Innovation and the Circular Economy

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Five major technological innovations are serving the growing worldwide population and rising middle class.

Internet **Internet of things** **Renewables** **Advanced Materials** **Batteries**

Let’s focus on advanced materials and rechargeable batteries as *enablers.*






One goal is to reduce the planet's dependence on fossil fuels.

This…

This…

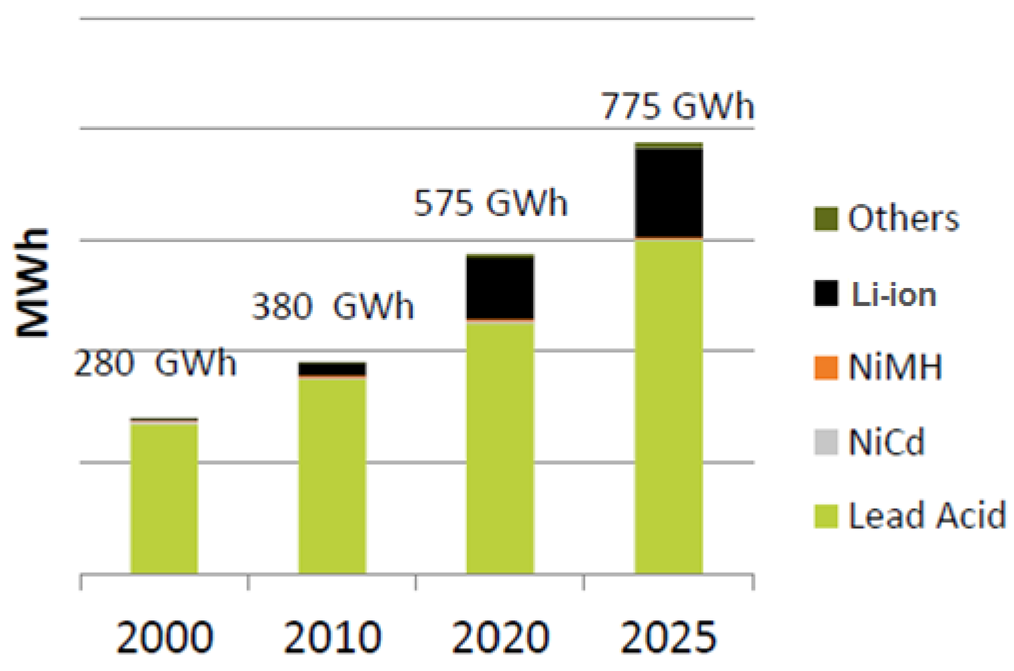
Not this…

Not this…

Rechargeable batteries are essential in the goal of reducing the world’s carbon footprint.

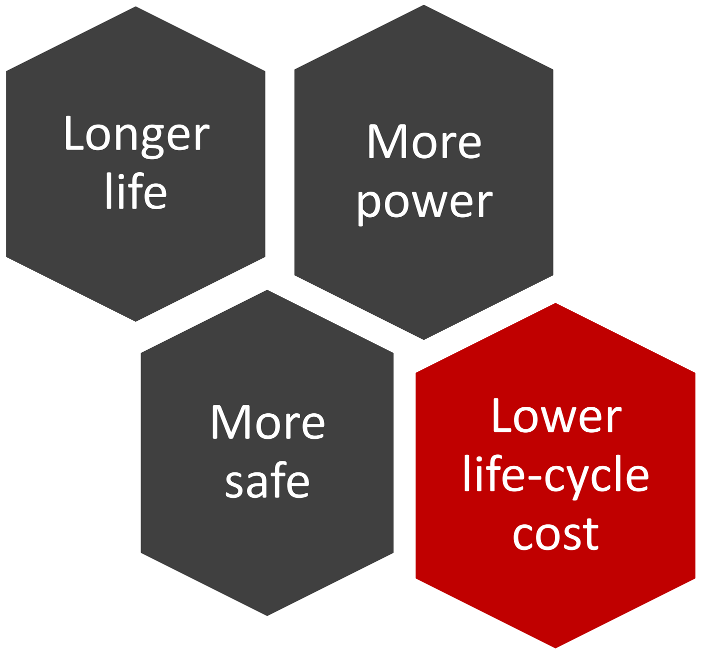
Worldwide Rechargeable Battery Sales

Estimated Projection



Source: Avicenne

Batteries face several challenges

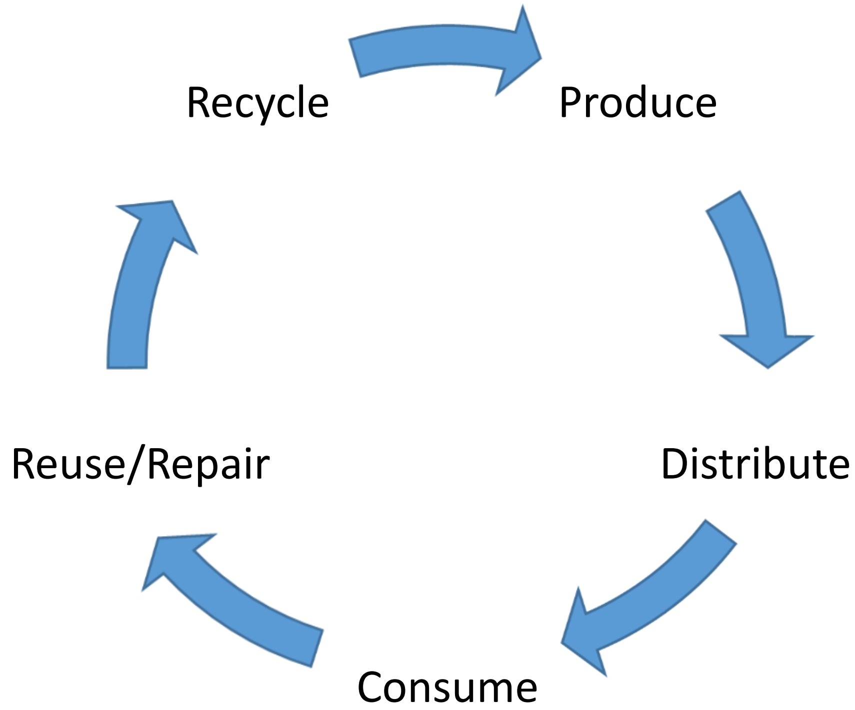


Each challenge is important, but life-cycle cost has been receiving inconsistent attention by government and industry.

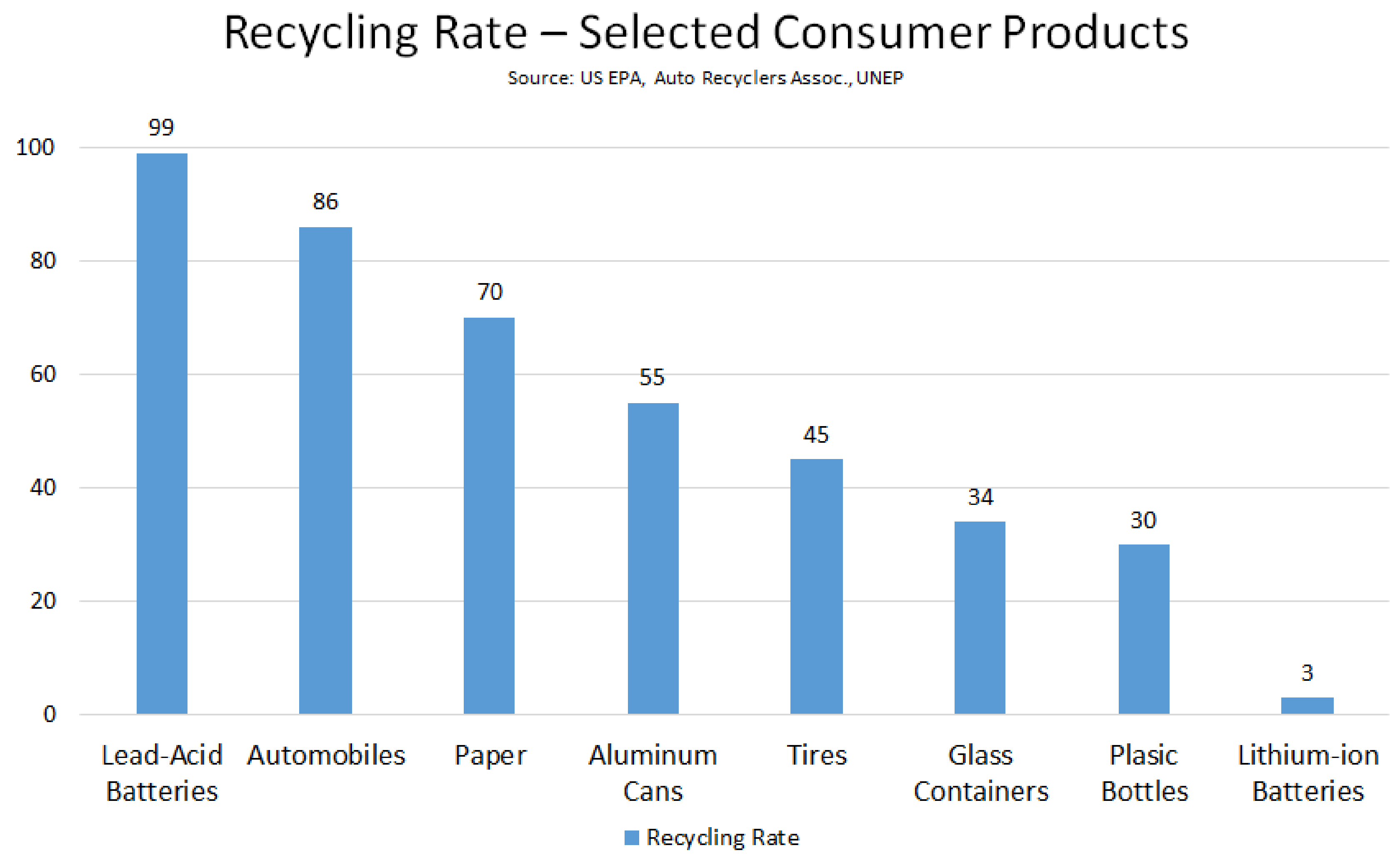
As batteries become more important, their life-cycle needs to move from *linear*…

Resource Extraction → Produce → Distribute → Consume → Dispose

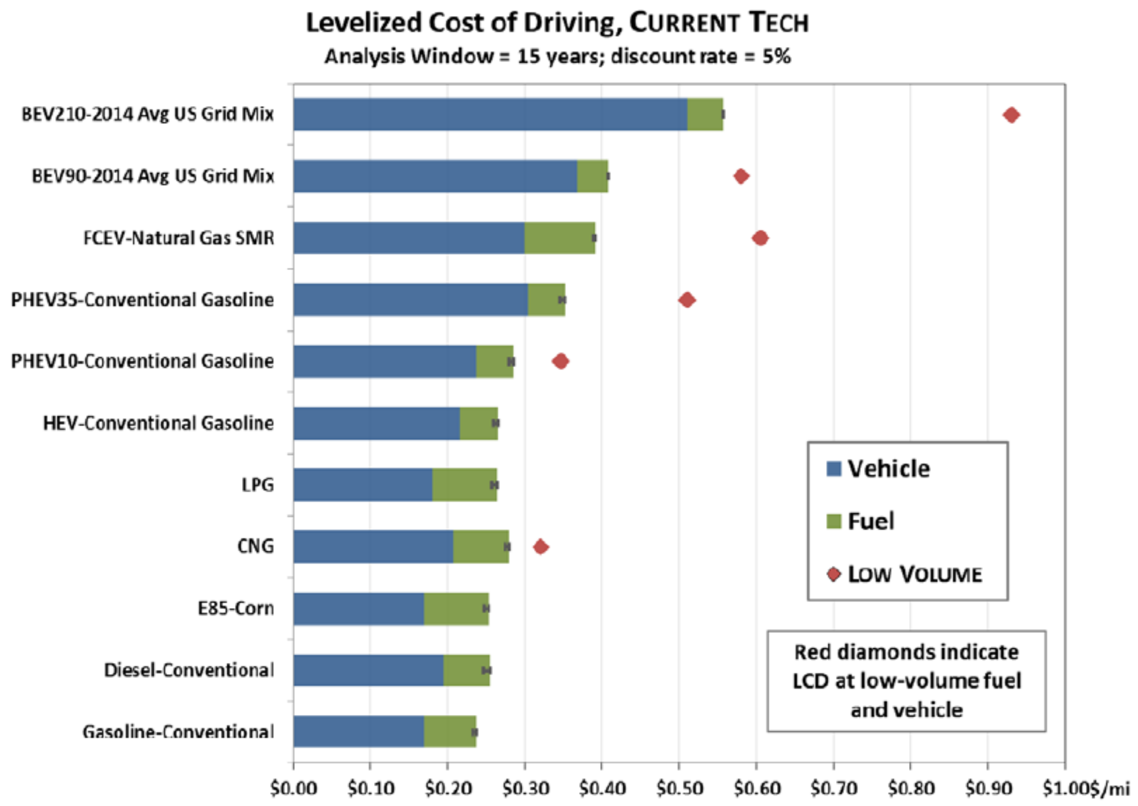
…to *circular* materials management.

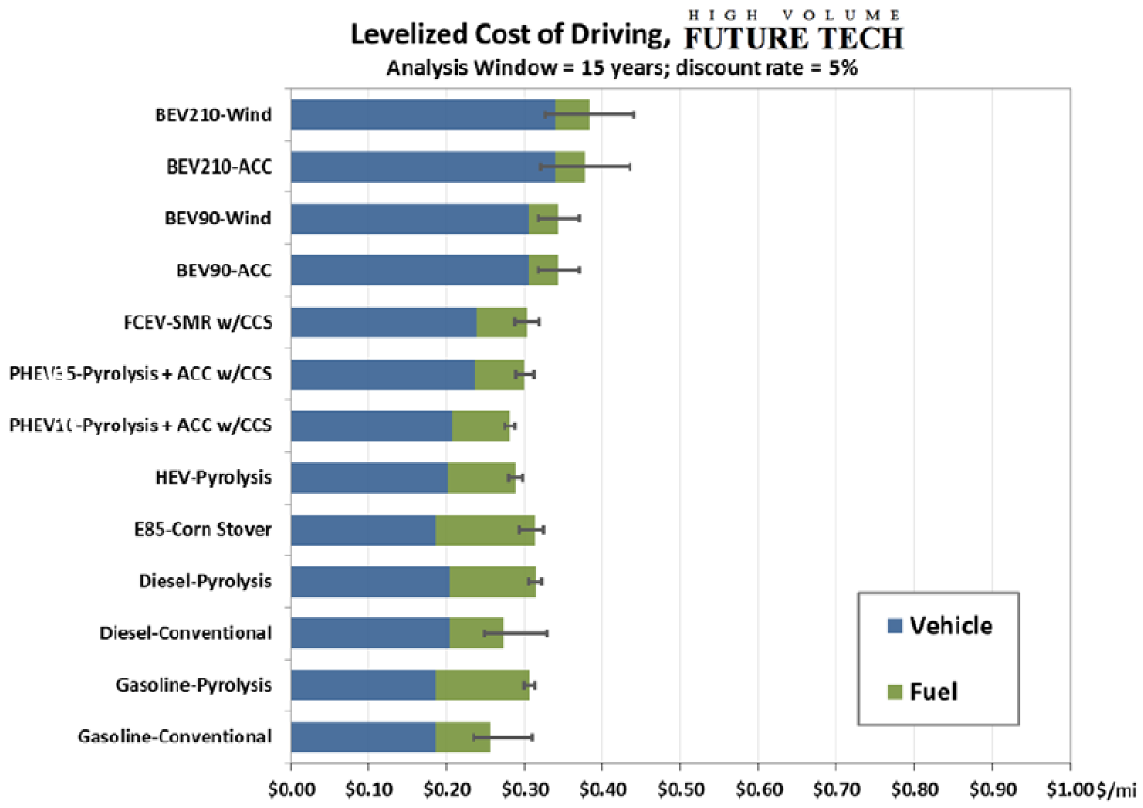


The consumer product challenge…



An electrified vehicle sounds terrific, but look at the levelized cost between BEVs and ICEs.



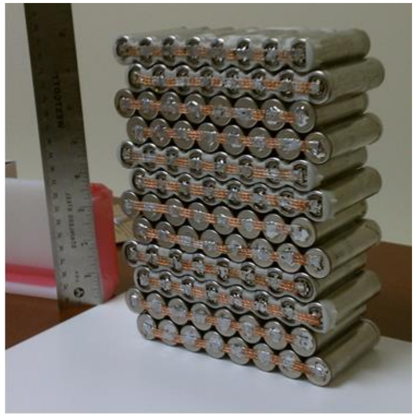


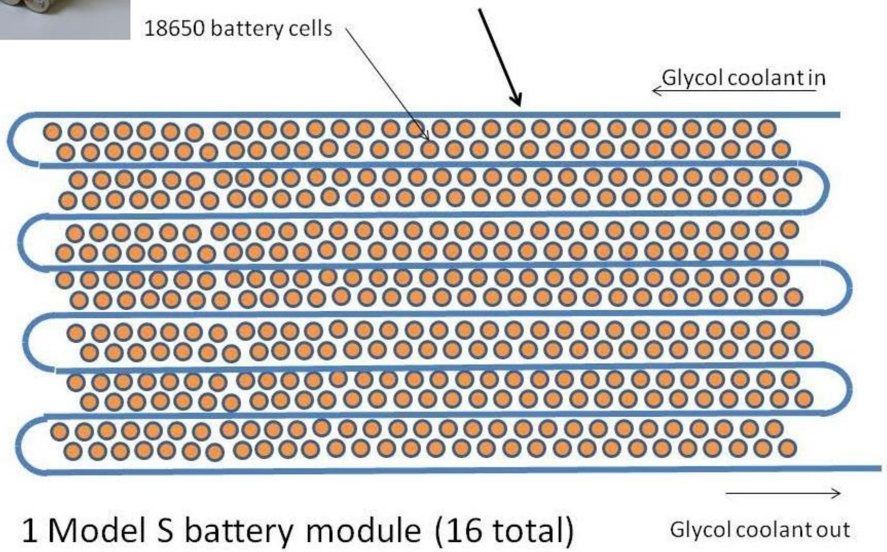
Argonne National Laboratory – Cradle to Grave Life-Cycle Analysis, ANL/ESD-16/7, 2016

The 18650 lithium-ion cell – indispensable in a wide range of products.

But, a sustainability problem is emerging...

There are 7,000 lithium-ion 18650 battery cells in a Tesla battery system.





1 Model S battery module (16 total)

A lot of engineering went into this,
but is it designed for cost-effective recycling?

Why should we care about recycling?

American Disposal Services

Safe operation is one part of the story.
Safe disposal is another part.

Explosions of discarded lithium-ion batteries are occurring in garbage trucks, landfills, warehouses and recycling plants.

Why is the lithium recycling rate so low?

- Lack of design for recycling.
- Inadequate delivery infrastructure.
- Insufficient incentives for consumers to place discarded batteries into recycling stream.

Courier-Gazette, Rockland, ME

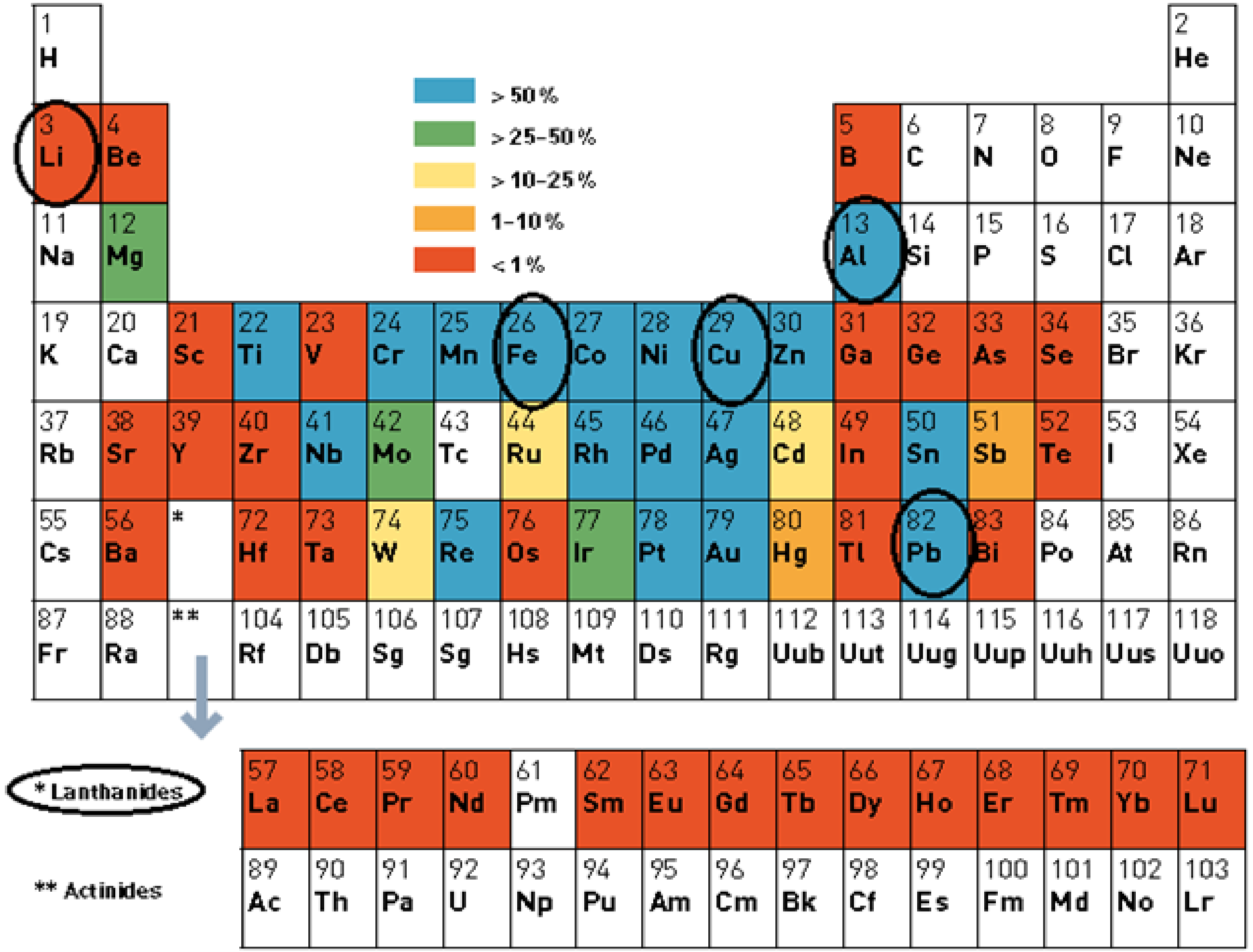
Why is recycling important in the circular economy?

- ✓Reduces life-cycle costs by saving energy and cutting pollution
- ✓Reduces the need for mining
- ✓Protects natural resources
- ✓Reduces the need for landfills
- ✓Facilitates efficient use of critical materials
- ✓Reduces legal risk for producers/customers
- ✓Reduces material imports
- ✓Generates income

Recyclers take feedstock from “mines” like this…

…and produce materials for new batteries.

The recycling challenge of the electronic age. Data from United Nations Environmental Program:

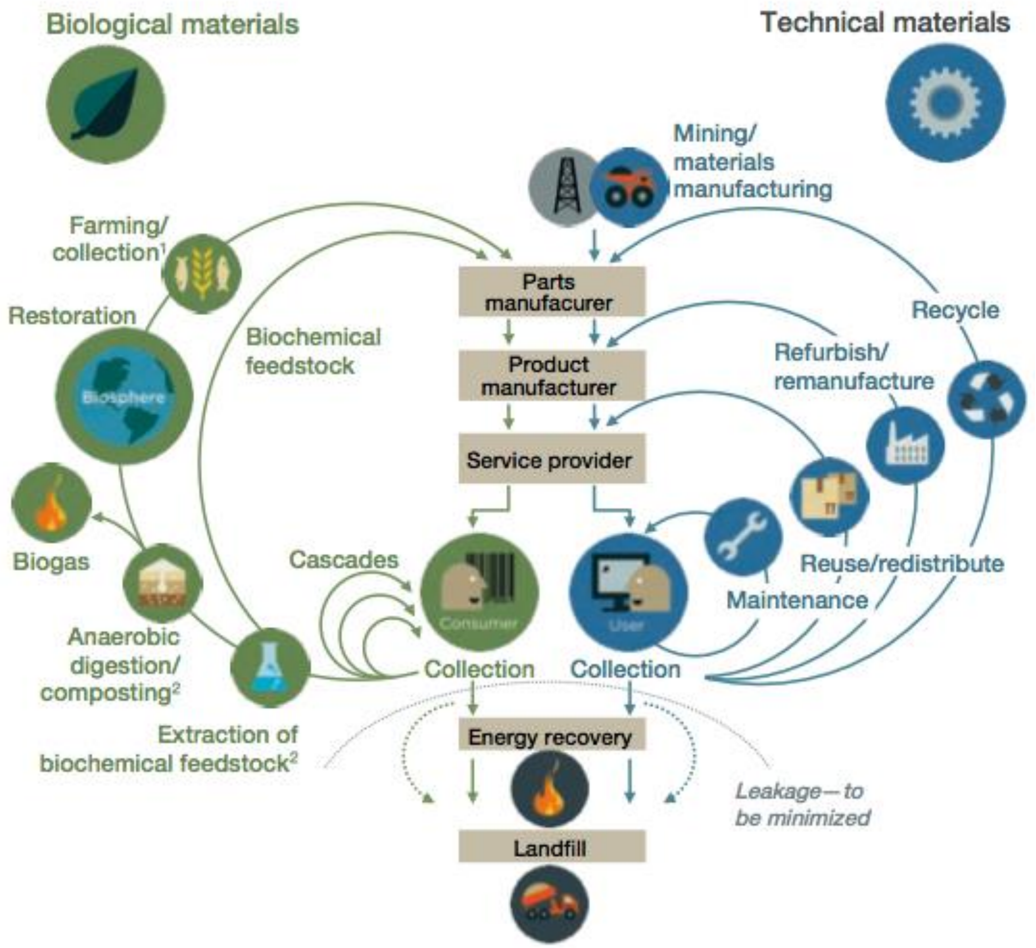


Base metals such as Iron (Fe), Copper (Cu), Lead (Pb) and Aluminum (Al) are recycled at rates greater than 50%.

Specialty metals like Lithium (Li) and Rare Earths like Lanthanides are recycled at less than 1%.

Source: UNEP - 2011

We need to understand what recycling is and what recycling is not.



[1] Hunting and fishing
[2] Can take both postharvest and postconsumer waste as an input
Source: Ellen MacArthur Foundation circular economy team drawing from Braungart & McDonough and Cradle to Cradle (C2C)

Recycling is the processing of used materials into reusable materials to reduce consumption of "virgin" materials.

To be considered recycled, materials must be competitive (price and function) with primary "virgin" materials.

Recycling is not downcycling, refurbishment or remanufacturing.

While downcycling, refurbishment and remanufacturing serve legitimate functions in a circular economy, they are not a substitute for recycling.

The economics of recycling in a circular economy

- The closed loop:
  - Products are produced, sold, used and collected at their end-of-life.
  - Recyclers separate and reprocess materials (metal, acids, plastics, etc.).
  - Separated materials are recycled and sold to product producers.
  - Prices charged for recycled materials produced in this closed loop are competitive with primary (or "virgin") materials.
  - The cost of recycling is embedded in the retail product price.
- How recyclers make profits:
  - Recyclers make a profit when the price of finished product sold to producers is higher than the price recyclers pay for used products at their end-of-life (scrap).
  - Sufficient production volume generates revenue to support the enterprise.

Calculate levelized cost of energy + end-of-life

$$\mathrm{LCOE} = \frac{\text{sum of costs over lifetime}}{\text{sum of electrical energy produced over lifetime}} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t + \mathbf{e}}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

- I_t : investment expenditures in the year t
- M_t : operations and maintenance expenditures in the year t
- F_t : fuel expenditures in the year t
- E_t : electrical energy generated in the year t
- r : discount rate
- n : expected lifetime of system or power station
- e : end-of-life