PLUG-IN 2010

# Lifecycle Analysis for Lithium-Ion Batteries

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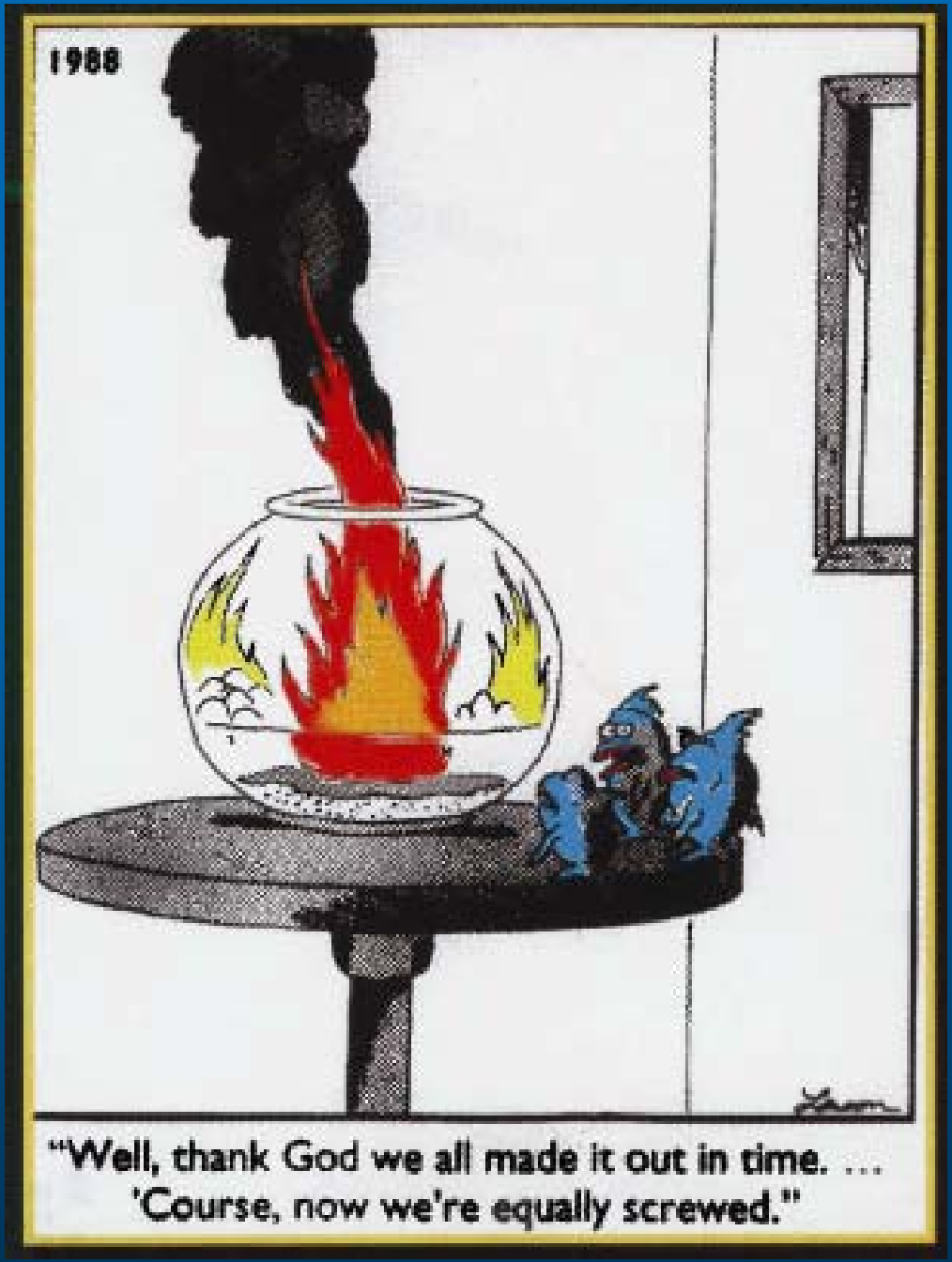
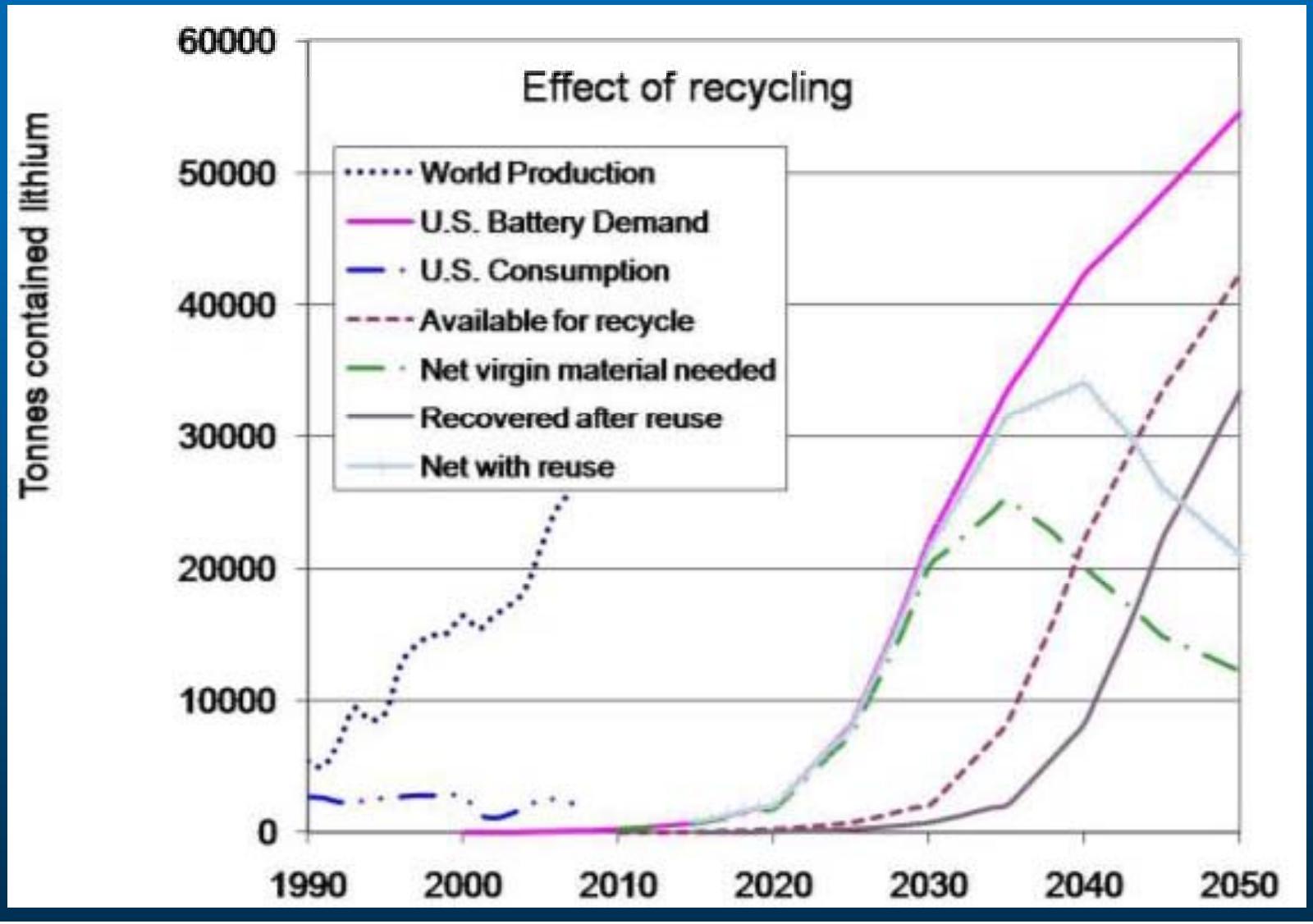
## We don't want to trade one crisis for another!

- Insure against material shortages
- Check for unforeseen environmental impacts



# Recycling reduces virgin material demand

- **Reuse delays return of material for recycling and increases peak demand for virgin material**



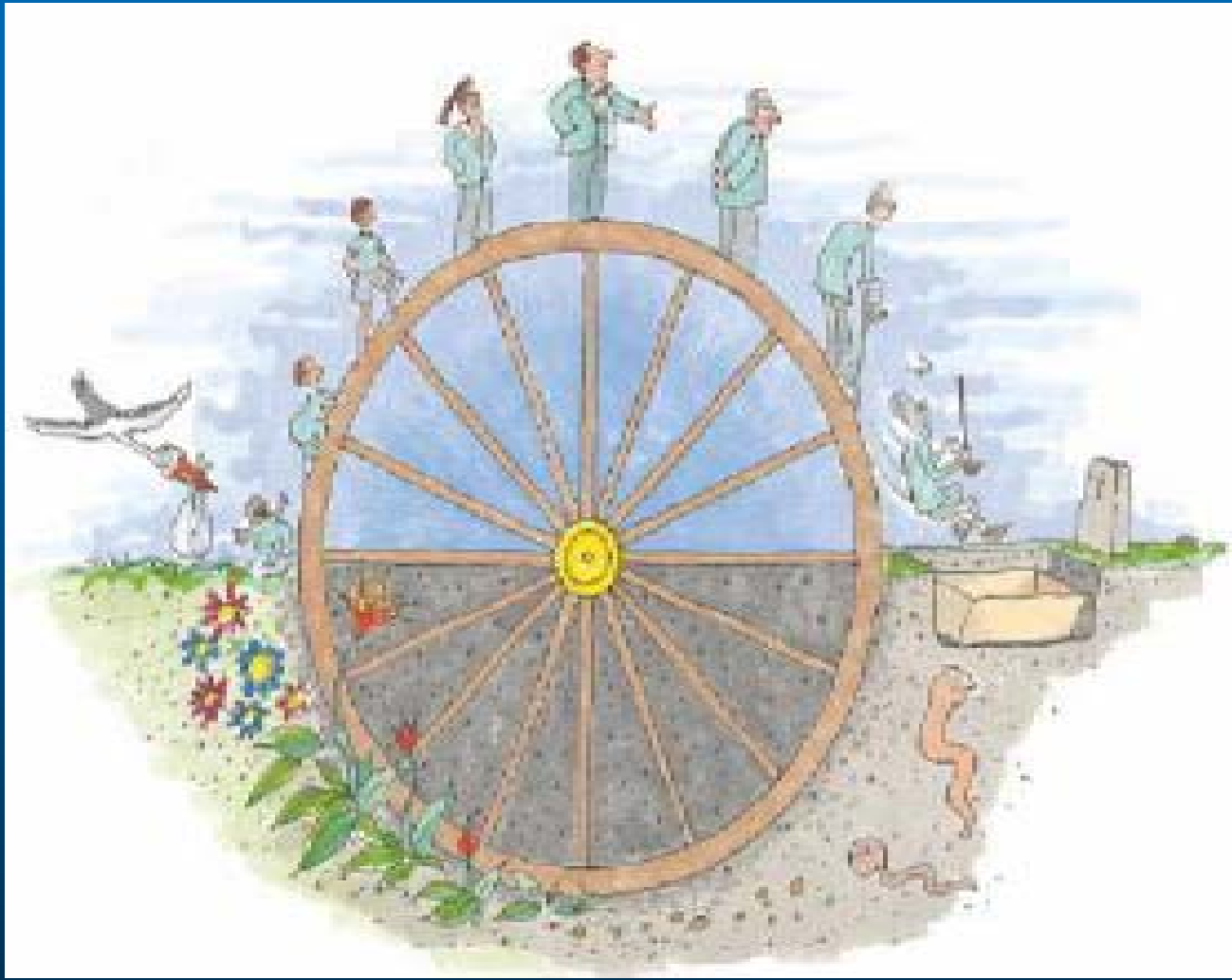
# Known Li reserves could meet world demand to 2050

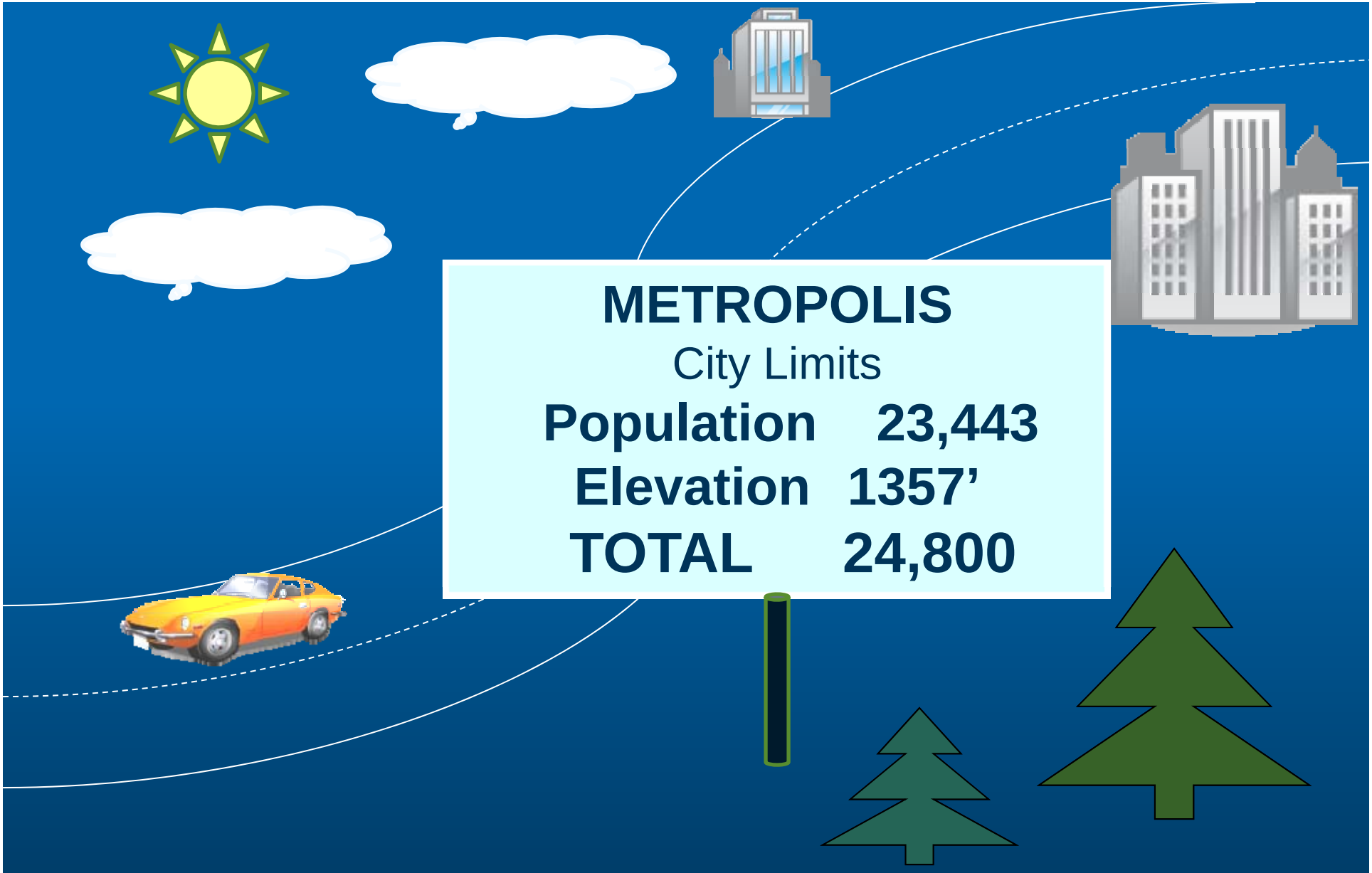
| | **Cumulative demand to 2050 (Contained lithium, 1000 Metric tons)** |
|---|---|
| Large batteries, no recycling | 6,474 |
| Smaller batteries, no recycling | 2,791 |
| Smaller batteries, recycling | 1,981 |
| | **Reserve Estimates** |
| USGS Reserves* | 9,900 |
| USGS World Resource* | 25,500 |
| Other Reserve Estimates | 30,000+ |

*Revised January 2010
http://minerals.usgs.gov/minerals/pubs/commodity/lithium/mcs-2010-lithi.pdf

# Lifecycle analysis compares all process impacts

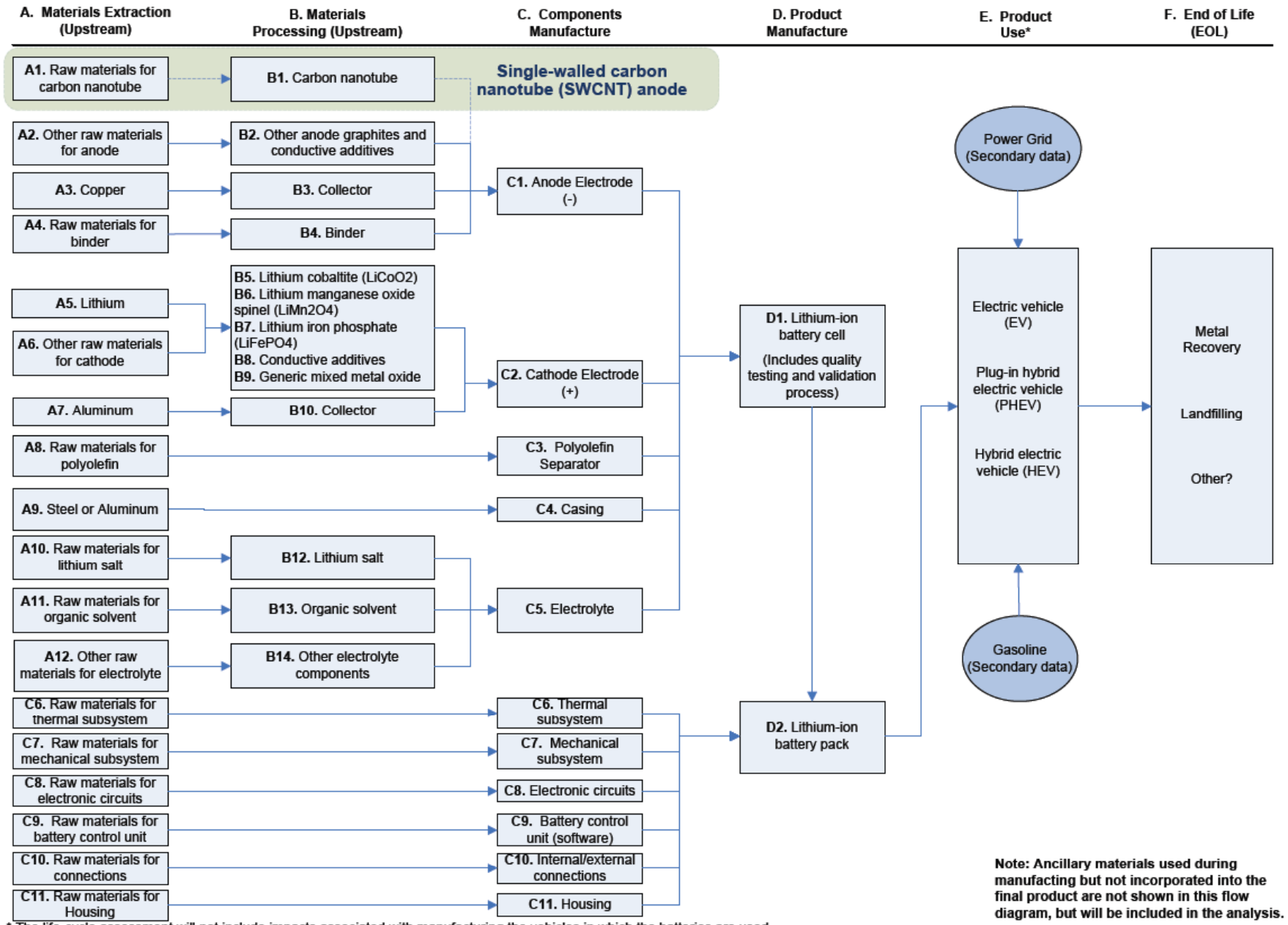
- LCA addresses the environmental aspects and potential environmental impacts throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling, and final disposal if any






**There is no correct way to aggregate impacts into a single “score.”**

## Generic Process Flow Diagram for Passenger Vehicle Energy Systems, Focusing on Lithium-ion Batteries



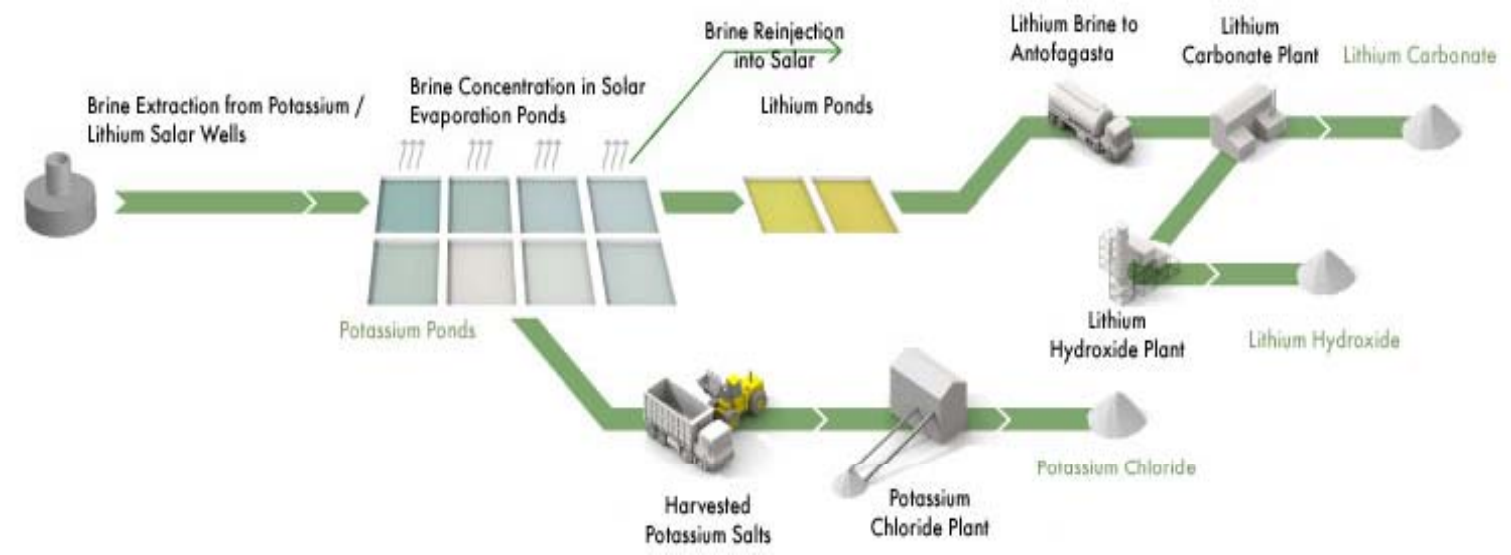

* The life-cycle assessment will not include impacts associated with manufacturing the vehicles in which the batteries are used.

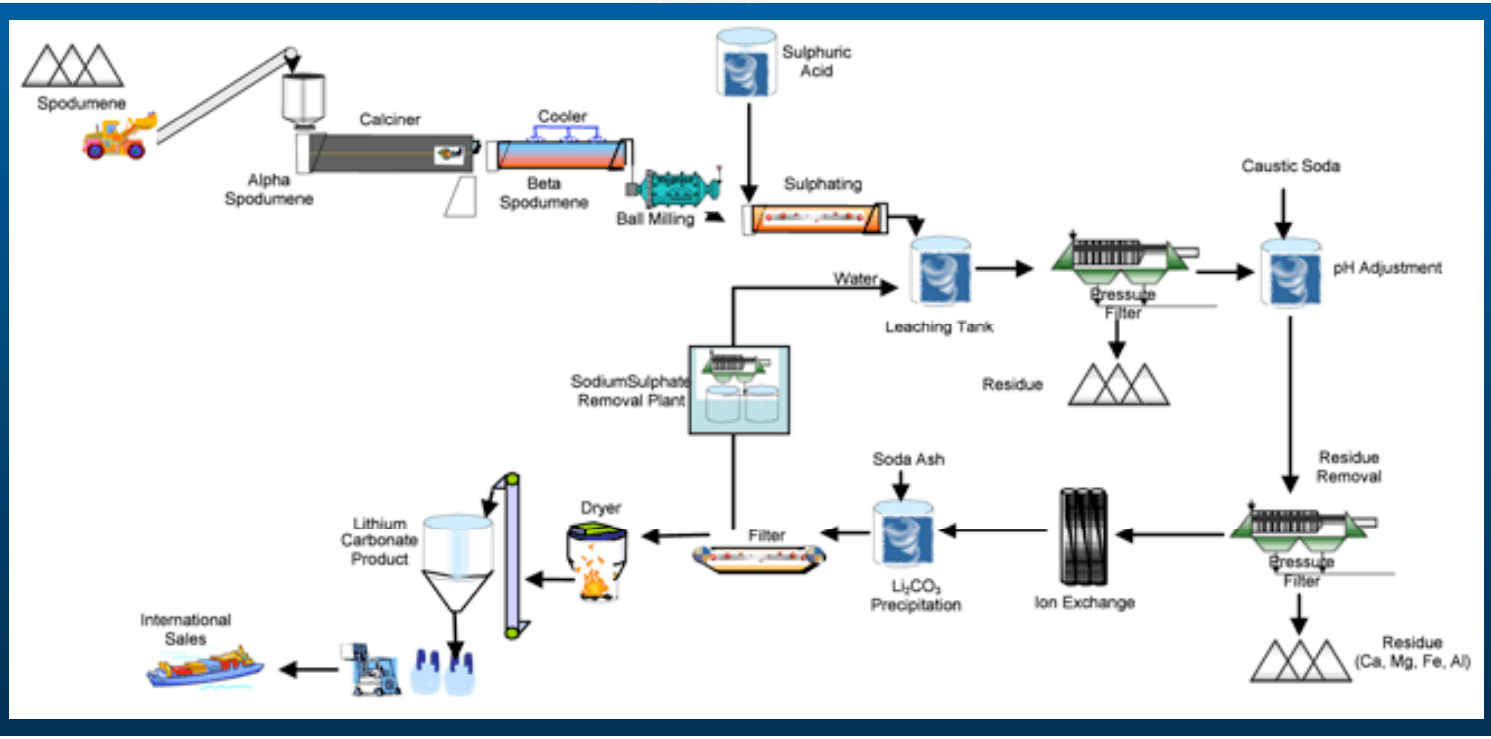

Sources: EPA, Design for Environment, Nanotech Partnership; Components of lithium ion rechargeable batteries, NEC/TOKIN (http://www.nec-tokin.com;
Olapiriyakul, S, Caudill, RJ. *A Framework for Risk Management and End-of Life (EOL) Analysis for Nanotechnology Products*: A Case Study in Lithium-Ion Batteries. IEEE.
Ganter, MJ, Seagar, TP, Schauerman, CM, Landi BJ, Raffaelle, RP. *A Life Cycle Energy Analysis of Single Wall Carbon Nanotubes Produced Through Laser Vaporization*. Rochester Institute of Technology.
Electropedia, Battery and Energy Technologies, Lithium Ion Battery Manufacturing (http://www.mpoweruk.com/battery_manufacturing.htm accessed on June 7, 2010)

# The bulk of battery materials are well characterized; we'll examine the others

| Material | Mass (kg) | Mass % |
|---|---|---|
| Positive active material | 2.25 | 13.1 |
| $LiO_2$ | 0.91 | 5.3 |
| Nickel | 0.46 | 2.6 |
| Cobalt | 0.46 | 2.7 |
| Manganese | 0.43 | 2.5 |
| Graphite and carbon | 1.82 | 10.6 |
| Binder | 0.35 | 2.1 |
| Copper parts | 4.21 | 24.5 |
| Aluminum parts | 3.20 | 18.6 |
| Aluminum Casing | 1.82 | 10.6 |
| Electrolyte | 1.50 | 8.7 |
| Separator | | |
| Polypropylene | 1.39 | 8.1 |
| Polyethylene | 0.492 | 2.9 |
| Steel | 0.029 | 0.2 |
| Thermal insulation | 0.089 | 0.5 |
| Electronic parts | 0.056 | 0.3 |
| Total battery mass | 17.21 | 100 |

# We get lithium carbonate from brine or minerals



# Several routes are available to cathode materials

- - $Li_2CO_3$ and $Co_3O_4$ to make $LiCoO_2$
- $Li_2CO_3$ and $FePO_4$ or iron oxalate and ammonium phosphate to make $LiFePO_4$
- $Li_2CO_3$ and $MnO_2$ to make $LiMn_2O_4$
- $Li_2CO_3$ and $(Ni_xCo_yMn_z)(OH)_2$ to make Li $(Ni_xCo_yMn_z)O_2$ or spinel
- $Li_2CO_3$ and $(Ni_xCo_yMn_z)CO_3$ to make Li $(Ni_xCo_yMn_z)O_2$ or spinel (available)
- $Li_2CO_3$ and $(Ni_xCo_yMn_z)C_2O_4$ to make Li $(Ni_xCo_yMn_z)O_2$ or spinel (Argonne)
- LiOH can also be used, but is harder to handle

# Several issues are encountered in cathode material production

- Use of nickel, cobalt, and manganese sulfates generates sulfuric acid (waste treatment is necessary, requiring water, so plant should be close to river or sea).

- Use of sodium hydroxide or sodium carbonate contaminates the resulting transition metal hydroxides or carbonates with sodium (Negative impact on the performance).

- Ammonia (seeding/chelating agent) needs to be separated from the waste.

- Waste treatment is a big concern (separation of sulfur and ammonia), sodium is OK.

- Nickel can’t be precipitated at 100 % (waste with nickel-ion contamination)

- High temperature treatment is necessary to make the lithiated compounds.

# Battery Manufacturing

## POSITIVE ELECTRODE

| Active Material | Conductive agent | Binder |
|---|---|---|
| $LiCoO_2$<br>$LiNi_xCo_{1-x}O_2$<br>$LiMn_2O_4$ | Acetylene black<br>Carbon | PVdF<br>NMP<br>DMF |

Paste mixing

Aluminum foil → Coating

Drying

Calendaring

Slitting to width

Reeling stock

## NEGATIVE ELECTRODE

| Active material | Conductive Agent | Binder |
|---|---|---|
| Graphite | Acetylene black<br>Carbon | PVdF<br>NMP<br>DMF |

Paste mixing

Coating ← Copper foil

Drying

Calendaring

Slitting to width

Reeling stock

Winding core

Separator → Inserting wound elements in can

Can, Case → Spot welding bottom contact

Vacuum & heat drying

Electrolyte → Vacuum addition of electrolyte

PTC, CID, Top insulator plate, Cap → Inserting top parts

Closing and sealing → Top can welding

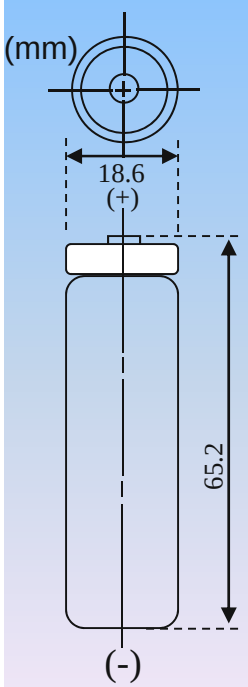
washing

Formation cycles

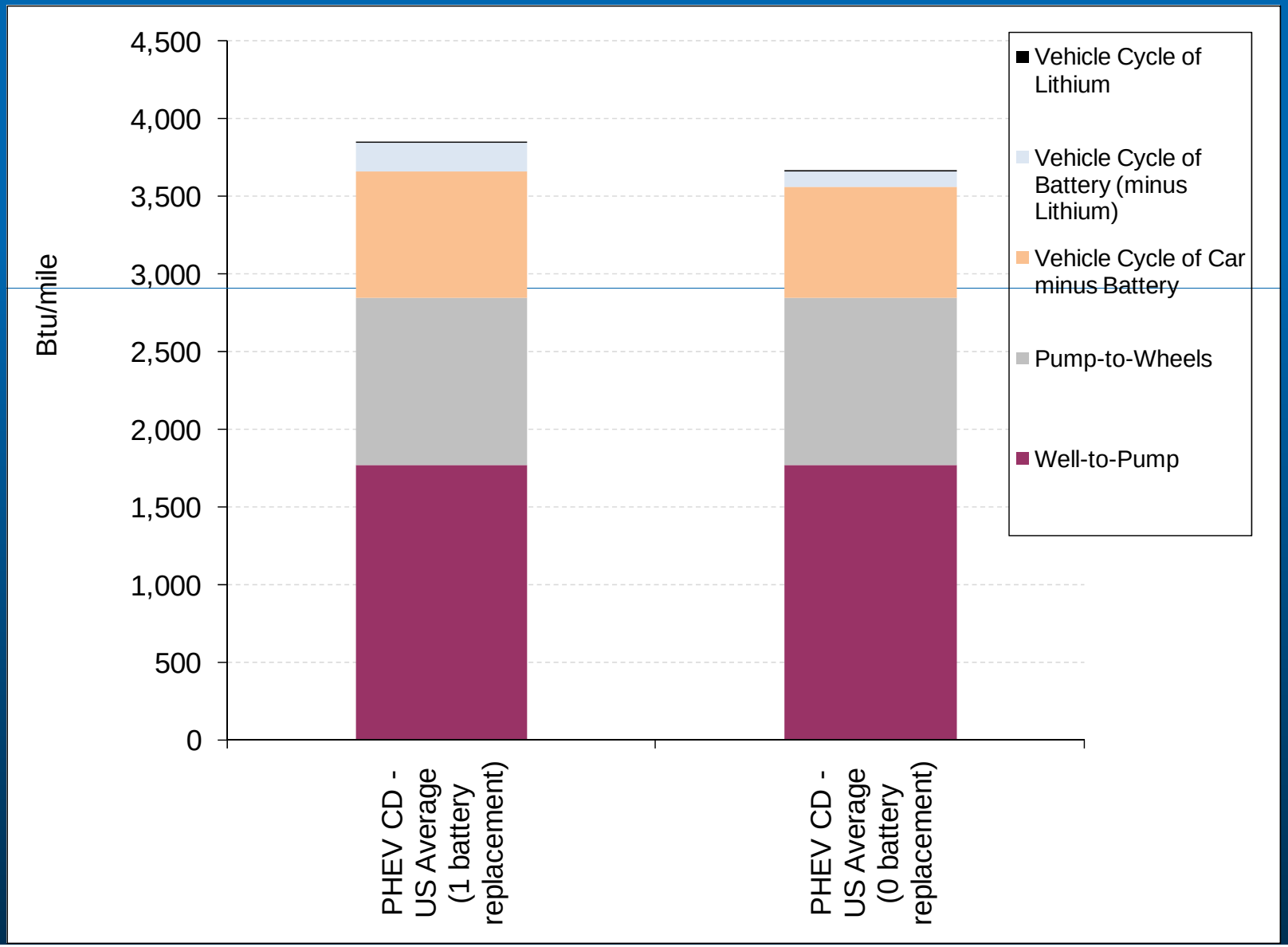
Storage & aging

Acceptance testing → Shipping

6-8$/cell

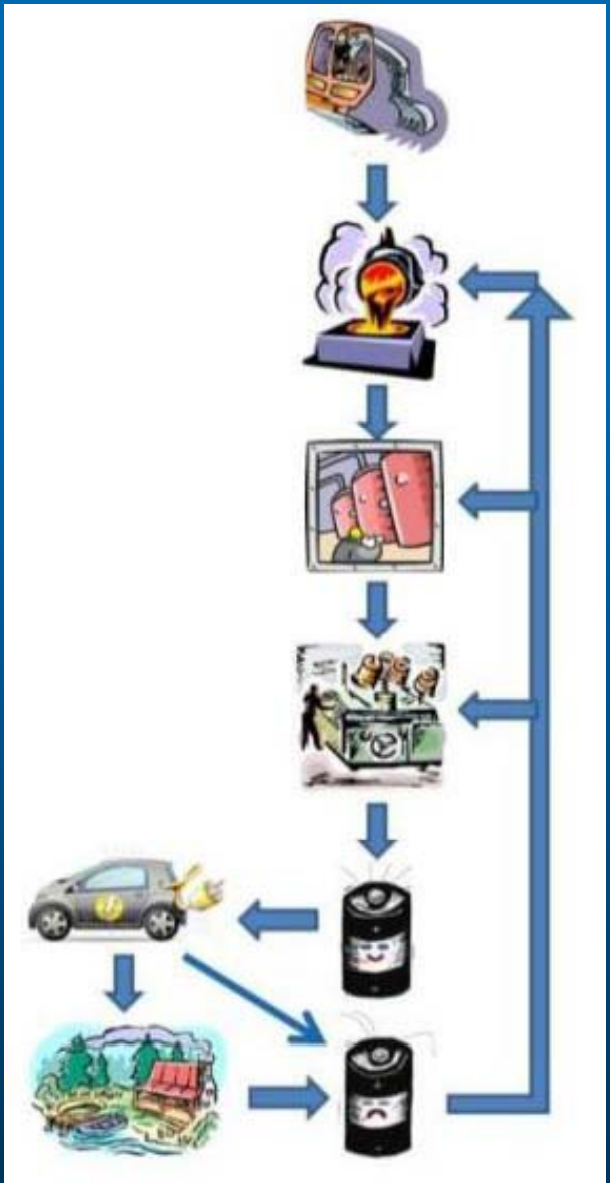


# The vehicle cycle is a small part of the total impact; the battery is a small part of that



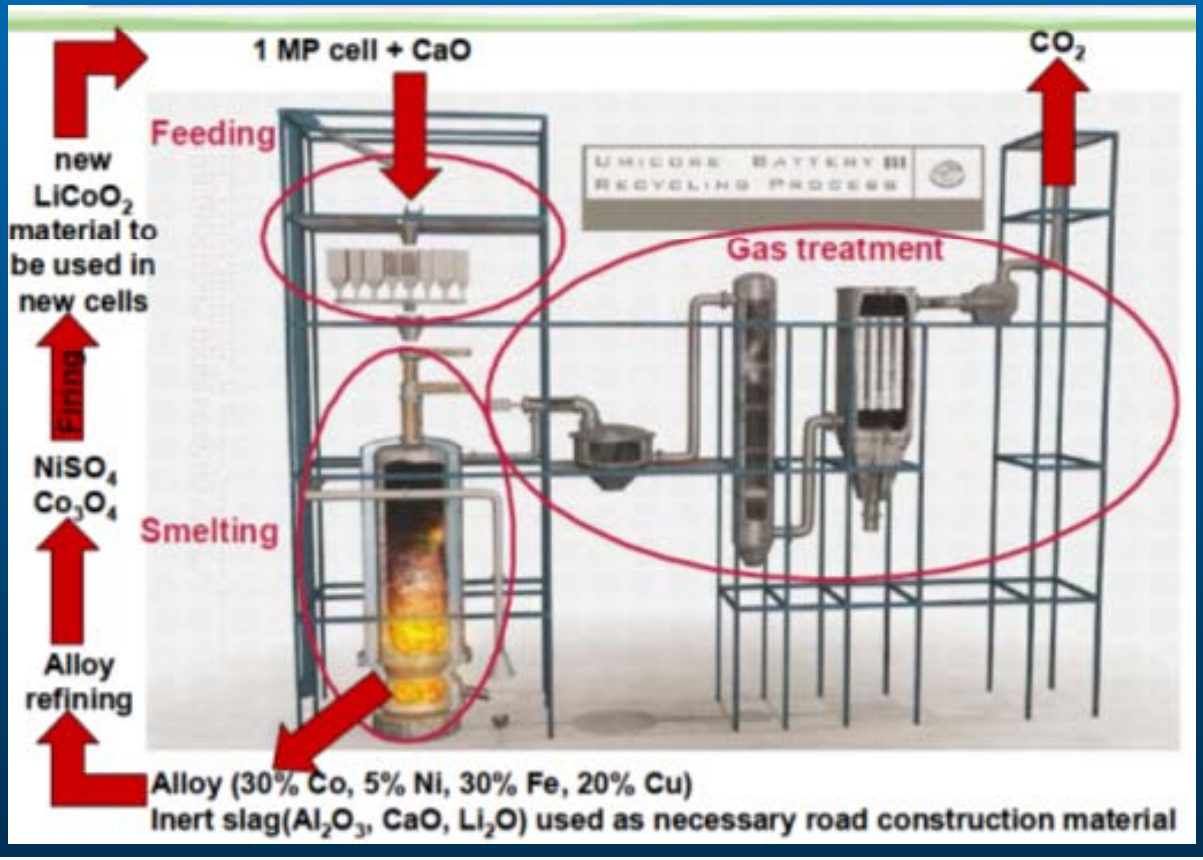
# Recycling can recover materials at different production stages

- **It is difficult to recover all materials**
- **One possible goal is to recover battery-grade materials**
  - **More energy saved if more steps avoided**
- **The other extreme would be to recover basic building blocks**
- **There are pros and cons of different approaches**
- **LCA identifies "greenest" processes**
  - **May not be most economical**

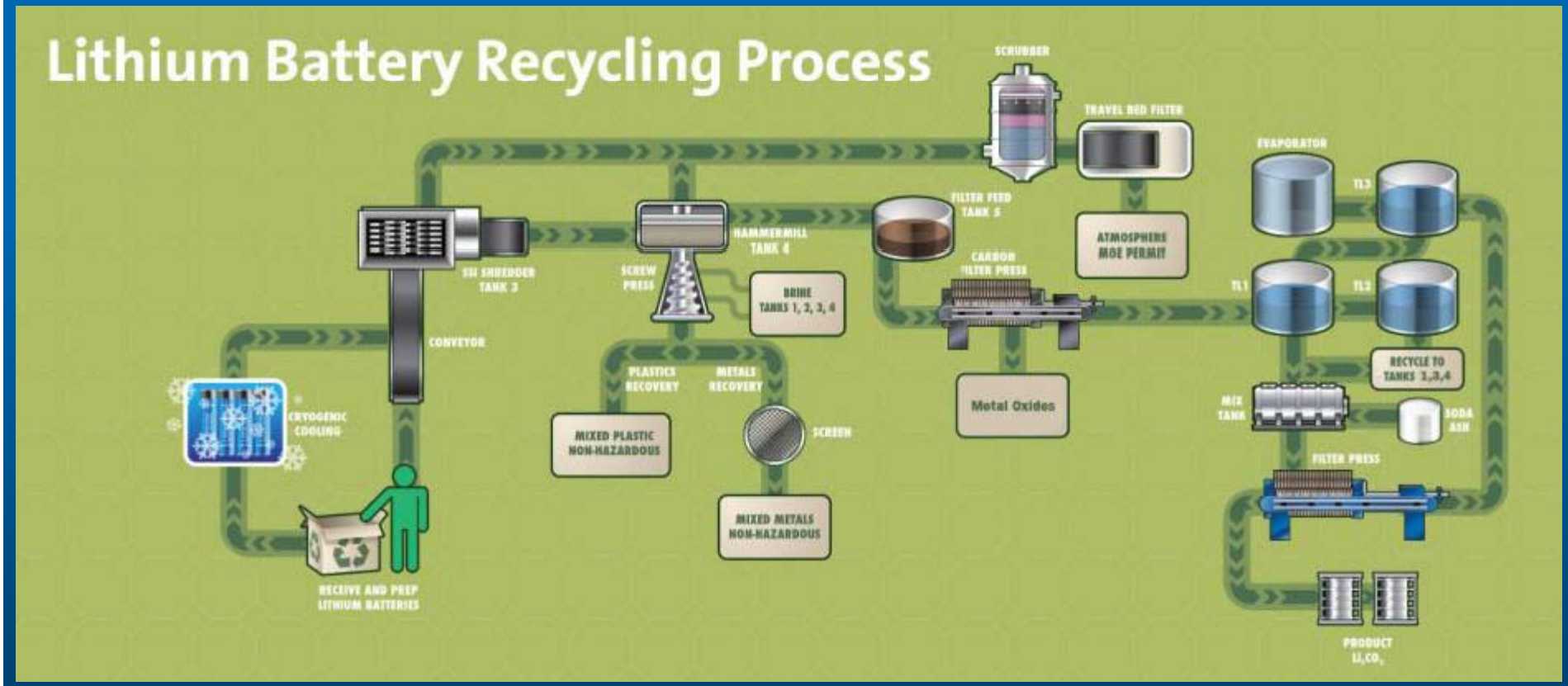


# Smelting processes are operating now

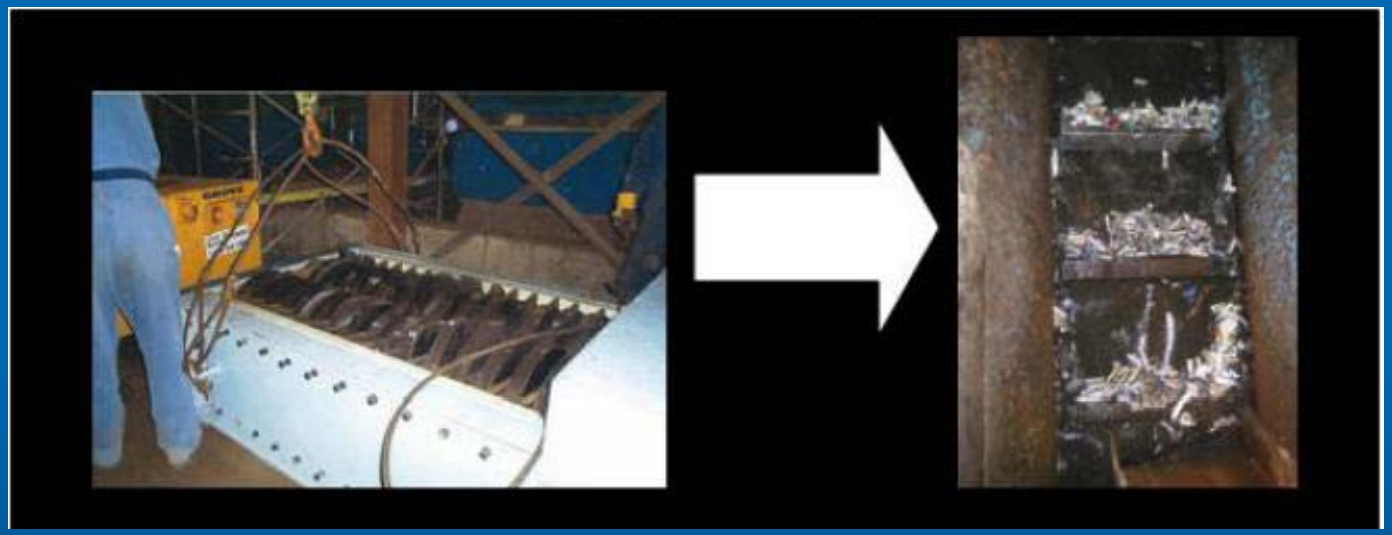
- **These can take just about any input, high volume**
- **High-temperature required**
  - Organics are burned for process energy
- **Valuable metals (Co and Ni) recovered and sent to refining**
  - Suitable for any use
- **Volatiles burned at high-T**
- **Li, Al go to slag**
  - Could be recovered



# Toxco Ohio plant will used improved process to recover lithium



# Shredded batteries go to hammermill



Copper cobalt and filter cake products

# Future recycling could reuse materials in batteries

- **Requires as uniform feed as possible**
- **Components are separated**
  - **Ideal is to retain valuable material structure**
- **All active materials and metals can be recovered**
  - **Purify/reactivate components if necessary**
    - *Ideal is to use product in new automotive batteries (will be largest market)*
  - **Separator is unlikely to be usable, as form cannot be retained**
- **Low-temperature process, low energy requirement**
- **Energy and processing to produce battery-grade material from raw materials is saved**
- **Costs lower than virgin materials**
- **Does not require large volume**

# Plastics can be made into C-nanotubes

- Argonne has developed a process for plastic bags
  - Vilas Pol is developer
  - Process could be used for battery plastics
- React with cobalt acetate catalyst at 700° C, cool 3 hours
  - Recover catalyst when battery recycled
- C-nanotube anodes are produced
  - Now made from petroleum
  - Cost ~$100/gram
  - Recycling process would be much cheaper

- Argonne solvent extraction process also could be used to recover battery plastics
  - Could utilize plastic stream from Toxco/Kinsbursky or Eco-Bat

# Stay tuned for results. Thank you!

- Work sponsored by DOE Office of Vehicle Technologies
- Colleagues: John Sullivan, Andy Burnham, Ilias Belharouak

Contact me: lgaines@anl.gov