End of Life Policies for Nano-enabled Electronics: Insights from Product Stewardship Programs

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Center for High-rate Nanomanufacturing

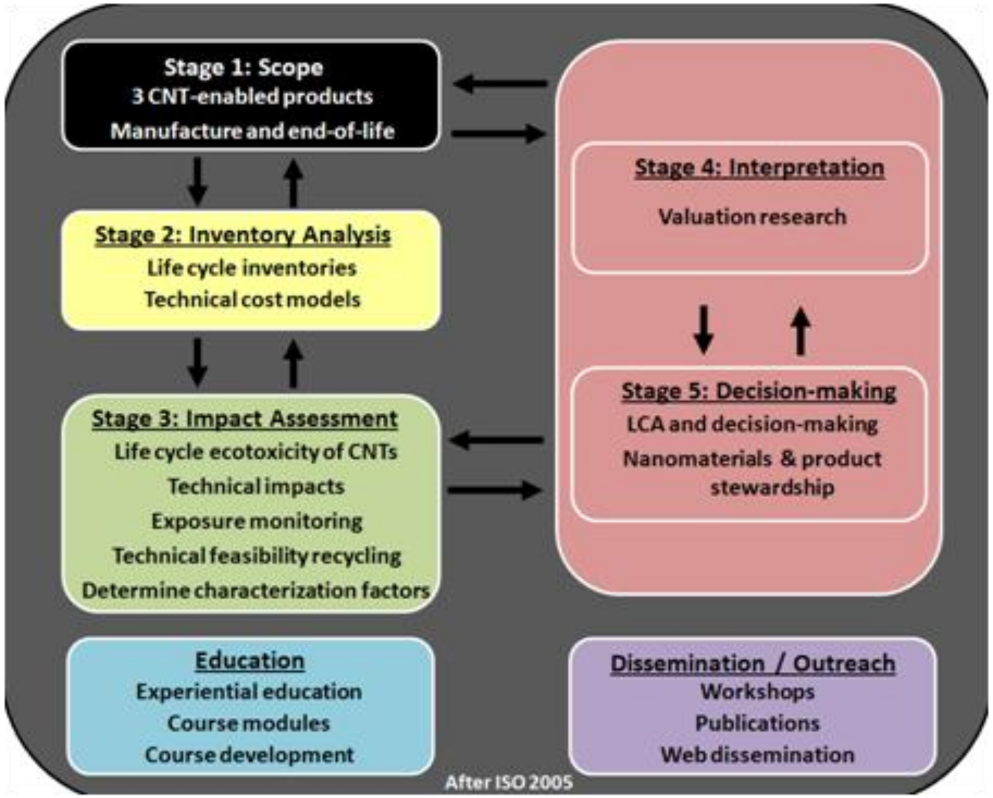
Northeastern University

Overview

- Disposal concerns for end-of-life next-generation electronic consumer nano-enabled products (NEPs)…
- Even if no novel EHS properties, such NEPs exacerbate current policy dilemmas, including how to promote recycling over disposal / incineration

How effective are product stewardship programs in the U.S. for portable electronics? What does this mean for infusion of CNT battery technologies?

NSF SNM: Designing and Integrating LCA Methods for Nanomanufacturing Scale-up



Isaacs, Bosso, Busnaina, Cullinane, Eckelman, Sandler : **Northeastern**
Mead, Bello: **U Mass Lowell**
Zimmerman: **Yale**
Nash: **Harvard**

- NSF scalable nanomfg award **#1120329**
- Lead Institution: NEU
- Collaborators at Yale, Harvard, UMass Lowell
- Project focuses on applications using carbon nanotubes (CNTs)
  - Composites (EMI shielding)
  - Sensors
  - Batteries

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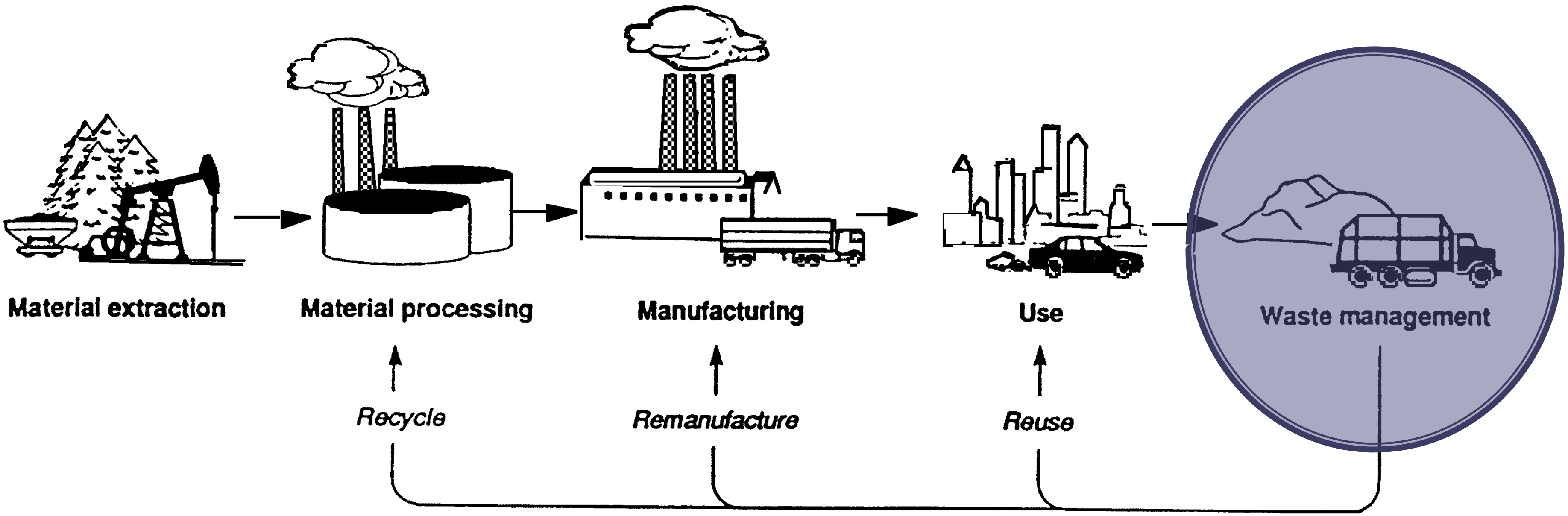
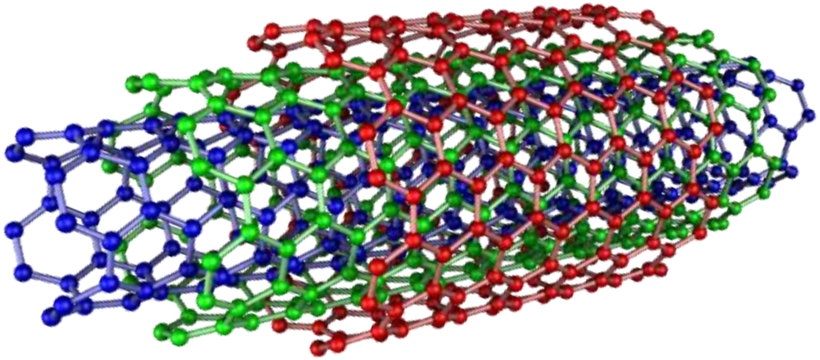
Our Use of Life Cycle Assessment

Conceptual framework and methodology for evaluating environmental effects of a product or activity by analyzing the whole life cycle of a product from raw material acquisition through production, use and disposal



Focus on Carbon Nanotube Enabled Batteries

Outstanding Properties



Expanding Global Market

Potential Environment Issues

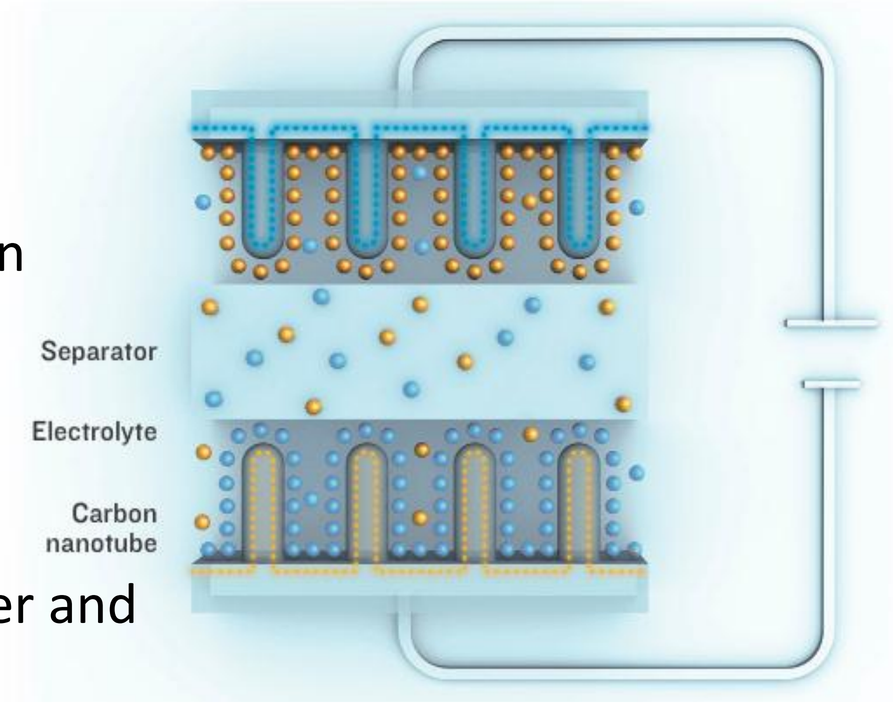
MWCNT Lithium-ion Battery

- Cathode: Lithium manganese oxide + MWCNT (Multi-Walled Carbon Nanotubes)

- Anode: similar processes /materials

- Advantages of MWCNT in lithium-ion batteries in cathodes
  - increases the conductivity
  - improves the capacity

  This would increase available power and reduce recharge times…



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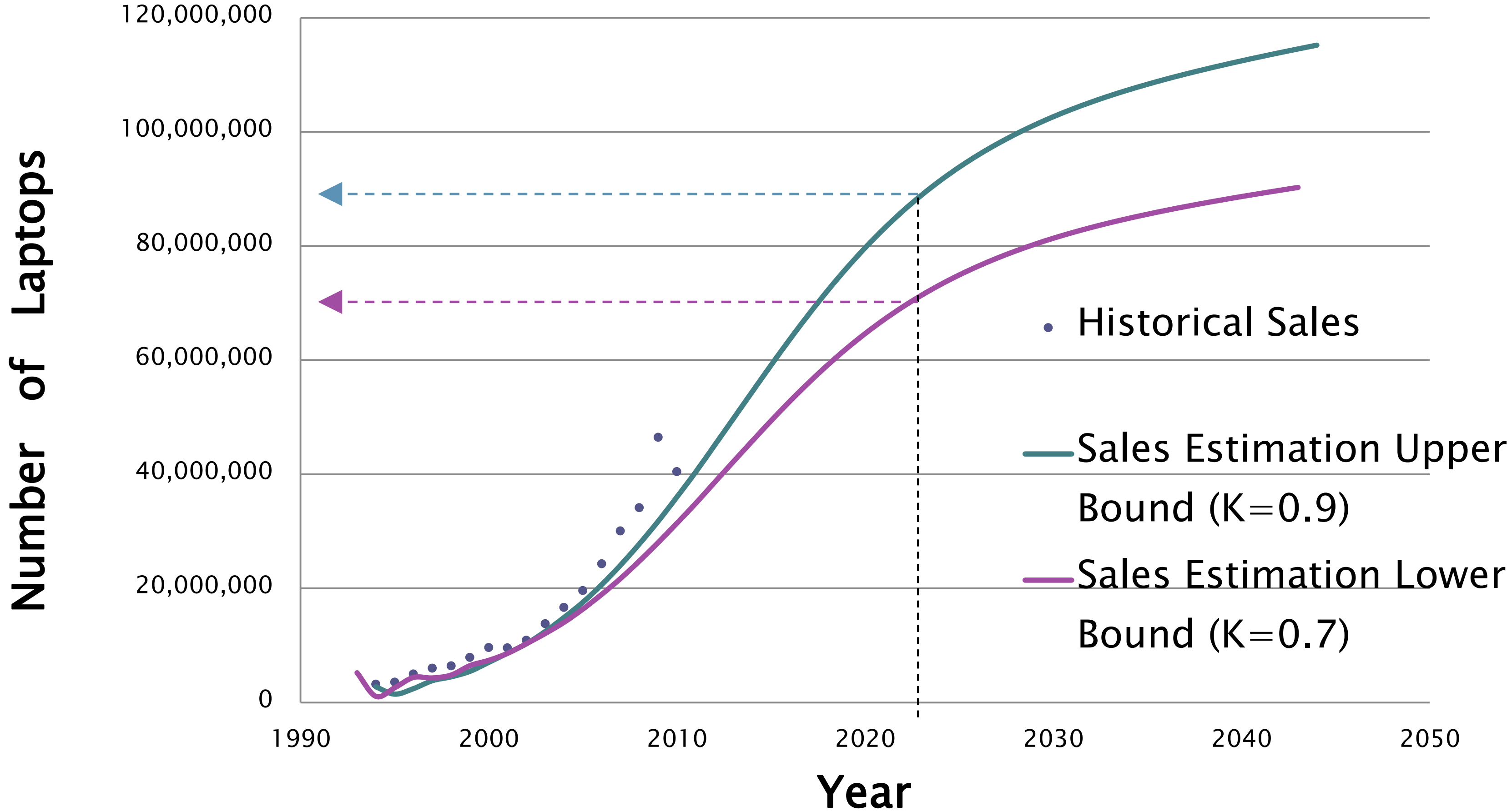
Enhanced Performance with CNTs

- CNT structure enhances the battery capacity by 10%
- Energy density improves similarly
- Significant improvement in the cell power density by 900%

Cell Parameters	Li-ion Laptop Cell (HP 6520)	MWCNT LiMnO Cell	% Cell Improved
Anode active material	Graphite	Graphite	
Anode substrate	Copper	Copper	
Cathode material	LiMnO	MWCNT LiMnO	
Cathode substrate	Aluminum	Aluminum	
Separator	Polyethylene	Polyethylene	
Electrolyte solvent	N-Methyl Pyrrolidone & lithium salt	N-Methyl Pyrrolidone & lithium salt	
Nominal capacity	4400mAh	4900mAh	**10%**
Dimensions	250*90*50mm	250*90*50mm	
Battery Voltage	10.8V	10.8V	
Specific energy	95 Wh/kg	110 Wh/kg	**10%**
Power density	130 W/kg	1300 W/kg	**900%**

Under development at CHN

Forecast for U.S. Laptop Annual Sales: 70 - 90 Million Units (2023)



Regardless of battery type

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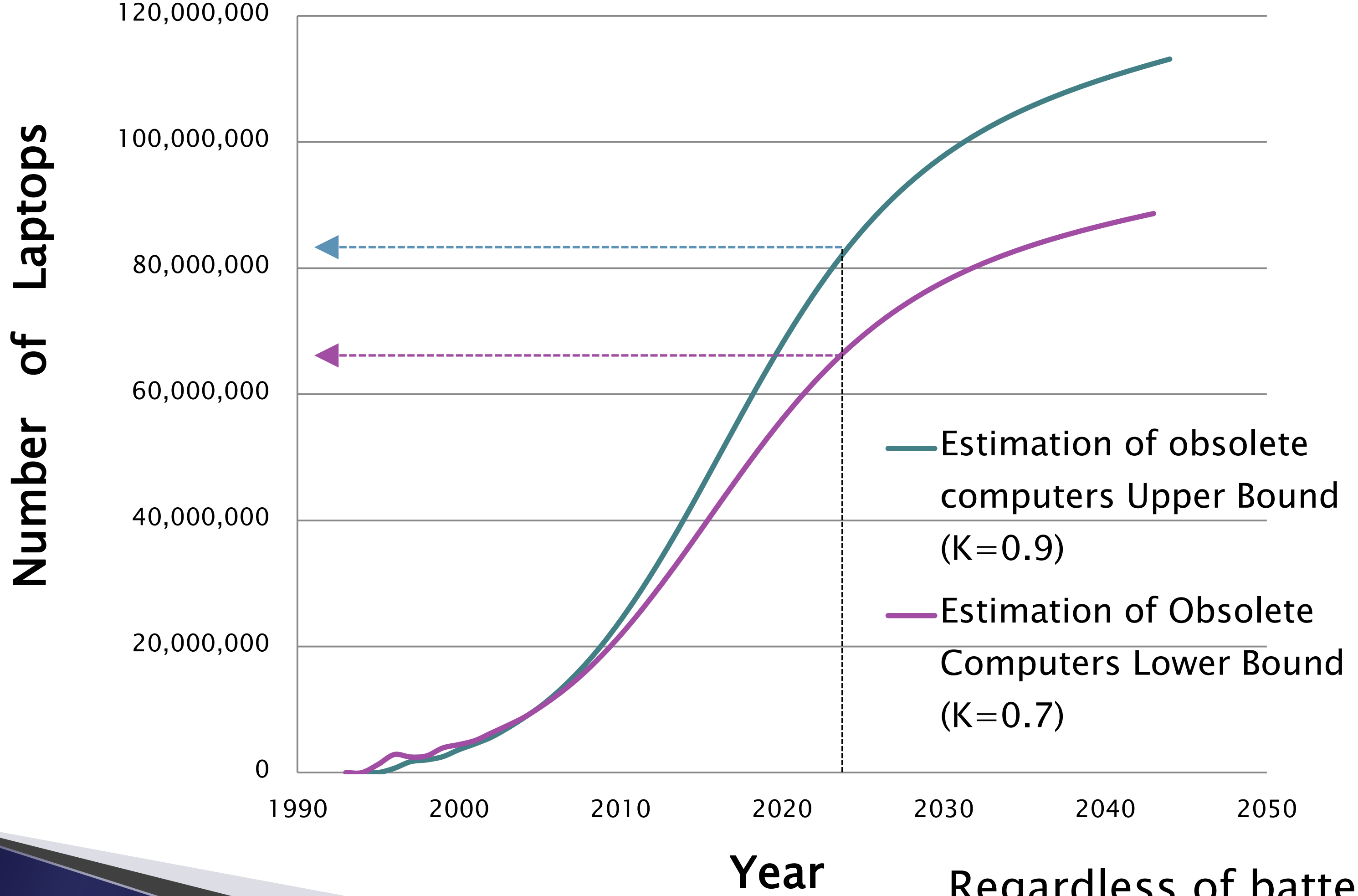
Challenge:
By 2023, 65-80 million portable computers obsolete

Combination of logistic model with material flow analysis (MFA) enables estimation of obsolete/discarded devices



Regardless of battery type

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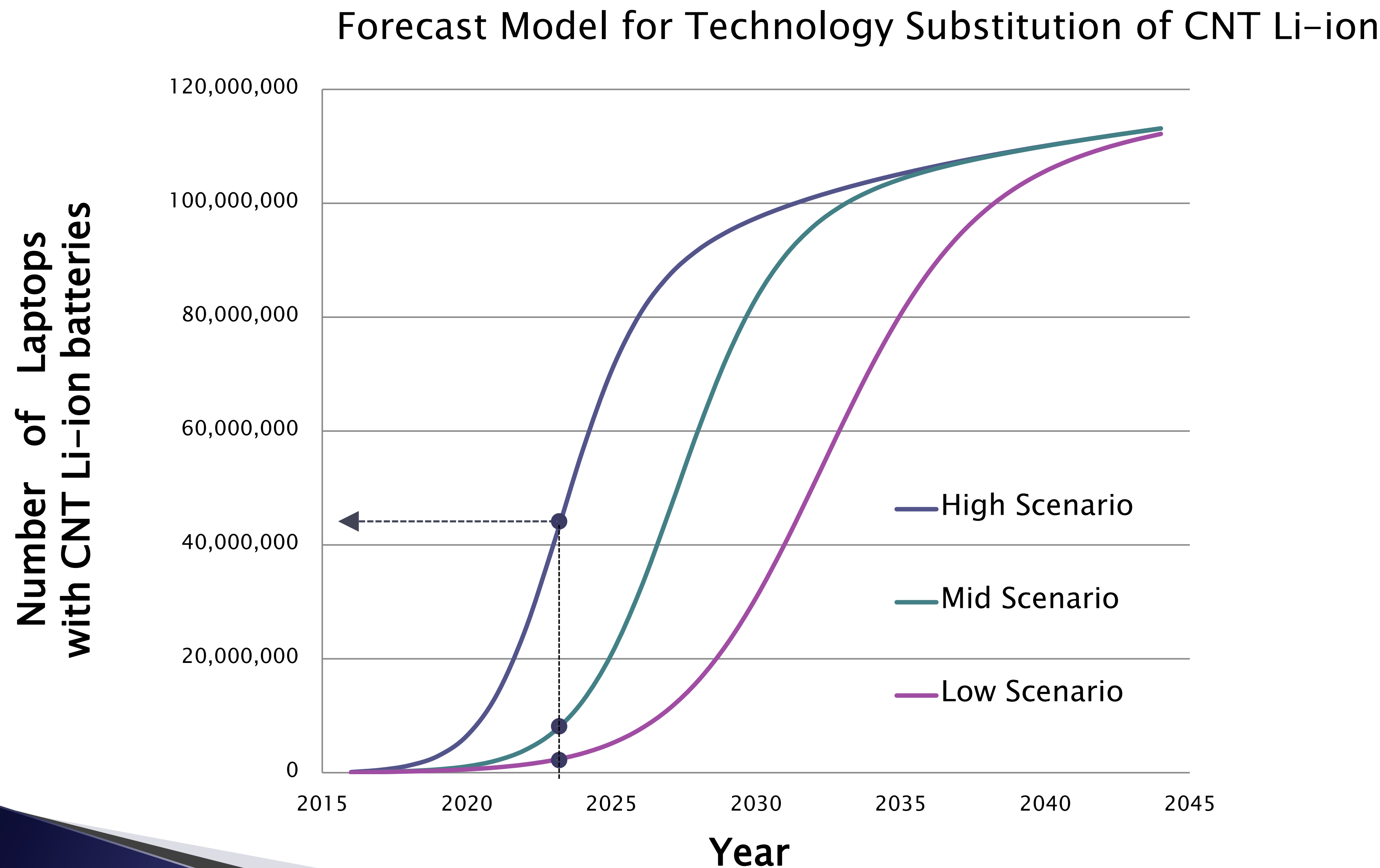
Discarded Laptops: Increased CNT Li-ion Batteries



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Amount of CNTs in Laptop Battery??

- Estimate 3 - 5 cells for CNT Li-ion laptop batteries
- Known mass of cathode active material: 200 g to 300 g
- Known MWCNT mass: ~ 1% of cathode active material

- 250g * 0.01 = 2.5 g MWCNT /cell
- 2.5 * 3 (number of cells) = 7.5 g MWCNT / battery

- 7.5 g MWCNT * 40,000,000 obsoletes = 300,000 kg MWCNTs ?

In 2023 Perhaps?

Product Stewardship Issues

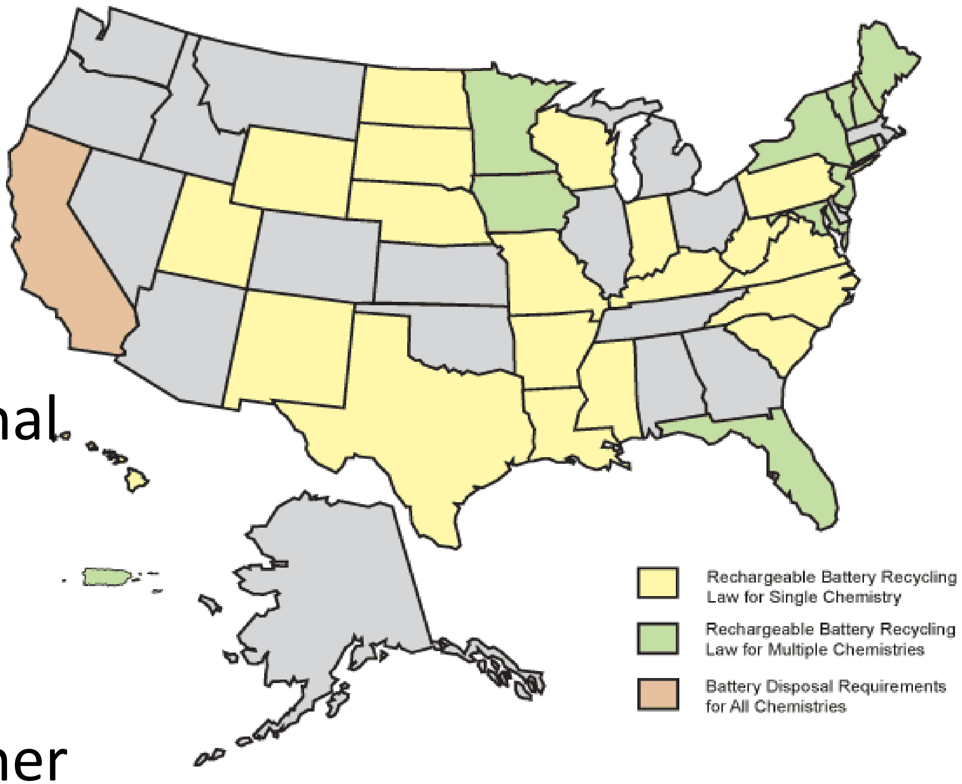
"Product stewardship calls on those in the product life cycle—manufacturers, retailers, users, and disposers—to share responsibility for reducing the environmental impacts of products."

US Environmental Protection Agency

1. Can nano-enabled products be handled appropriately using the stewardship collection infrastructure developed for other products, or must manufacturers provide some form of special handling for products containing nanomaterials?
2. Does mixing of recyclate from nano-enabled products impact markets for recycled materials?
3. Does the collection of nano-enabled products pose particular challenges to household waste facilities run by municipalities in terms of costs, worker health and safety, or public perception?

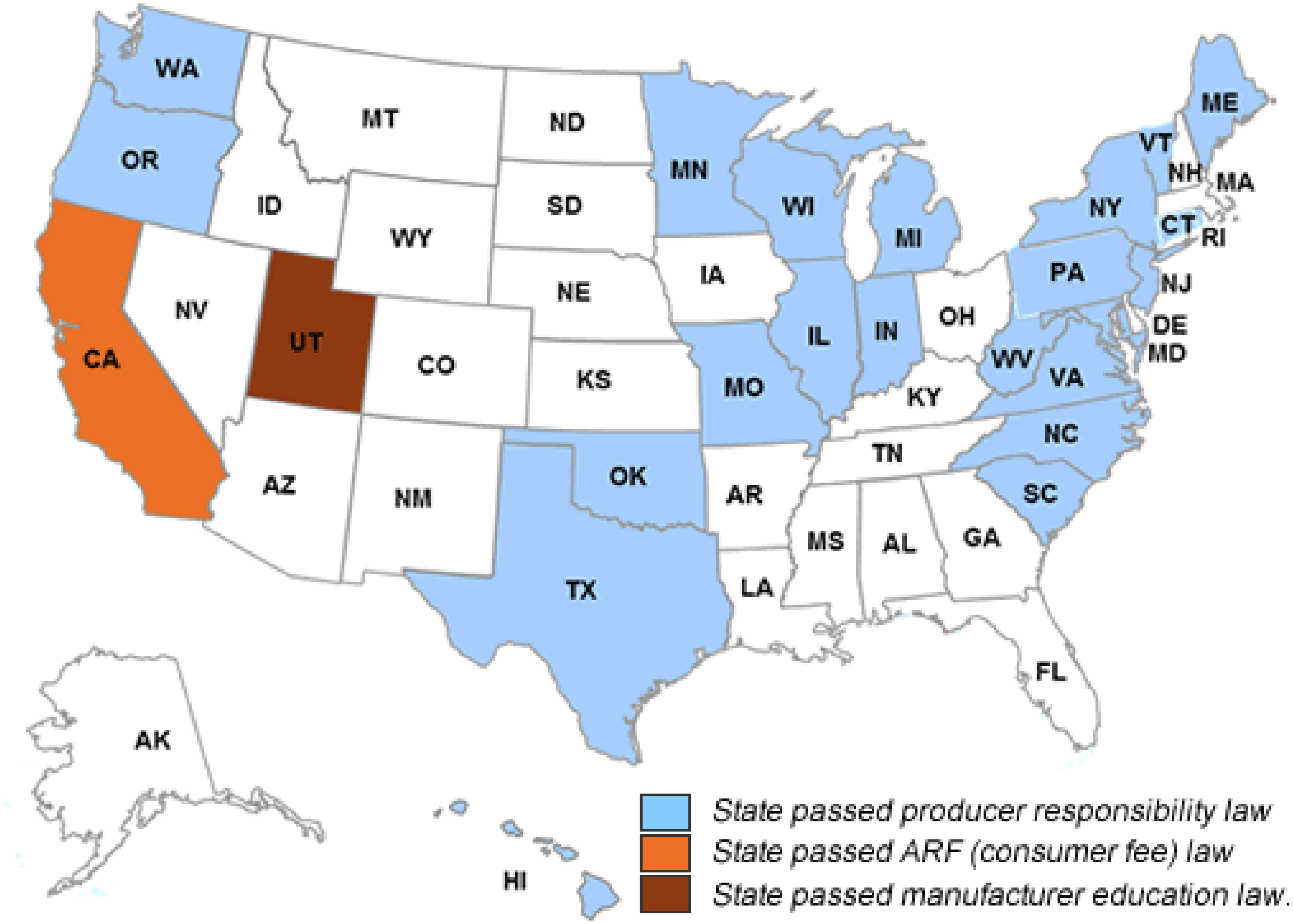
No Uniform Approach to Recycling Batteries

- 8 states enacted EPR laws (1990s)
- Response: creation of voluntary program (Rechargeable Battery Recycling Corporation)
- Effectively dissuaded additional states from enacting laws
- U.S. Collection rate for rechargeable batteries only 10% -12% (July 2010)
- Response: New laws from other states with emphasis on retailer responsibilities for collection



Source: Recycling Laws Map http://www.call2recycle.org/recycling-law-map/

Electronics Recycling Programs also Vary

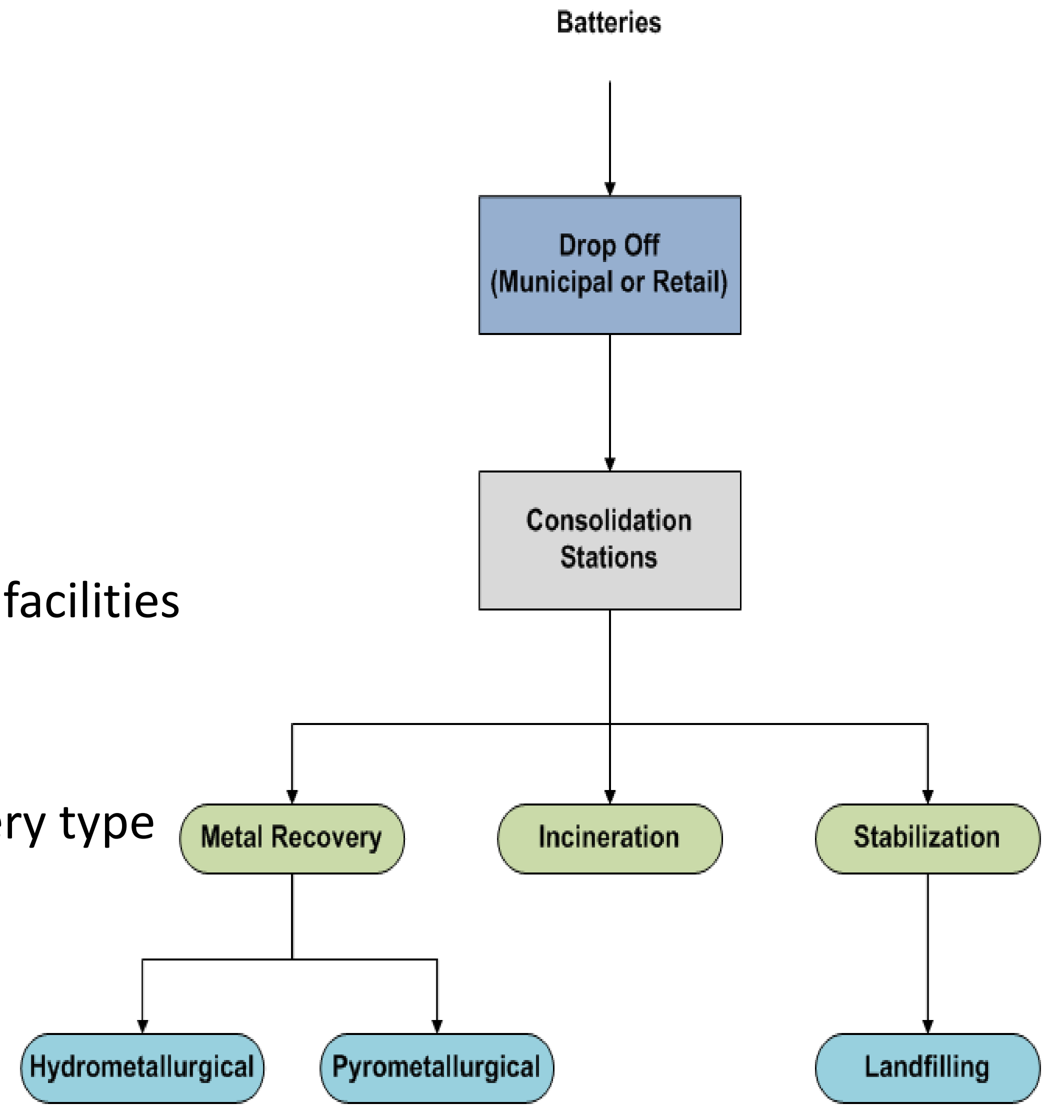


Source: Electronics TakeBack Coalition:
http://www.electronicstakeback.com/promote-good-laws/state-legislation/

End-of-Life Alternatives for Batteries

Alternatives for final disposition:

- Landfill
  - Most household batteries
  - 87% of all waste batteries
- Stabilization
  - Prior to landfill
  - Not used in general
- Incineration
  - Municipal waste combustion facilities
- Recycling
  - High temperature processes
  - Percentage depends on battery type



How Well Do E-waste Programs Work?

E-Waste by the UNIT in 2010 – Was it Trashed or Recycled
(Same report as above, but reported in UNITs, not by TONS)

Products	Total disposed**	Trashed	Recycled	Recycling Rate
	Units	Units	Units	%
Computers	51,900,000	31,300,000	20,600,000	40%
Monitors	35,800,000	24,100,000	11,700,000	33%
Hard copy devices	33,600,000	22,400,000	11,200,000	33%
Keyboards and Mice	82,200,000	74,400,000	7,830,000	10%
Televisions	28,500,000	23,600,000	4,940,000	17%
Mobile devices	152,000,000	135,000,000	17,400,000	11%
TV peripherals*	Not included	Not included	Not included	Not included
Total (in units_	384,000,000	310,000,000	73,700,000	19%

40% (300,000) kg MWCNTs
0.18 MT ?
250 MT MSW (2011)

What's included here?
Computer products include CPUs, desktops and portables.
Hard copy devices are printers, digital copiers, scanners, multi-functions and faxes.
Mobile devices are cell phones, personal digital assistants (PDAs), smartphones, and pagers
*Study did not include a large category of e-waste: TV peripherals, such as VCRs, DVD players, DVRs, cable/satellite receivers, converter boxes, game consoles.

**"Disposed" means going into trash or recycling. These totals don't include products that are no longer used, but which are still stored in homes and offices.

Source: EPA [1]

Source: Electronics TakeBack Coalition, based on EPA data:http://www.electronicstakeback.com/wp-content/uploads/Facts_and_Figures_on_EWaste_and_Recycling.pdf;

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State E-Waste Programs – Modest Impacts

- While *per capita* collections increased gradually over time in U.S., overall national collection rates remain low – ~ 15-20% for electronics (Remainder disposed in MSW landfills)
- U.S. e-waste recycle rates ~ 1.4 pounds per capita nationwide in 2010 (natl avg same as states as with weak or no electronics recycling laws)
- EU e-waste recycle rates > 8.8 pounds per capita
- Better collection rates in states with electronics program that include relatively stringent accountability mechanisms:
  - Minnesota, Oregon, Washington, and Wisconsin
  - Such laws cover a small portion of the US consumer electronics market

See J. Nash and C. Bosso, 2013. "Extended Producer Responsibility in the U.S.: Full Speed Ahead?" *Journal of Industrial Ecology*, v. 17, n. 2 (April): 175-185; DOI: 10.1111/j.1530-9290.2012.00572.x.

Need for a National Framework?

- Stronger state EPR laws tend to be enacted *after* manufacturer-initiated voluntary programs yield disappointing results
  - Absence of sufficient incentives to induce consumer participation
  - Absence of "teeth" to ensure retailer and producer compliance
- State policies are moving away from voluntary approaches toward more demanding and specific mandates.
- More vigorous state efforts only cover a fraction of the nation and products
- NEPs may pose additional challenges to an already inadequate patchwork of state EPR programs.
- If history guides, federal government action may be key to creating coherent and effective national electronics EPR framework in light of CNTs uncertainties

- **Such action is not likely in near future, raising concerns about capacity of e-waste system to handle next generation batteries.**

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WHERE DISCOVERIES BEGIN

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