

UNIT II

Lifecycle Sustainability of Computing Systems and Circular Economy

Most of a device's environmental cost is paid before it is ever switched on. This unit moves from code to the physical hardware behind it.

06 Hours

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Unit at a Glance

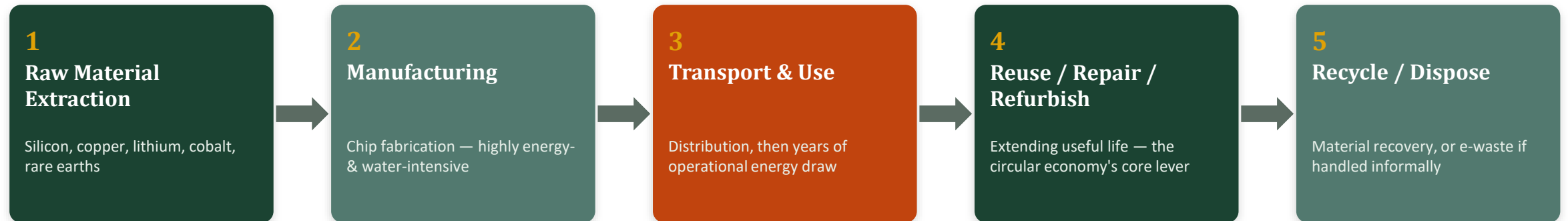
Purpose: Shifts students from thinking only about software to thinking about the material lifecycle of the devices, chips and data-centre hardware their software runs on.

- Lifecycle of computing devices: manufacture, use, disposal
- Energy use of processors, GPUs, edge & IoT devices
- Embodied energy: concept & estimation methods
- Electronic waste (e-waste): management & impacts
- Circular economy in IT: reduce, reuse, recycle
- Sustainable supply chains & green hardware design
- Life Cycle Assessment (LCA): what it measures & why
- Four phases of LCA: goal/scope, inventory, impact, interpretation
- ISO 14040 & ISO 14044 standards for LCA

Maps chiefly to CO2/CO3 · Prescribed case study: Circular Economy and Lifecycle Analysis of a Computing Device

CORE CONCEPT

The Lifecycle of a Computing Device



Key insight to emphasise: research consistently shows that manufacturing — especially chip fabrication — accounts for a large share of a device's total lifetime emissions, often more than years of actual use. This is why "buy less, use longer" beats "buy efficient, replace often."

CORE CONCEPT

Embodied Energy and the Circular Economy (3R Model)

Circular economy replaces the linear "take–make–dispose" model computing has followed for decades:

R1 Reduce

Design for fewer materials, longer service life, and lower embodied energy from the outset — e.g. modular laptops, repairable phones.

R2 Reuse

Refurbishment and resale markets extend a device's productive life, deferring the need for new manufacturing entirely.

R3 Recycle

Formal recovery of silicon, copper, gold and rare earths from end-of-life devices, reducing demand for virgin material extraction.

CORE CONCEPT

Life Cycle Assessment (LCA) — ISO 14040 / 14044

LCA is the standardised, science-based method for measuring a device's total environmental footprint across its life — used throughout Units II–IV:

1 Goal & Scope Definition

Define what is being assessed, the boundaries (cradle-to-grave vs cradle-to-gate), and the functional unit of comparison.

2 Inventory Analysis

Collect data on all material and energy inputs/outputs at every lifecycle stage — the most data-intensive phase.

3 Impact Assessment

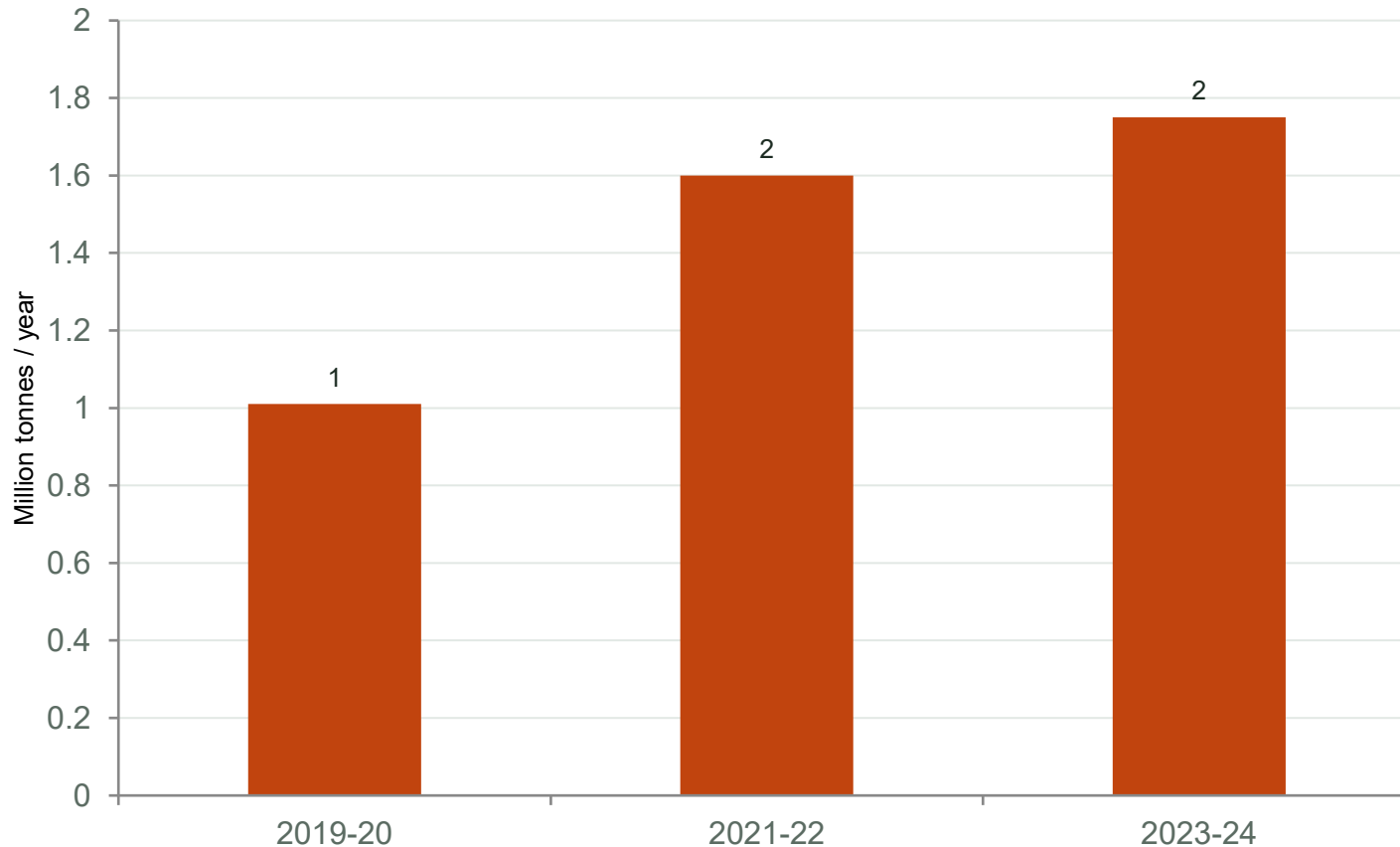
Translate inventory data into environmental impact categories: carbon footprint, water use, resource depletion, toxicity.

4 Interpretation

Draw conclusions, identify hotspots, and recommend design or policy changes to reduce impact.

DATA & STATISTICS

India's E-Waste Problem Is Growing Faster Than Its Recycling Capacity



Why this matters

India generates roughly 1.6–1.8 million tonnes of e-waste annually and ranks 3rd globally after China and the US. Formal recycling has improved from 22% to about 43% of generated e-waste — still leaving well over half unaccounted for through safe, formal channels.

Sources: Global E-waste Monitor 2024 (UNITAR); Lok Sabha/Rajya Sabha government data, 2024

CASE STUDY (SYLLABUS-PRESCRIBED)

Case Study: Circular Economy and Lifecycle Analysis of a Computing Device

- Consider a typical laptop: manufacturing (chip fabrication, aluminium/plastic casing, battery production) can account for the majority of its total lifetime carbon footprint — often more than 2–3 years of active daily use.
- A 4-year-old laptop that is refurbished and resold (new battery, cleaned components, updated OS) avoids the embodied-energy cost of manufacturing an entirely new unit — directly applying the "reuse" principle.
- At end of life, over half of India's e-waste is still processed informally by unregulated recyclers, releasing lead, mercury and brominated flame retardants into soil and water rather than recovering materials safely.
- Applying LCA's four phases to this laptop — goal/scope, inventory, impact assessment, interpretation — lets an engineering team identify that battery and chip manufacturing, not years of usage electricity, is the biggest hotspot to target.

Discuss in class

- Where in this laptop's lifecycle would you invest first to cut its footprint — manufacturing, use, or disposal?
- Why does refurbishment save more emissions than most people intuitively expect?
- What incentives would make formal (rather than informal) e-waste recycling more attractive in India?
- How would extending device life by 2 years change the LCA impact-assessment numbers?

Suggested Pedagogy for Unit II

1

Device tear-down or dissection video

Show (in class or as homework) a short teardown video of a laptop/smartphone to make raw-material extraction and embodied energy visible and concrete.

2

Mini-LCA group exercise

In groups, have students sketch a simplified 4-phase LCA for a device they own — goal/scope, rough inventory, likely impact hotspot, one interpretation/recommendation.

3

Debate: repair vs replace

Split the class to argue for buying a new energy-efficient device vs repairing/extending the life of an existing one — surfaces the embodied-vs-operational-energy trade-off.

4

Field-linked assignment on local e-waste

Ask students to identify where e-waste from their own college/hostel goes — a registered recycler or an informal channel — and report findings.

5

Compare-and-contrast worksheet: linear vs circular

Use a two-column worksheet contrasting take-make-dispose vs reduce-reuse-recycle for a chosen product category (phones, servers, EV batteries).

6

Bring in ISO standards as a research skill

Have students locate (not memorise) the scope of ISO 14040 vs 14044 — builds the habit of consulting standards documents, a real engineering skill.

Faculty tip: *This unit is highly visual — use images/diagrams of device teardown and the LCA phases liberally. Students retain lifecycle concepts far better when they can picture the physical supply chain.*

Evaluation Techniques for Unit II

Assessment Component	Weight	How it maps to this unit
CCE numerical/short-answer quiz	5 Marks	Define embodied energy, name the 4 LCA phases in order, distinguish ISO 14040 vs 14044 scope.
Mini-LCA report (individual/group)	10 Marks	Apply the 4-phase LCA structure to a device of the student's choice — tests application, not recall.
E-waste field/desk investigation	5 Marks	Short written finding on a real or researched e-waste disposal pathway, with a circular-economy recommendation.
End-Semester theory question	Included in 35 Marks	Typically a descriptive question on circular economy principles or the LCA methodology with a computing example.

This unit lends itself well to project-based/group evaluation — consider replacing one quiz with the mini-LCA report to build applied skill rather than only definitional recall.

Unit II — Key Takeaways for Faculty

- ✓ Sustainability is not only about energy used while a device runs — manufacturing often dominates lifetime impact.
- ✓ The circular economy (reduce, reuse, recycle) offers concrete, teachable levers students can apply to real devices.
- ✓ LCA (ISO 14040/14044) gives a standardised, four-phase method for evaluating any product's environmental impact — a transferable skill beyond this course.
- ✓ India's e-waste challenge (1.6+ million tonnes/year, ~3rd largest generator globally) makes this unit locally urgent, not just theoretical.

For faculty-led discussion

- Should manufacturers be legally required to publish embodied-energy figures, the way food products list nutrition?
- Is Extended Producer Responsibility (EPR) working in India — what evidence would convince you either way?
- How might AI/DS-specific hardware (GPUs, TPUs) change this lifecycle picture compared to a laptop?