Evaluation of Battery End-of-Life Strategies

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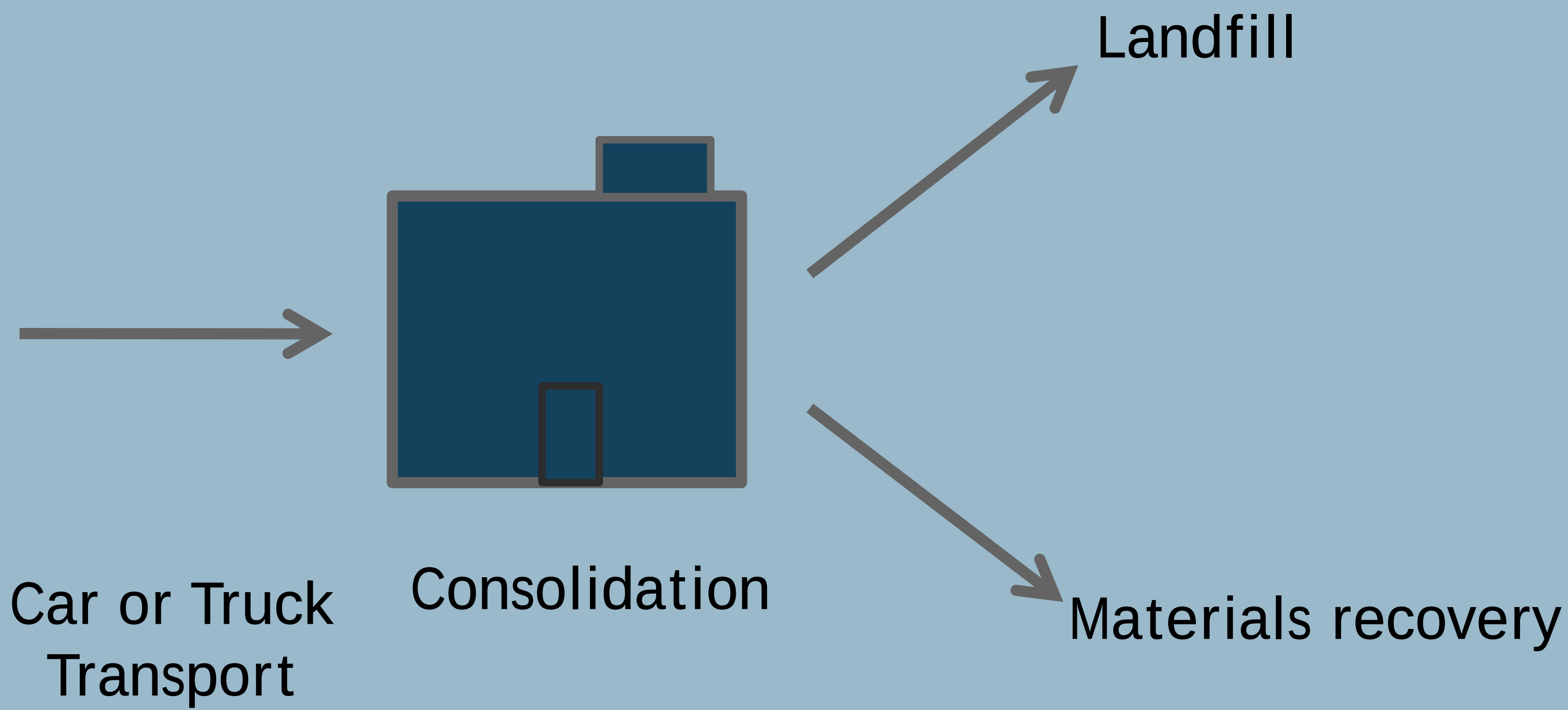
What are the net environmental impacts of different end-of-life strategies for alkaline batteries in the United States?



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Alkaline battery landscape

- Total US Sales in 2007: 5.4 billion batteries (w/rechargeable)
  - 85% of total battery sales are alkaline
  - < 1% of MSW
- Concern over landfill of materials in batteries
- End-of-life battery directives in Europe and Canada
- California landfill ban - universal waste rule prohibits CA throwing batteries in the trash

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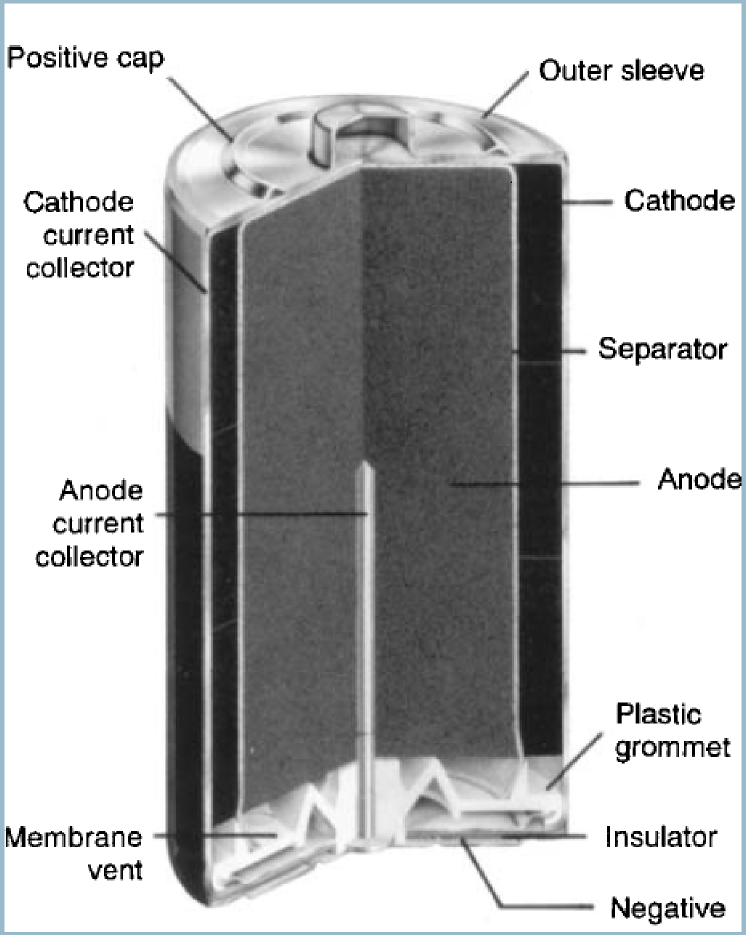
Bill of materials for an alkaline battery

- **Dominant materials:**
  - **Manganese - ~25 wt%**
  - **Steel - ~20 wt%**
  - **Zinc - ~20 wt%**
  - **Other (KOH, graphite)**

Material	Mass (g) 1 kg batteries
Mn	250
Zn	190
Steel	190
K	26
Graphite	36
Copper	20
Nickel	4
PVC	15
Nylon	15
Paper	15
Moisture content ~6 wt%	



Life cycle impact assessment

Raw Materials

- Copper
- Aluminum
- Iron
- Lead

Energy

- Oil
- Coal
- Natural gas

Releases to Land

- Heavy metals
- Pesticides
- Zinc

Air Emissions

- VOCs
- CO_2
- SO_2
- NO_x

Water Effluents

- Pesticides
- Arsenic
- Cadmium

Cumulative Energy Demand

Energy (MJ)

Global Warming Potential

Gas Emissions ($kg\ CO_2$ eq.)

Eco-indicator

Damage to:

- Human Health (DALY)
- Ecosystems (PDF*m^2yr)
- Resources (MJ surplus)

Relative impacts of some common products

Product or Process	CED (MJ)	GWP (kg CO_2 eq)	Human Health (DALY)	Ecosystem Quality (PDF*m^2yr)
Production of 25 g PET beverage bottle (20 fl oz/590 ml)	2	0.07	6.8×10^{-8}	0.005
1 weighted-average battery (33 g)	2	0.14	4×10^{-7}	0.07
Production of 14 g aluminum beverage can (12 fl oz/350 ml)	3	0.2	2.6×10^{-7}	0.007
1 kg weighted-average batteries	68	4.3	1.2×10^{-5}	2.1
100 km fuel consumption in a European passenger car	305	18	2×10^{-5}	1
Coffee pot: 5 years	5400	220	2×10^{-4}	30

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Relative impact of end-of-life

	CED (MJ/1 kg WAAB)	GWP (kg CO_2 eq./1 kg WAAB)	Human Health (DALY/1 kg WAAB)	Ecosystem Quality (PDF*m^2yr/1 kg WAAB)
Production	66	3.8	1.1×10^{-5}	1.5
End-of-Life	2.5	0.6	9.7×10^{-7}	0.62
TOTAL	**68**	**4.3**	**1.2×10^{-5}**	**2.1**
% EoL contribution	**4%**	**13%**	**8%**	**29%**

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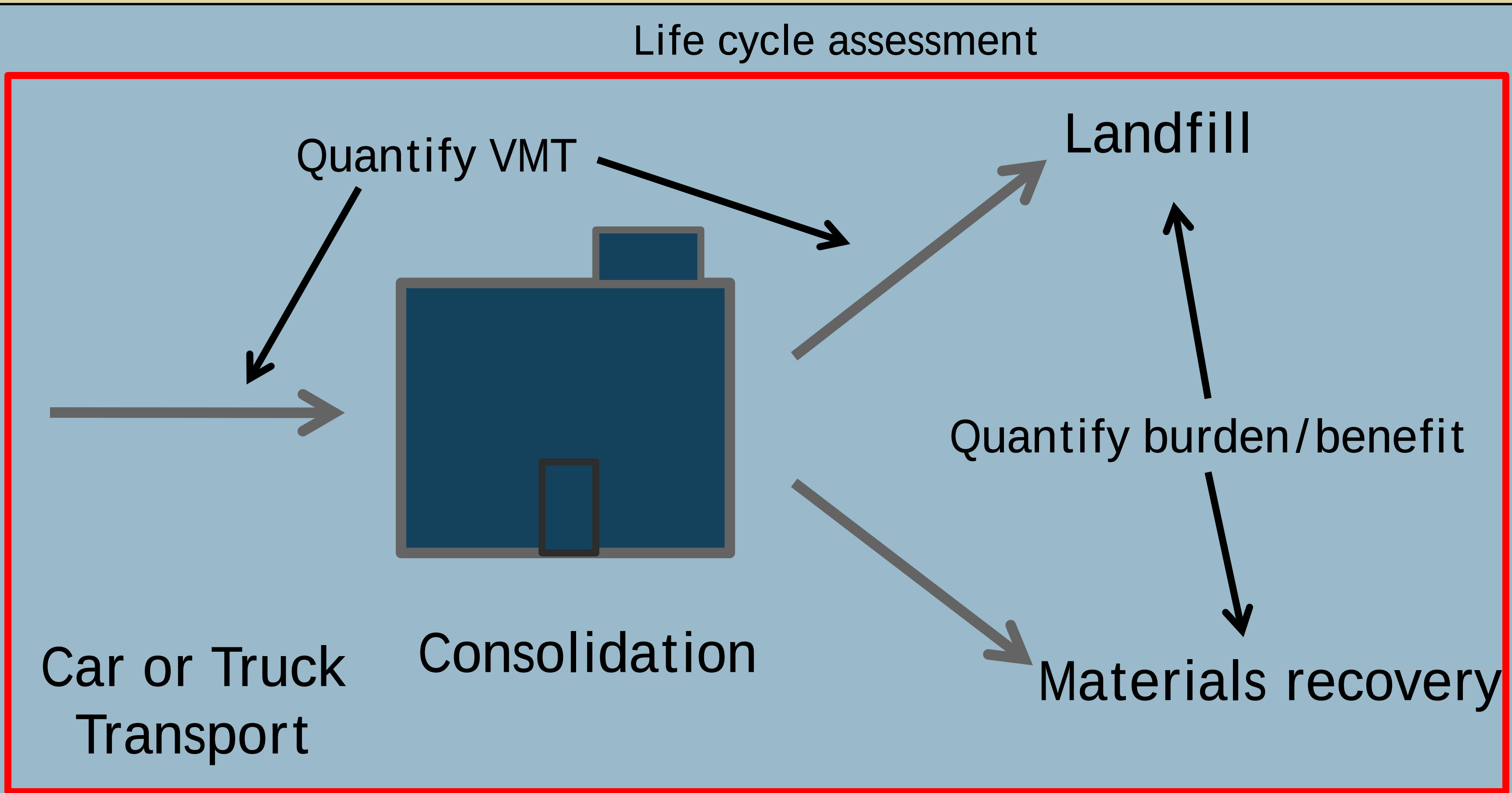
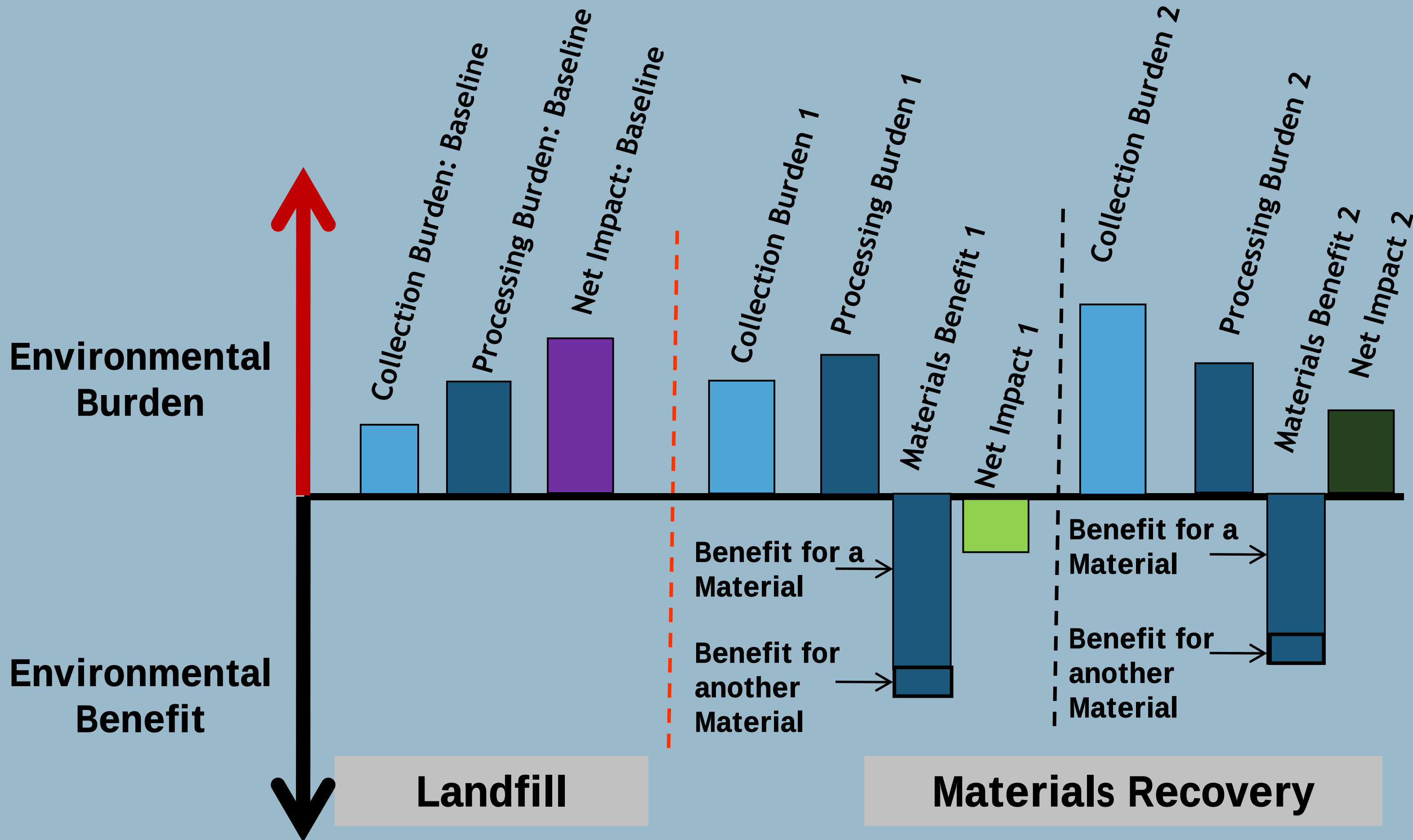
System boundary



Evaluating end-of-life environmental impact:
When does benefit outweigh burden?



Note: schematic only, not real results

End-of-life Scope

- **Focus on California**
- **Disposal**
  - **Collection: MSW**
    - Based on fuel consumption from CA MSW vehicles
    - Avg. battery distance traveled vary with population density
  - **Treatment: landfill**
- **Recycling**
  - **Collection: Retail/municipal pickup and drop-off for recycling**
    - 600 existing Call2Recycle CA sites
  - **Treatment: pyrometallurgical**
    - Processing burden = 3 North American recyclers + Electric Arc Furnace + EU recyclers
- **Excluded items: Sorting facility, collection container**

Challenge: Many recycling technologies

- Pretreatment and postreatment
- Feedstocks added
- Energy used, emissions generated
- Materials recovered

Scenario	Materials recovered
A	Zinc (metal value) Steel and Manganese (cement)
B	Steel & Zinc (metal value) Manganese (part metal value part cement)
C	Steel (metal value) Zinc/Manganese (micronutrient)
D	Steel, Zinc and Manganese (metal value)
E	Steel, Zinc and Manganese (metal value)

Scenarios A–C: Sampling of current technologies

Scenarios D–E: European

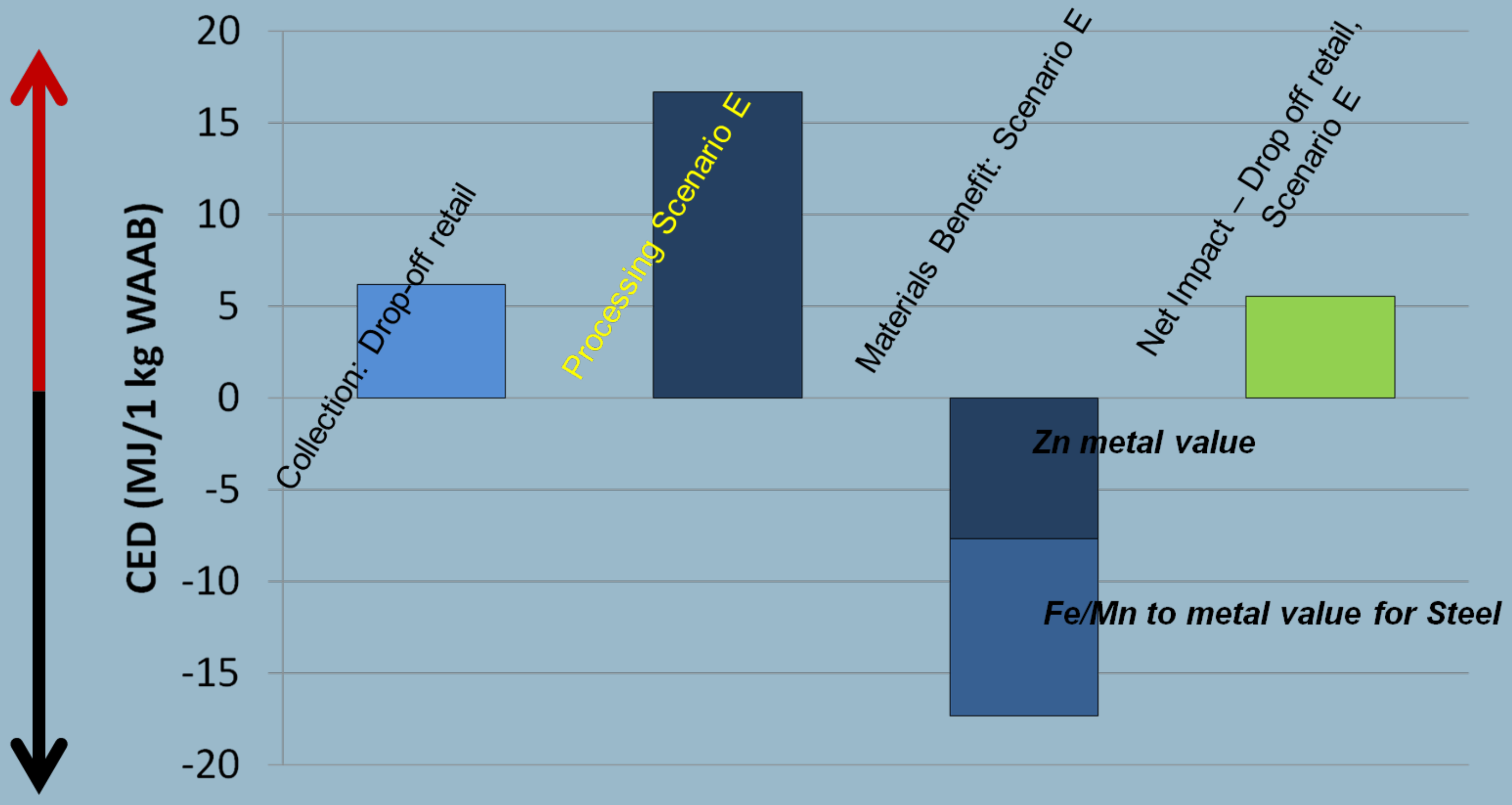
Challenge: Disparate leachate information

- **How much will leach from a landfilled battery?**
- **Tracking: Zn, Mn, Cu, Ni, Fe, and K**
- **Range of results in the literature that vary depending on oxide vs. metallic form, assumptions about landfill conditions, etc.**

Finneveden, *Int. J. of LCA*, 1996
Rydh, *Resource, Conserv. and Recycling*, 2002
SWANA, 2004
O'Brien et al., *MSW management*, 2005
Slack et al., *Science of the Total Environment*, 2005
Karnchanawong, *Waste Management*, 2009

Net results aggregate:

Collection & processing burden and materials benefit



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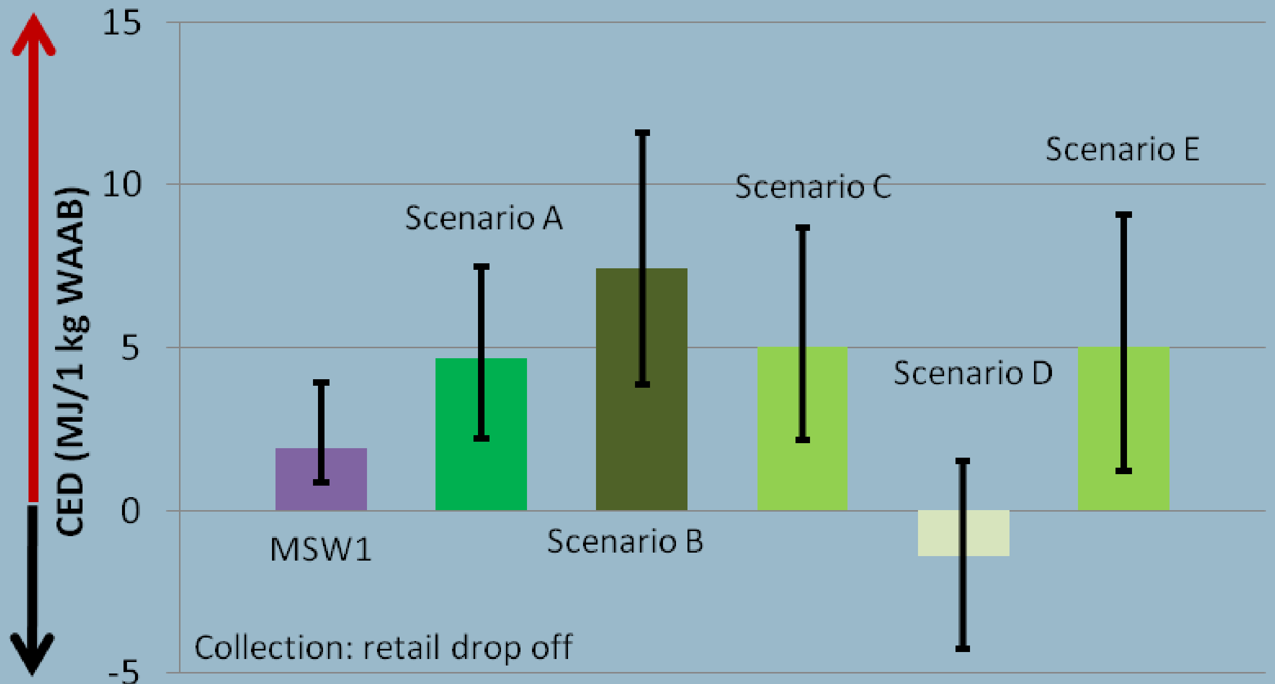
Results of end-of-life treatment:
Cumulative Energy Demand

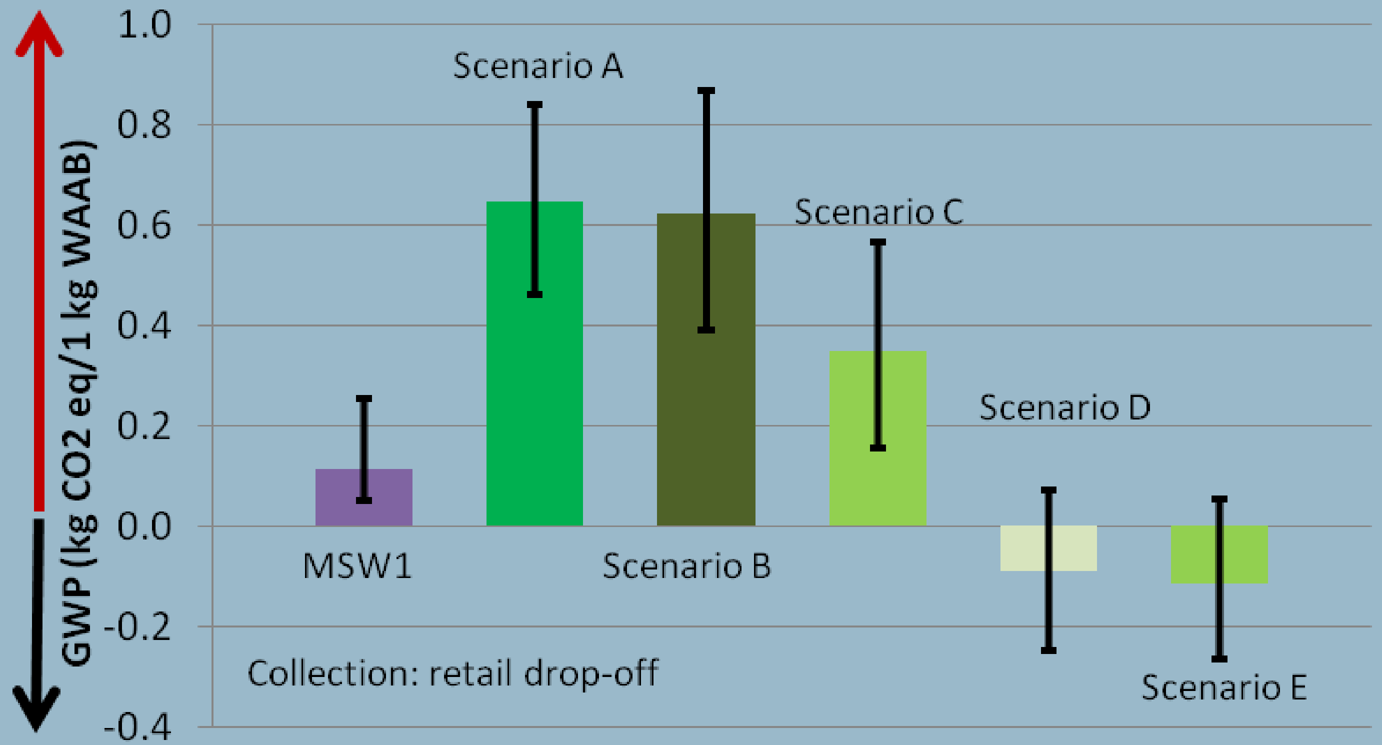
- **Burden from materials disposition of 1 kg of batteries**



Using CED, the majority of current US technologies alkaline battery recycling may not be beneficial

Results:
Global Warming Potential

- **Burden from materials disposition of 1 kg of batteries**



Global warming potential reflects the carbon intensity of fuel used in processing

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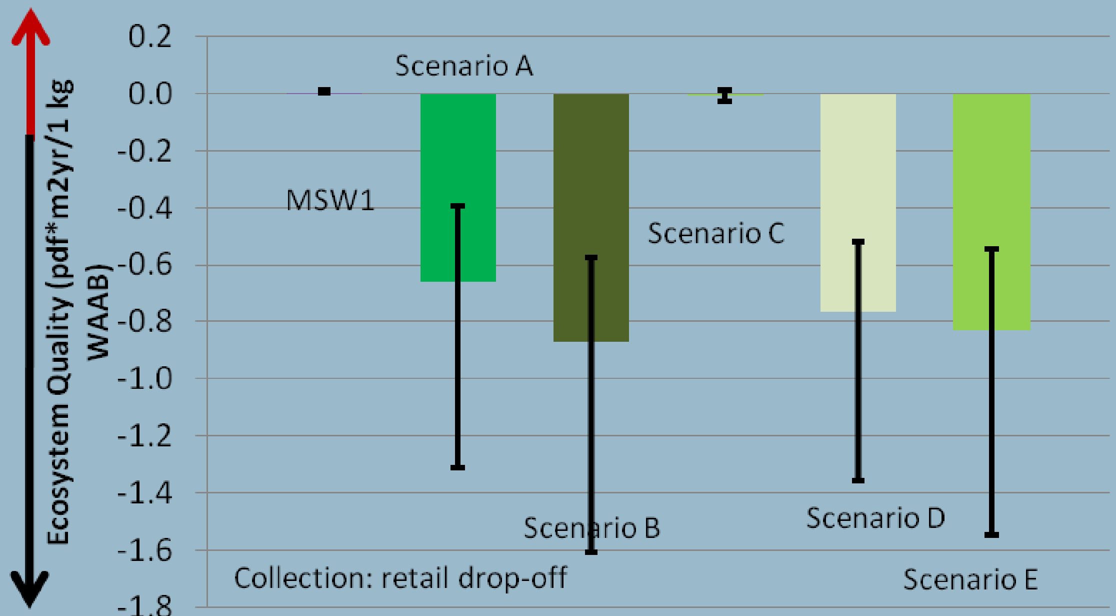
Results:
Ecosystem Quality

- **Burden from materials disposition of 1 kg of batteries**



Recovery of zinc dominates ecosystem quality metrics

Using Ecosystem Quality, the majority of current US technologies for alkaline battery recycling may be beneficial

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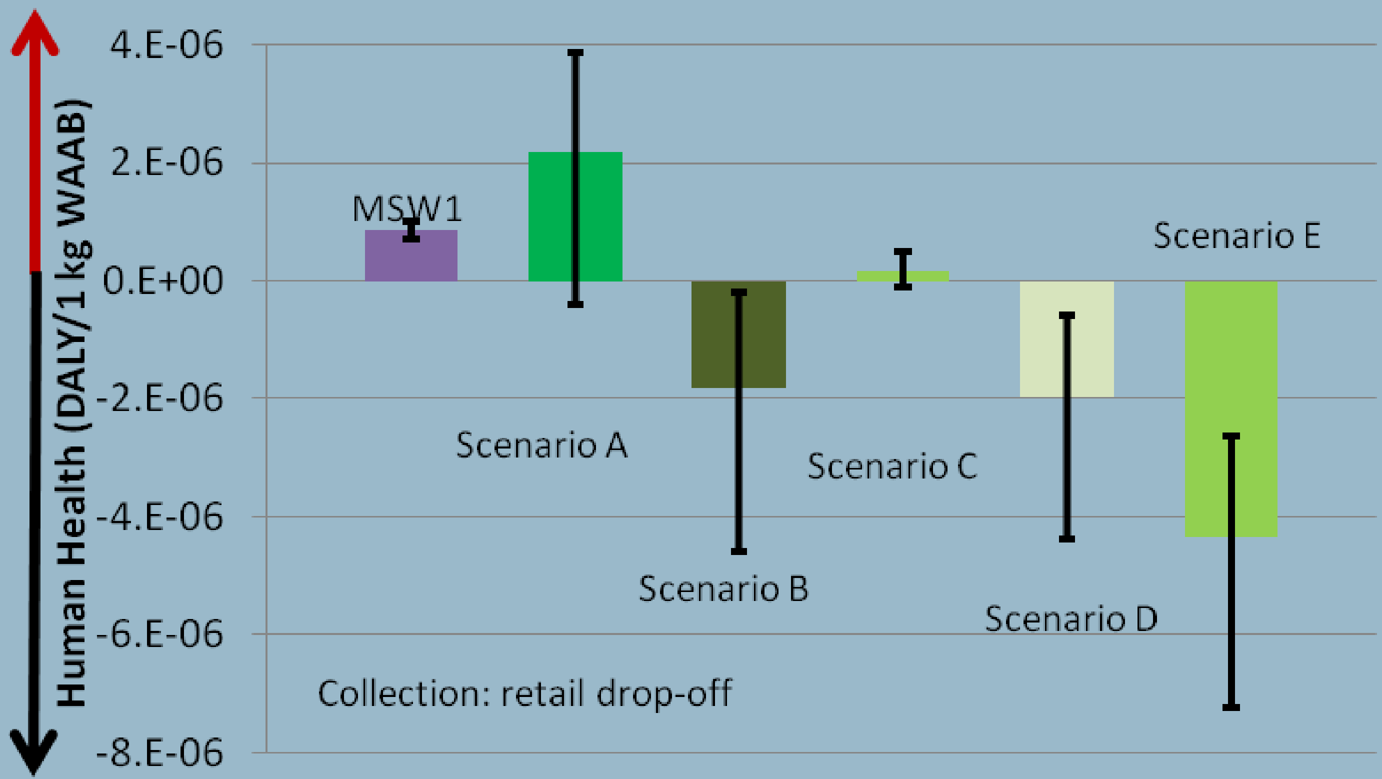
Results:
Human Health

- **Burden from materials disposition of 1 kg of batteries**



Using Human Health, the US technologies for alkaline battery recycling can either be beneficial or burdensome

Key Findings

The benefit of recycling alkaline batteries at end-of-life depends considerably on several factors:

- Energy intensity of the recycling scenario
- Mass and nature of materials recovery (more than Zn important)
- Prevalence of dedicated trips to drop-off batteries
- Impact assessment method (i.e. GWP vs. ecosystem toxicity)

Summary and conclusions

- **Concern over materials in landfills**
  - **Recycling reduces that concern, collection creates burden**
- **Alkaline battery recycling impact sensitive to**
  - **Transport distance**
  - **Materials recovered**
    - Recovering more than Zn important
    - Less than 40% Zn recovery problematic
  - **Impact assessment method**
    - Energy only – strongly recovery dependent
    - Considering toxicity – less ambiguous for base case
- **Significant uncertainty:**
  - **More primary data on processing technologies**
  - **Further collection scenario analysis**
  - **Customer behavior**