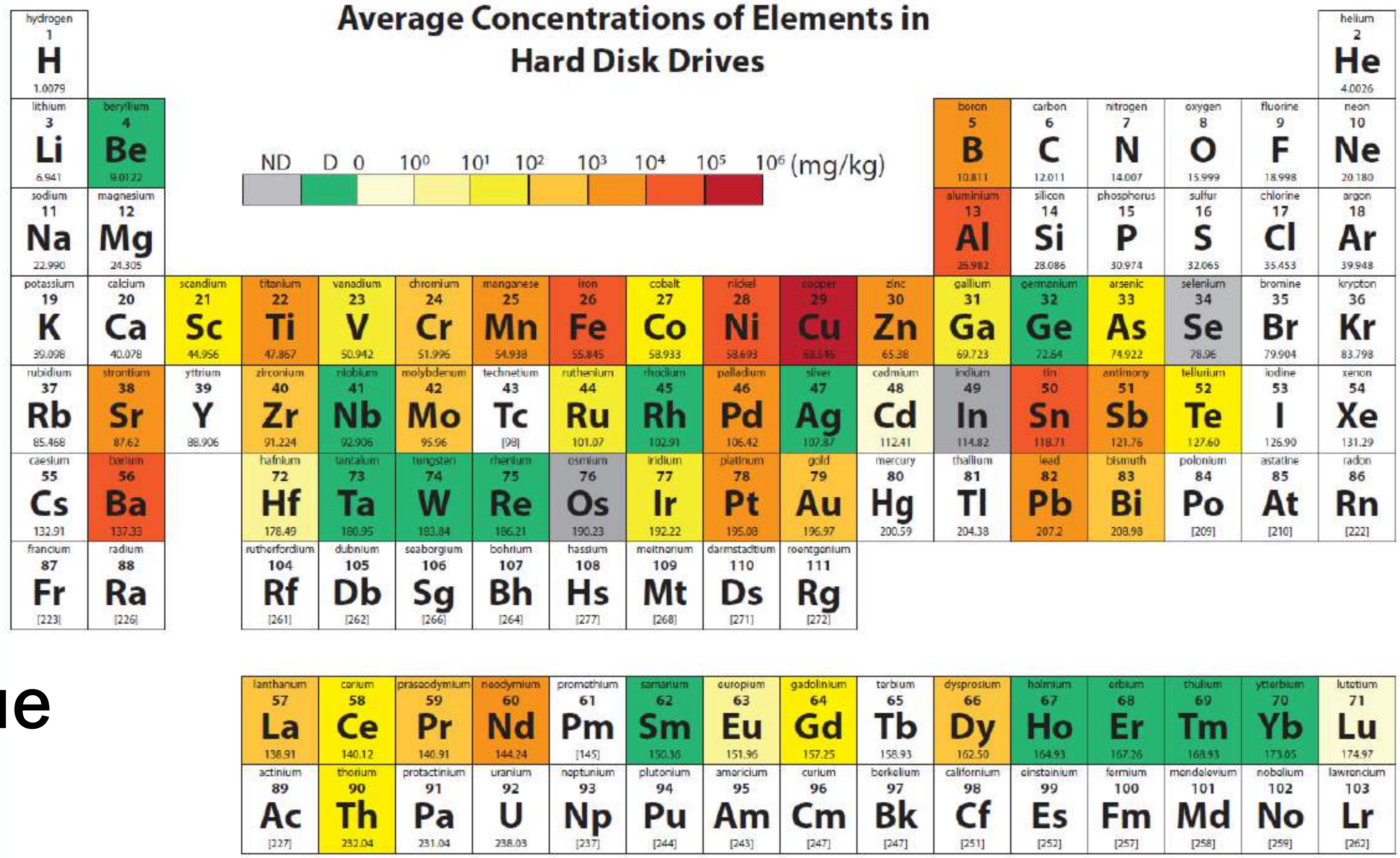
Samples for digestion were prepared using 0.5 g of powder or ash, 9 mL of 35% HCl, and 3 mL of 70% HNO_3. Samples were pre-digested in the vessels for 30 minutes *(left)*.PCB Powder and ashed samples were digested using a CEM Mars 6 Microwave Digestion System *(center)* at 200° C for 15 minutes at a power of 900 W. Vacuum filtration was used to remove the undigested sample *(right)* before ICP-OES analysis.

ICP-OES Analysis

Concentrations of 60+ elements were tested using an iCAP 7400 Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES).

Variety of elements detected in a single device

Full results available in: “Comprehensive Elemental Analysis of Consumer Electronic Devices: Rare Earth, Precious, and Critical Elements,” Dylan T. Buechler, Nadezhda N. Zyaykina, Cole A. Spencer, Emily Lawson, Natasha M. Ploss, Inez Hua, *Waste Management*, 2019



*Economic value

Significance, limitations, implications

- Incomplete digestion of solid samples → underestimate concentrations

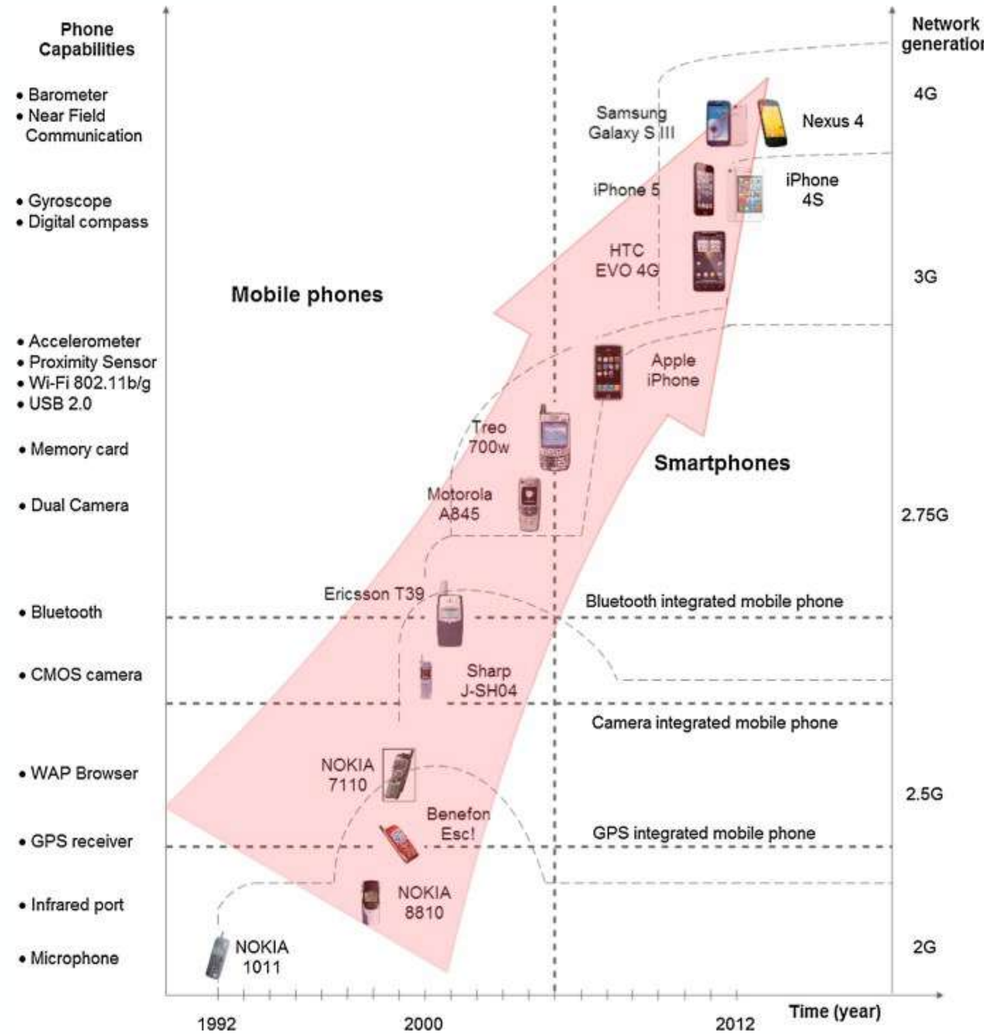
- Sub-sampling of components

- ”Snapshot” of multiple devices

- **Next steps:** refine methodology (complete digestion using HF), and focus on specific device

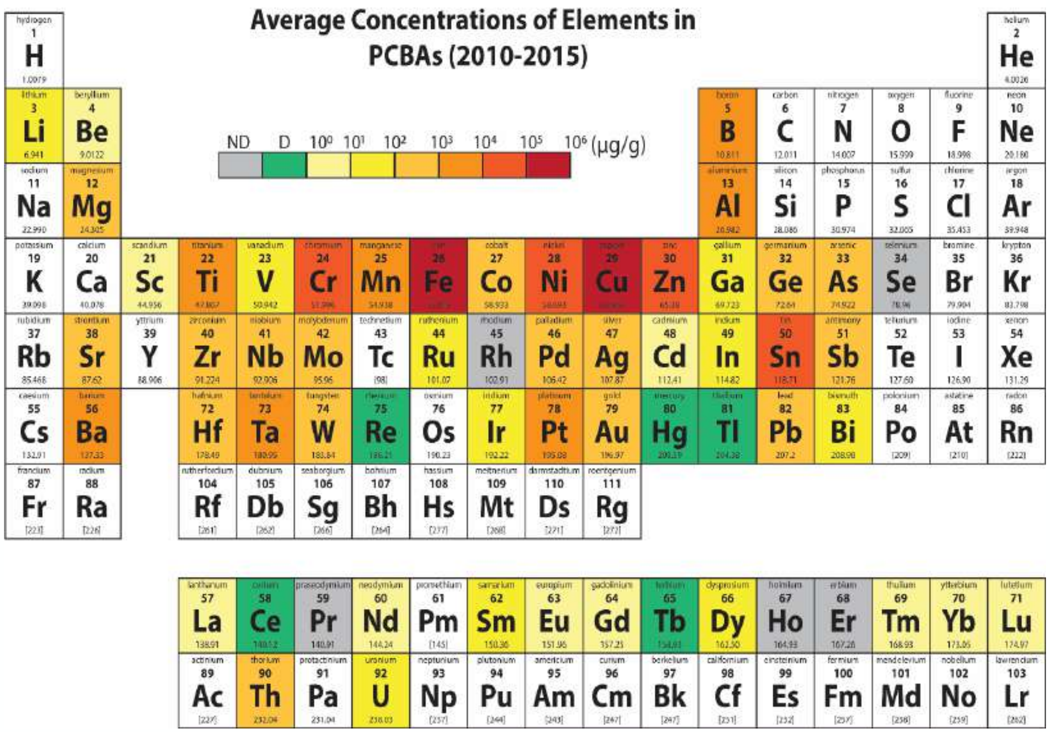
Smartphone Functionality

Does environmental impact change as smartphone functionality evolves?



P. Daponte, L. De Vito, F. Picariello, and M. Riccio, "State of the art and future developments of measurement applications on smartphones," *Measurement: Journal of the International Measurement Confederation*, vol. 46, no. 9. Elsevier B.V., pp. 3291–3307, 2013.

Printed Circuit Board Assembly



*Economic value

- PCBAs are the “brain” of the device.
- Cu, Ni, Zn and Fe are 93.3 % of total metals quantified weight.
- PGMs and REEs 0.53%

Stock and Flow Model of Consumer Electronic Devices in U.S. Households

Prior studies quantify:
1) Precious, rare earth, and critical elements in a variety of consumer electronic devices
2) Changes in function correspond to changes in composition
3) Resource intensity of cradle-to-gate processes
4) Benefits of closing the ”larger” loops.

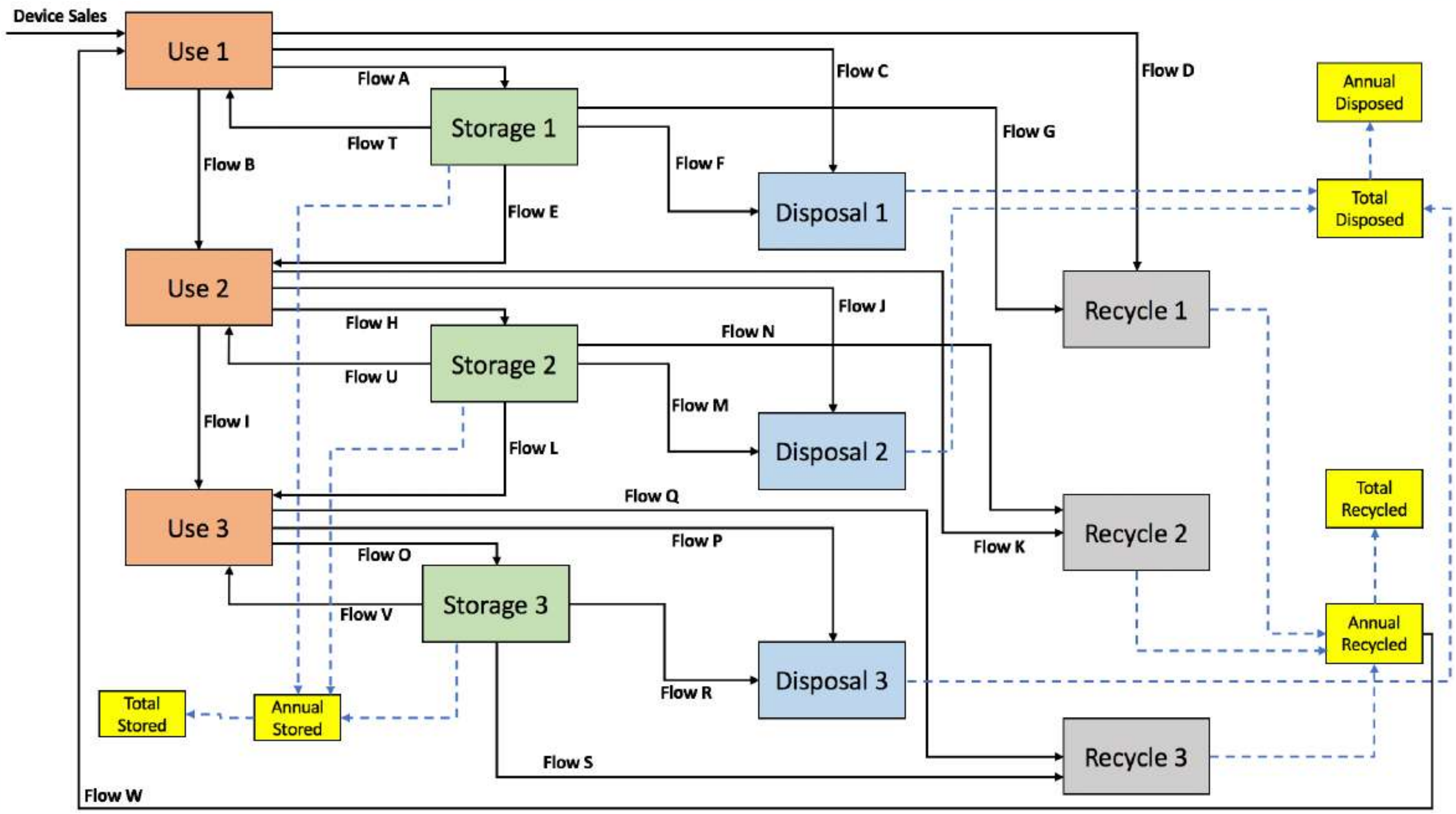
Principles of circular economy: minimize inputs and maintain materials at highest quality for as long as possible.

Research question: *how circular is the flow of consumer electronic devices?*

Stock and Flow Model

Inputs: annual sales data and transfer coefficients between stocks.

Transfer coefficients calculated from household survey.



<u>Eight devices: </u>cell phones, laptops, tablets, smart watches, headphones, desktop computers, televisions, and printers

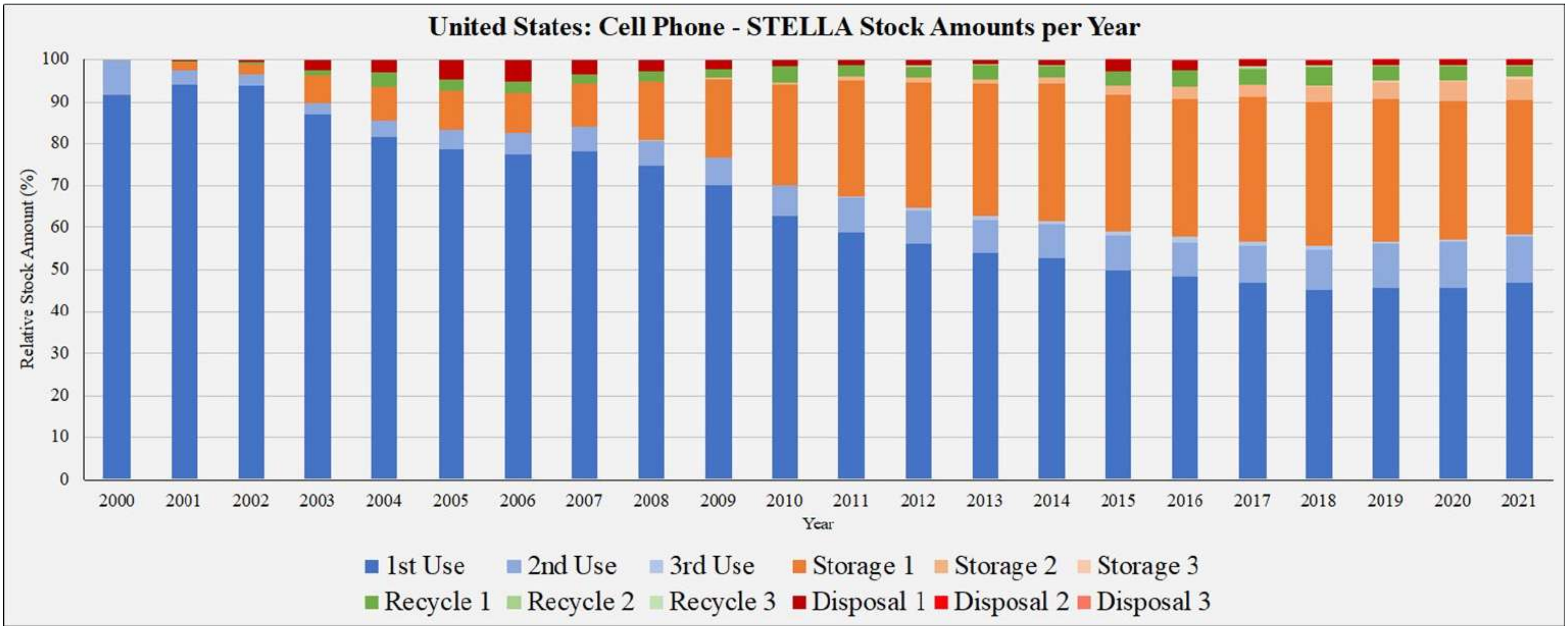
U.S. Household Survey

Devices of Interest Cell Phone, Laptops, Tablet Computer, Smart Watch, Headphones, Desktop Computer, Printer, Television	Shared Questions	Unique Questions	Outcomes
1. **Start of Survey** In-Use	• Year Acquired • Current user/last user • Previous usage duration • Previous storage duration		Pathways of devices currently in-use
2. In-Storage		• Year last used	Pathways of currently stored devices
3. EoL (recycling, disposal)		• Year last used • Year disposed/recycled • Method of disposal/recycle	Pathways of devices not currently owned
4. Demographic **End of Survey**	• Household Members • Gender • Age • Education • Zip Code		Pathway trends based on US demographics

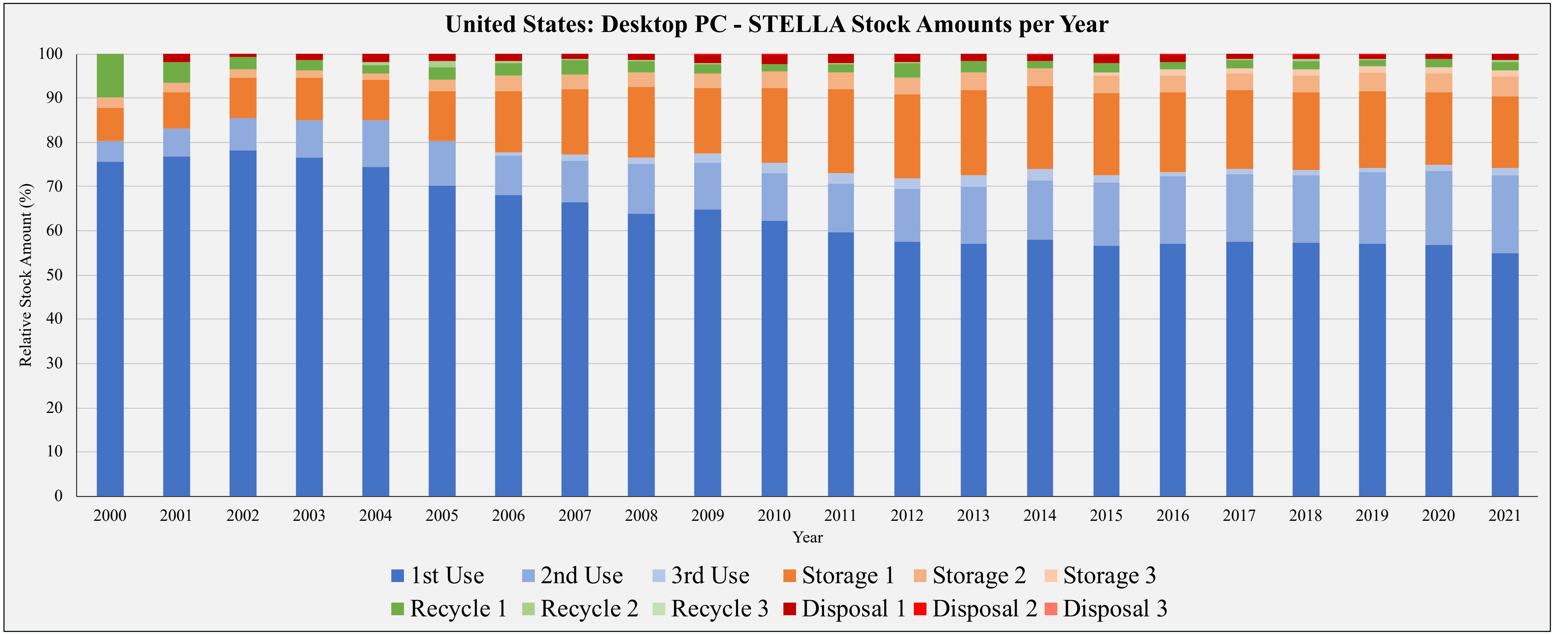
- Data collected February 2021-January 2022 (digital)
- 903 U.S. households (every state except Alaska)
- Sample size sufficient to be ”representative” of the U.S. (based on Census Bureau guidance)
- Derive transfer coefficients A-V for eight devices

Survey approved by Purdue University Institutional Review Board (IRB-2020-1626)

Model Output: Cell Phones

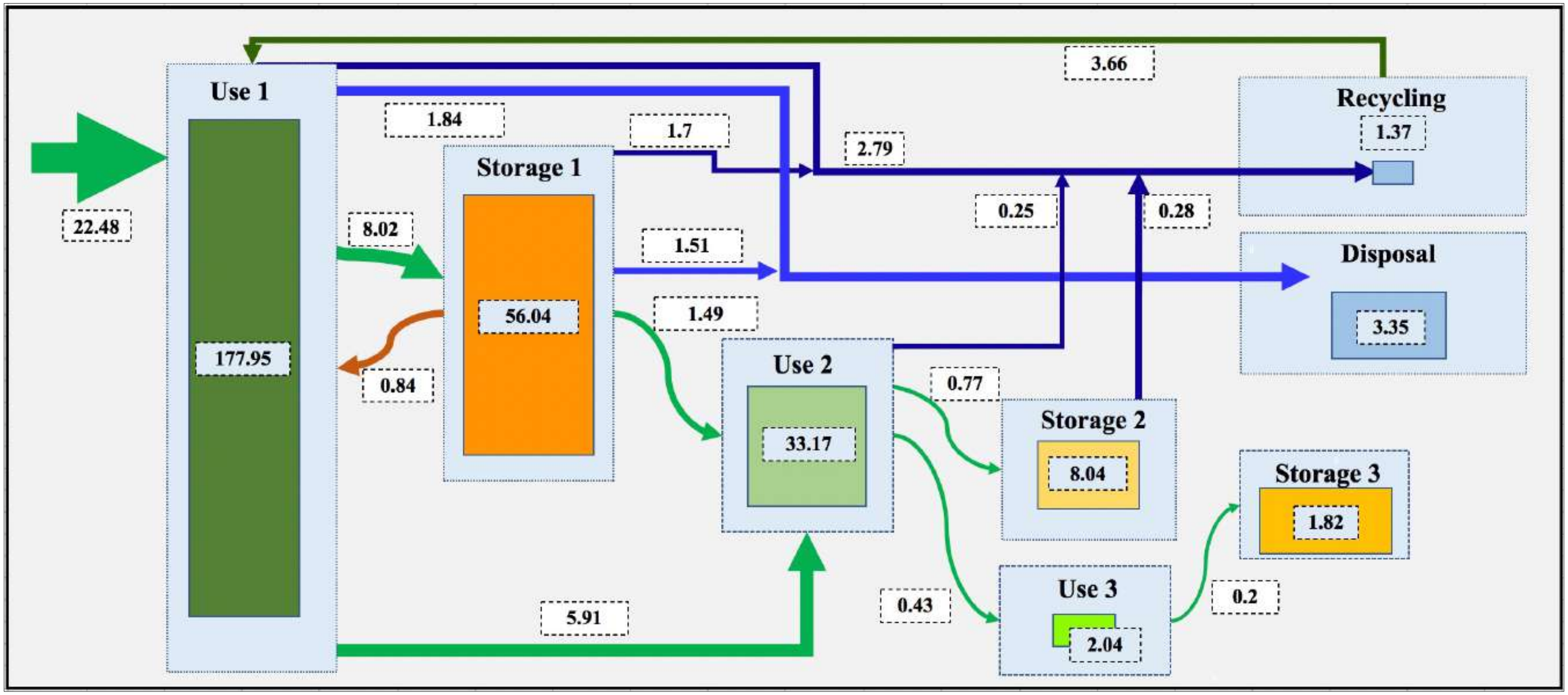


Model Output – Desktop computers



Model Output: Stocks of Metals

Combine model output (numbers of devices in each stock) with Bill of Materials data for each device to estimate total stocks of metals in U.S. households.



Sankey diagram: stocks and flows of gold (tons) in consumer electronics in U.S. households (2020).

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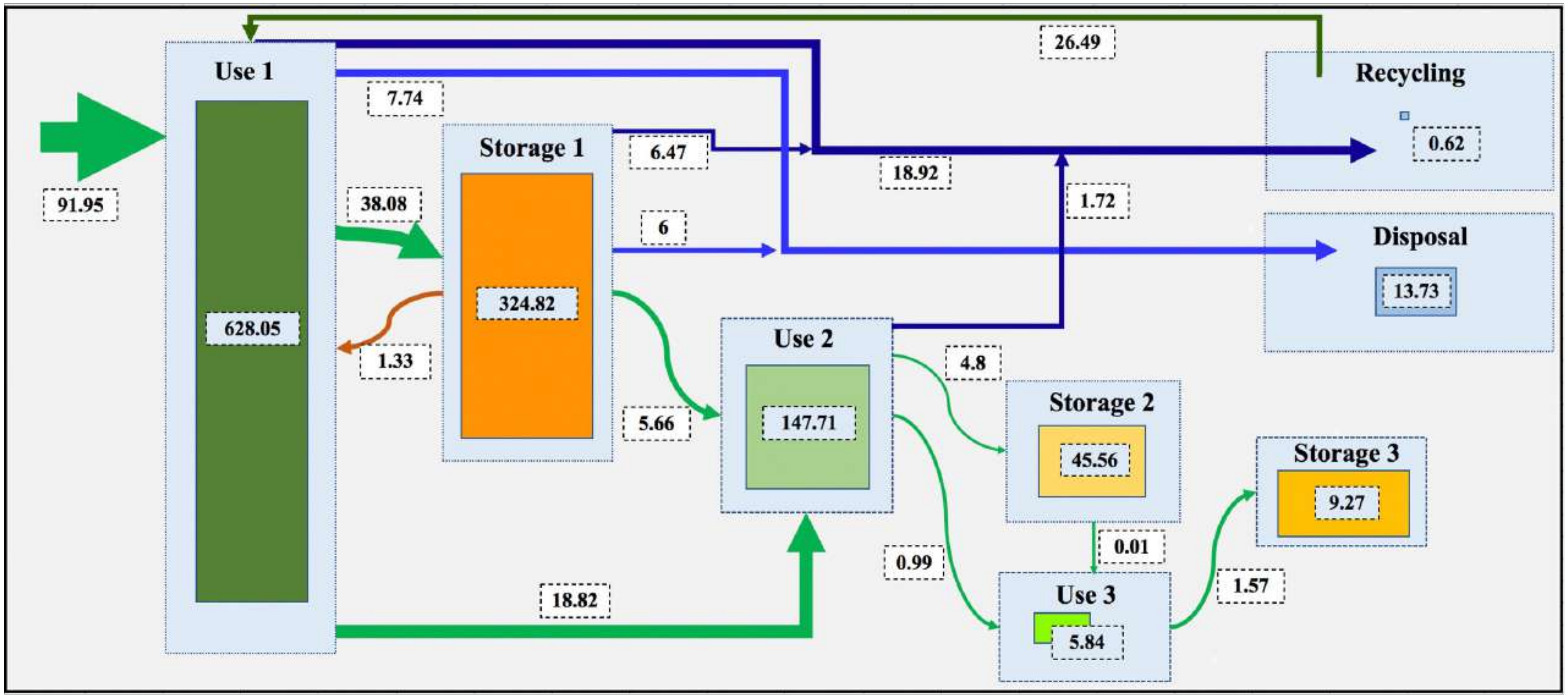


Sankey diagram: stocks and flows of platinum (tons) in consumer electronics in U.S. households (2020).

Significance and Limitations

1)Substantial economic value (metals) for 8 electronic devices ***in storage*** in U.S. households.

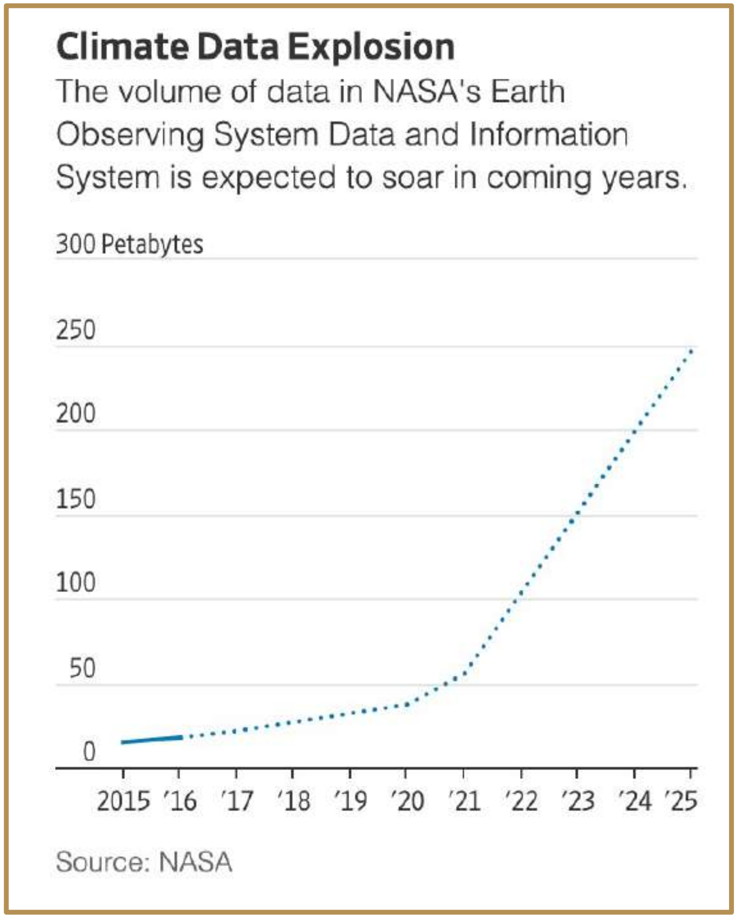
2)Recovering value requires behavioral change (transferring in-storage devices to recyclers) and technological innovation (separating and refining the metals).

3)Improving model input (transfer coefficients) requires actual observation of household devices (versus survey responses).

Next Generation Technology and Talent

Observations from a 12 month sabbatical

- Hosted by Western Digital Corporation (WDC), Hard Disk Drive (HDD) Business Unit, Chief Technology Officer
- Interactions with multiple functions at WDC
- HDD technology very complex; demanding performance requirements
- Data storage enables many societal functions, including scientific research.
- Integrate sustainability into technological innovation.



WD External blog -- Live link:

Why Collboration Matters for Climate Action

Questions and discussions