# Comparison of Lithium Ion Battery Recycling Processes

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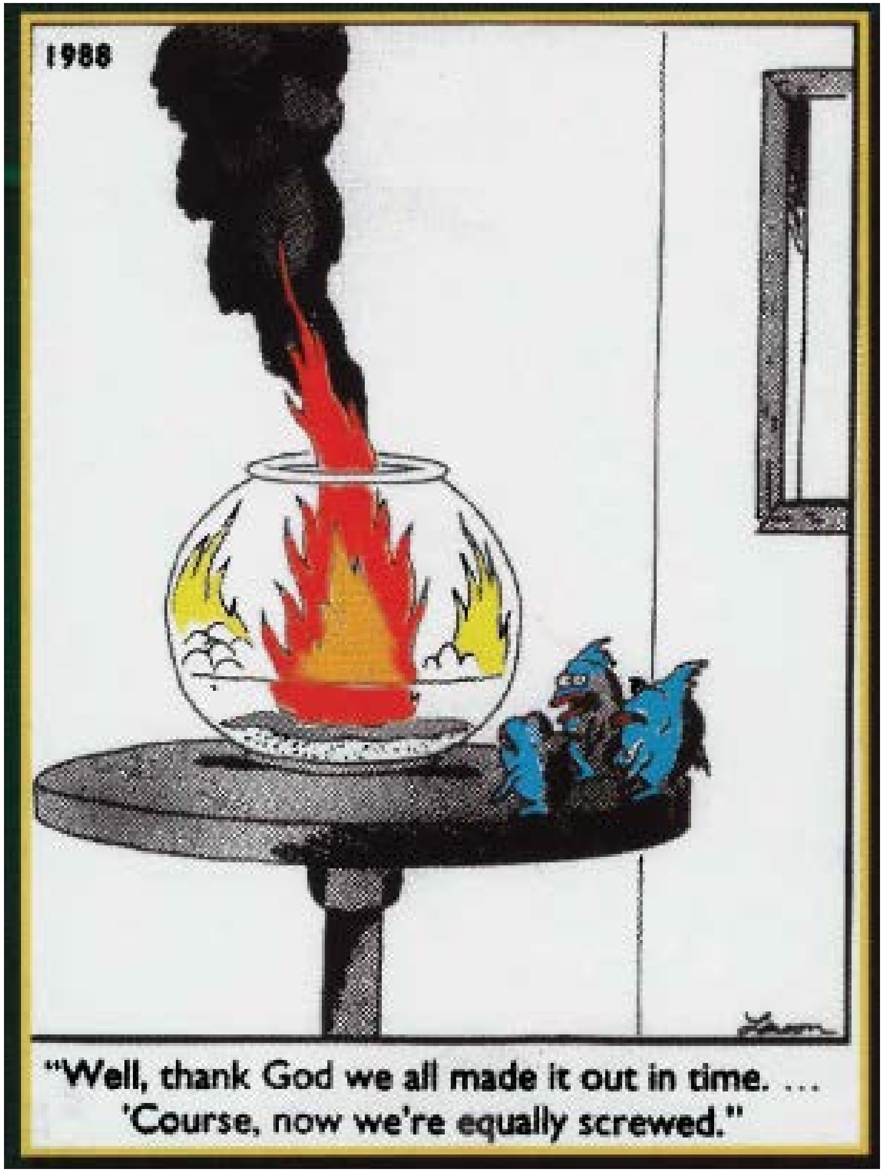
**Linda Gaines**
**Center for Transportation Research**
**Argonne National Laboratory**

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

- **Battery material shortages are unlikely**
  - We demonstrated that lithium demand can be met
    - Co supply and price will reduce importance of NCA-G chemistry
  - Scenarios included rapid growth of EVs  to 2050
  - Recycling mitigates potential scarcity
- **Now we're checking for unforeseen impacts**

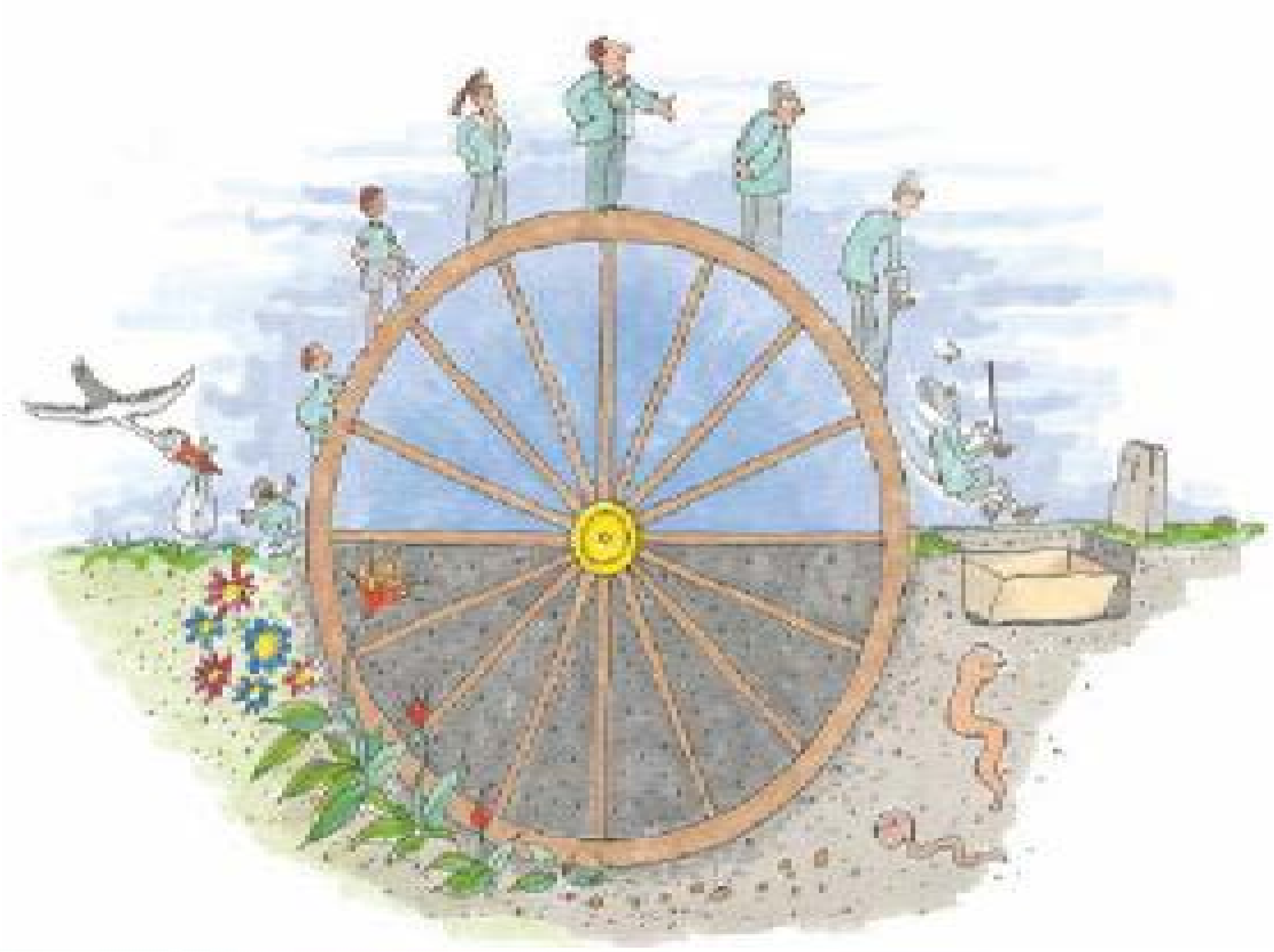


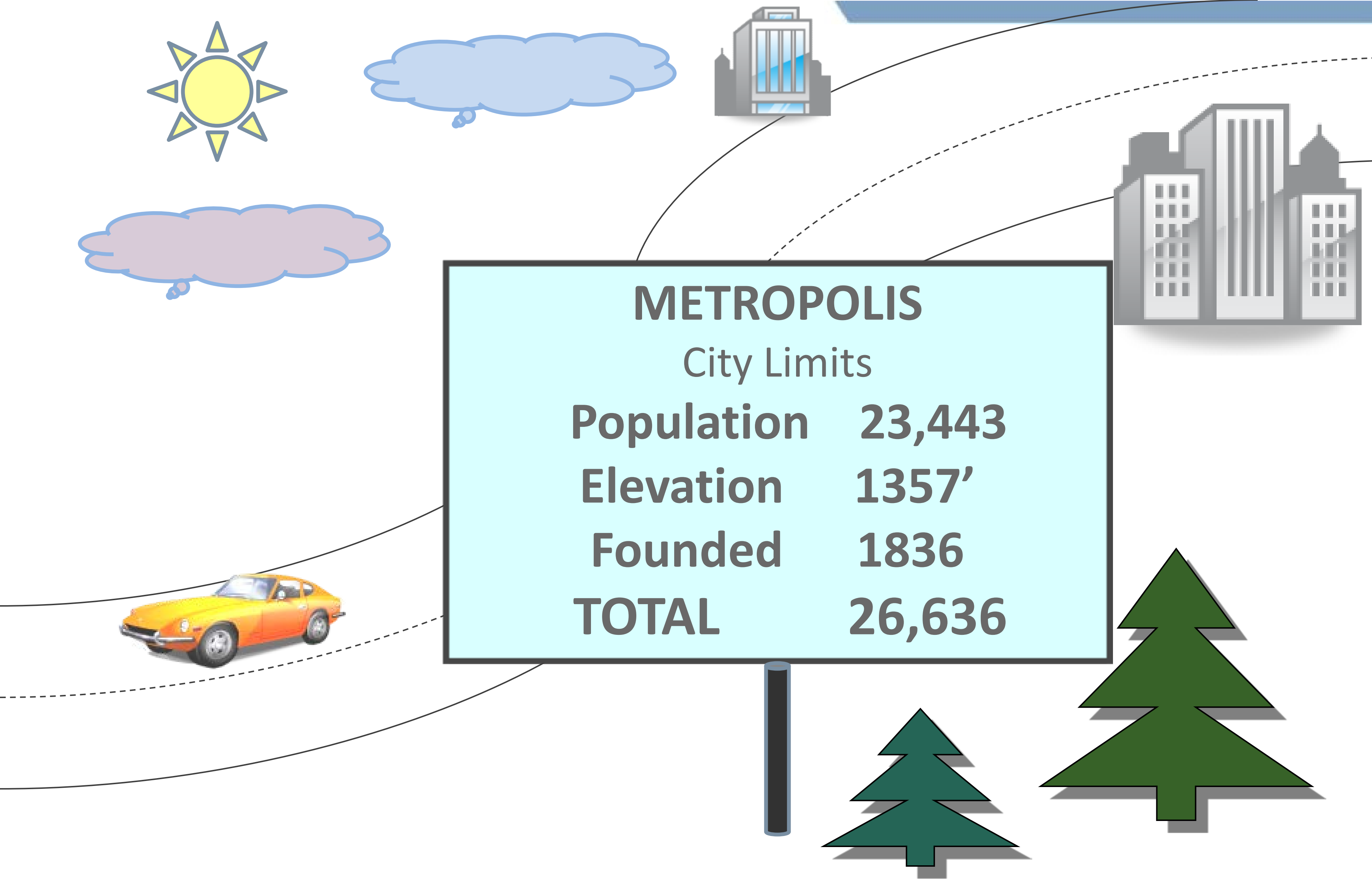
# U.S. cobalt use could make dent in reserve base by 2050

| Material | Availability (million tons) | Cumulative demand | Percent demanded | Basis |
| --- | --- | --- | --- | --- |
| Co | 13 | 1.1 | 9 | World reserve base |
| Ni | 150 | 6 | 4 | World reserve base |
| Al | 42.7 | 0.2 | 0.5 | US capacity |
| Iron/steel | 1320 | 4 | 0.3 | US production |
| P | 50,000 | 2.3 | ~0 | US phosphate rock production |
| Mn | 5200 | 6.1 | 0.12 | World reserve base |
| Ti | 5000 | 7.4 | 0.15 | World reserve base |

# Lifecycle analysis compares all process impacts

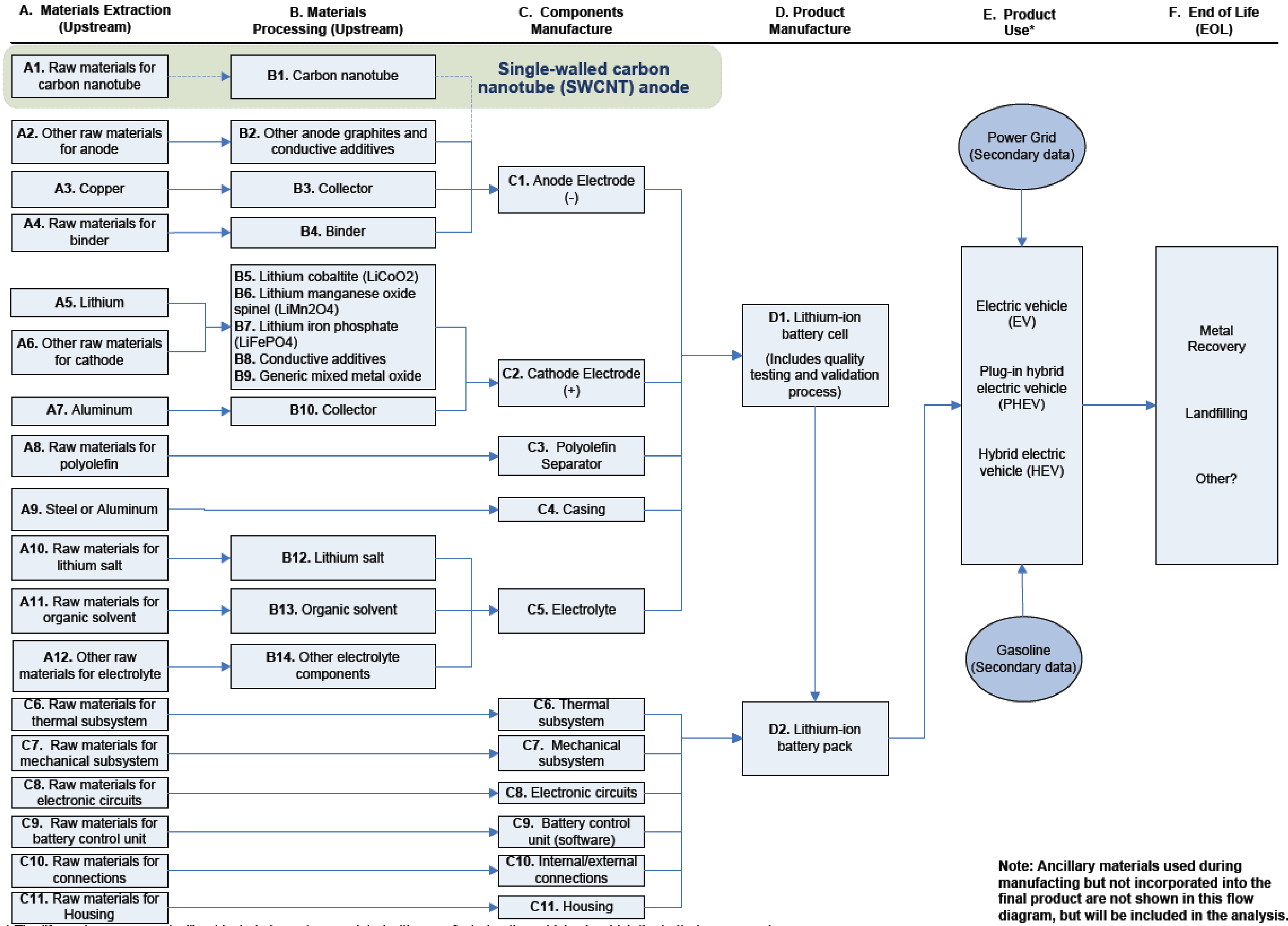
of a product's life cycle, from raw material acquisition through production, use, end-of-life treatment, recycling, and final disposal if any.






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

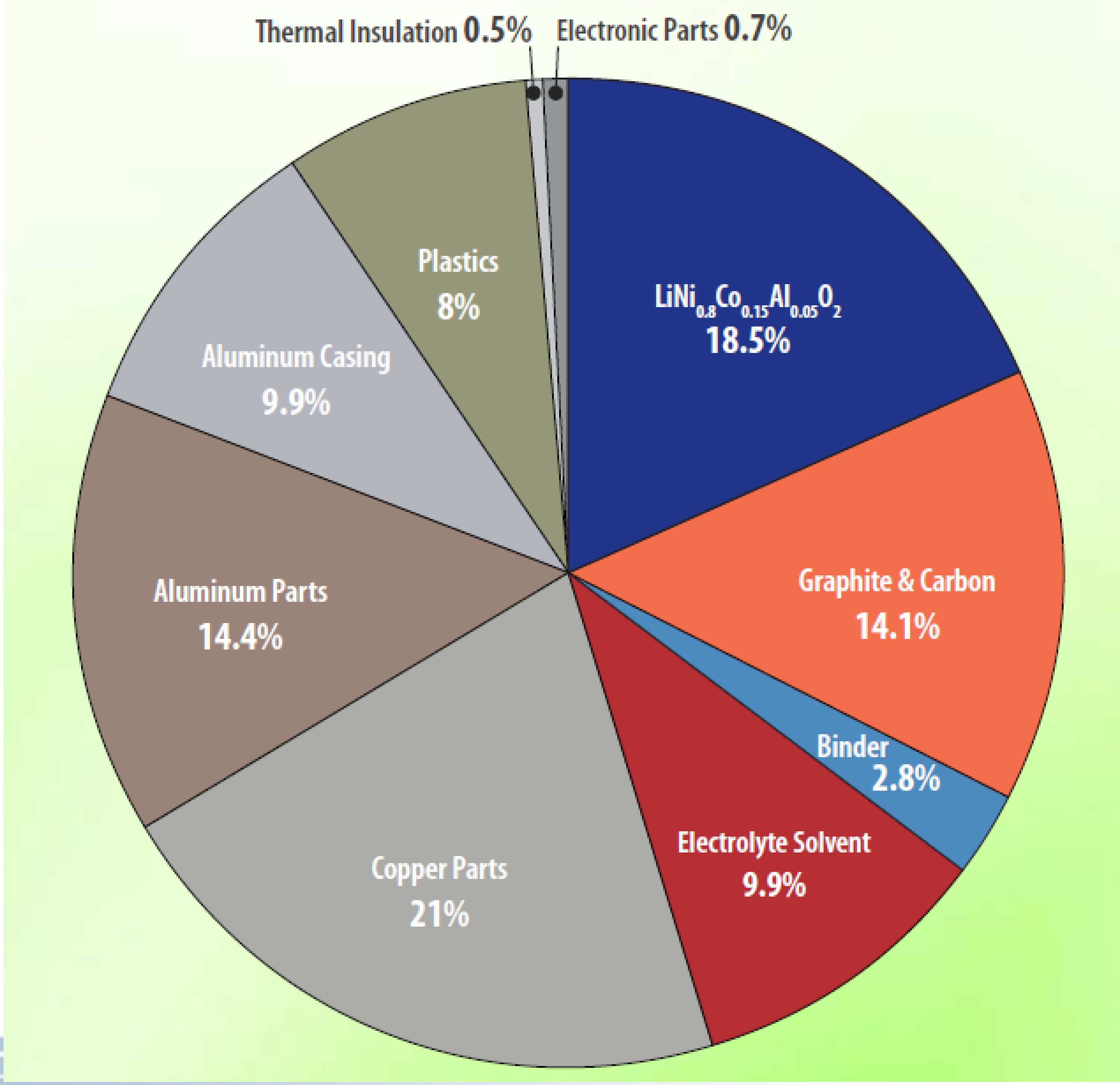
# Generic Process Flow Diagram for Passenger Vehicle Energy Systems, Focusing on Lithium-ion Batteries




* 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)

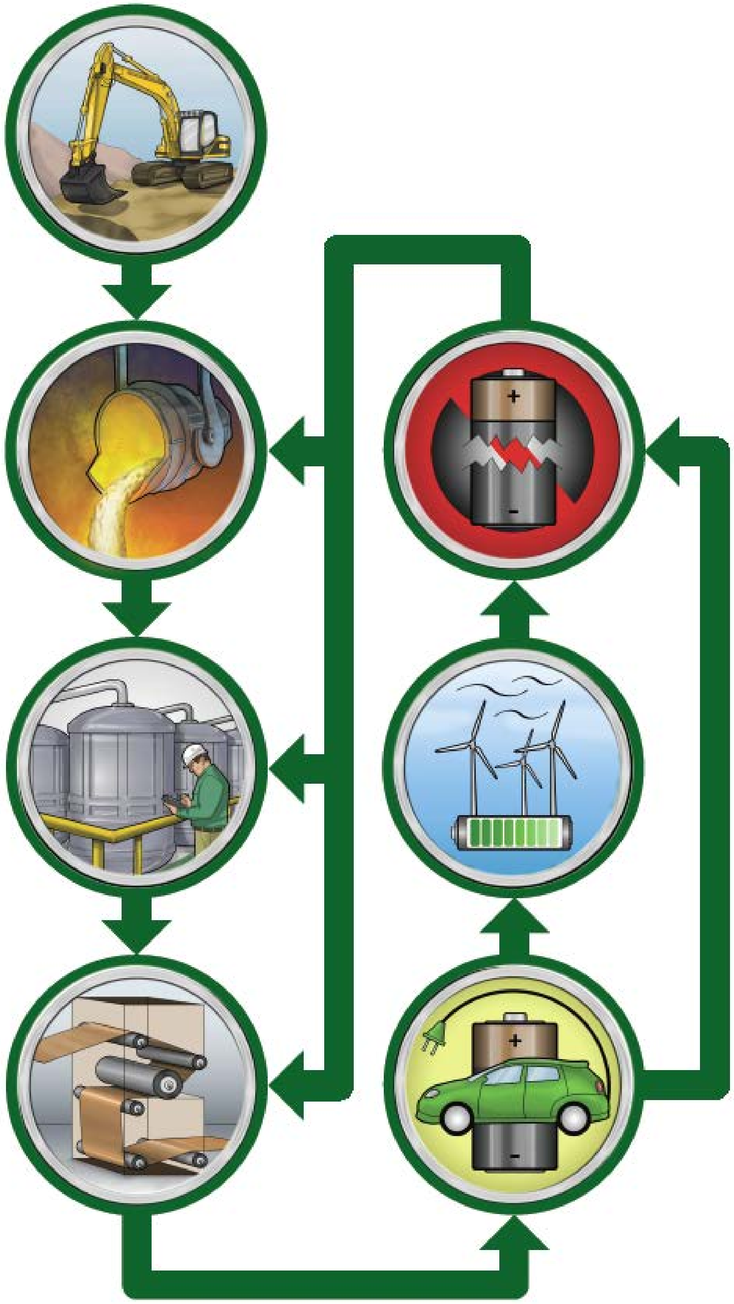
# The bulk of battery materials are well characterized; we are now examining the others



# Why think about recycling?

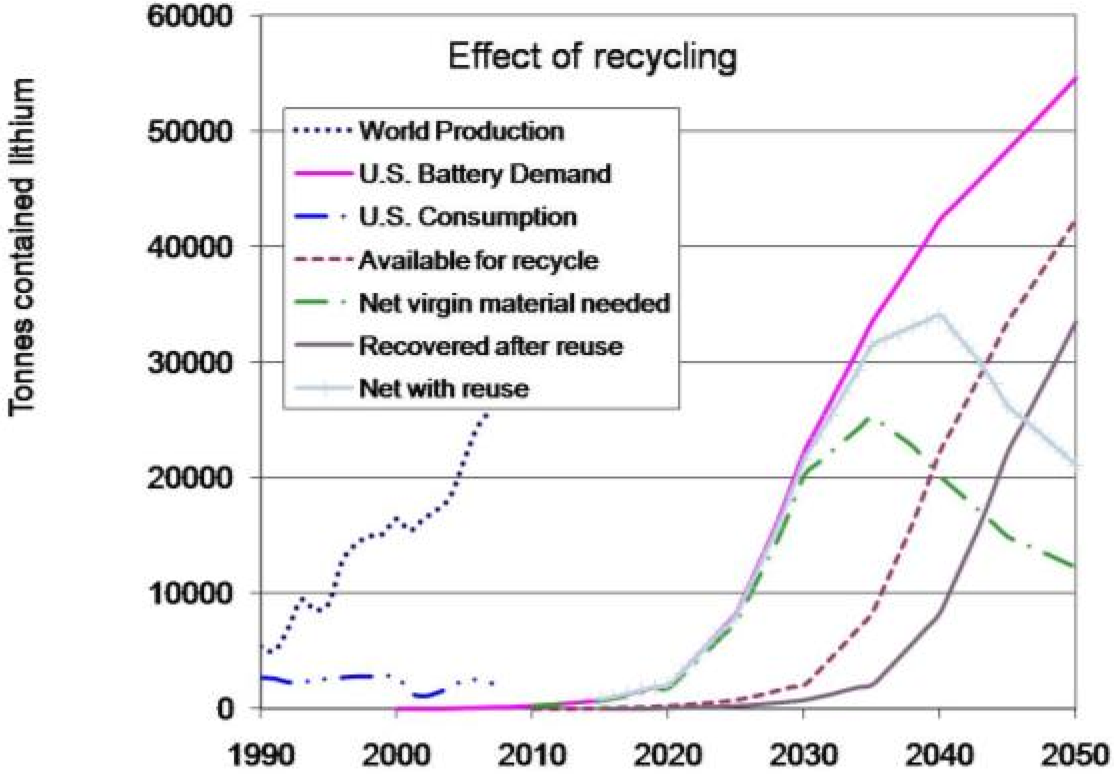
- **Material scarcity alleviated**
- **Recycled materials cheaper**
- **Production impacts avoided**
  - Energy use
  - Emissions
  - Mining impacts
- **Legally required**

- **But not all recycling processes are created equal**
- **Which is best?**
  - LCA identifies "greenest" processes
  - May not be most economical
  - There may be other issues as well



# A word about battery reuse

- Reuse takes battery directly back to lower-performance use
- Nissan will reuse batteries to store energy from PV panels or to store back-up power
- Reuse delays return of material for recycling and increases peak demand for virgin material
  - Assumes virgin material would not be used for backup batteries



# Recycling reduces production burdens

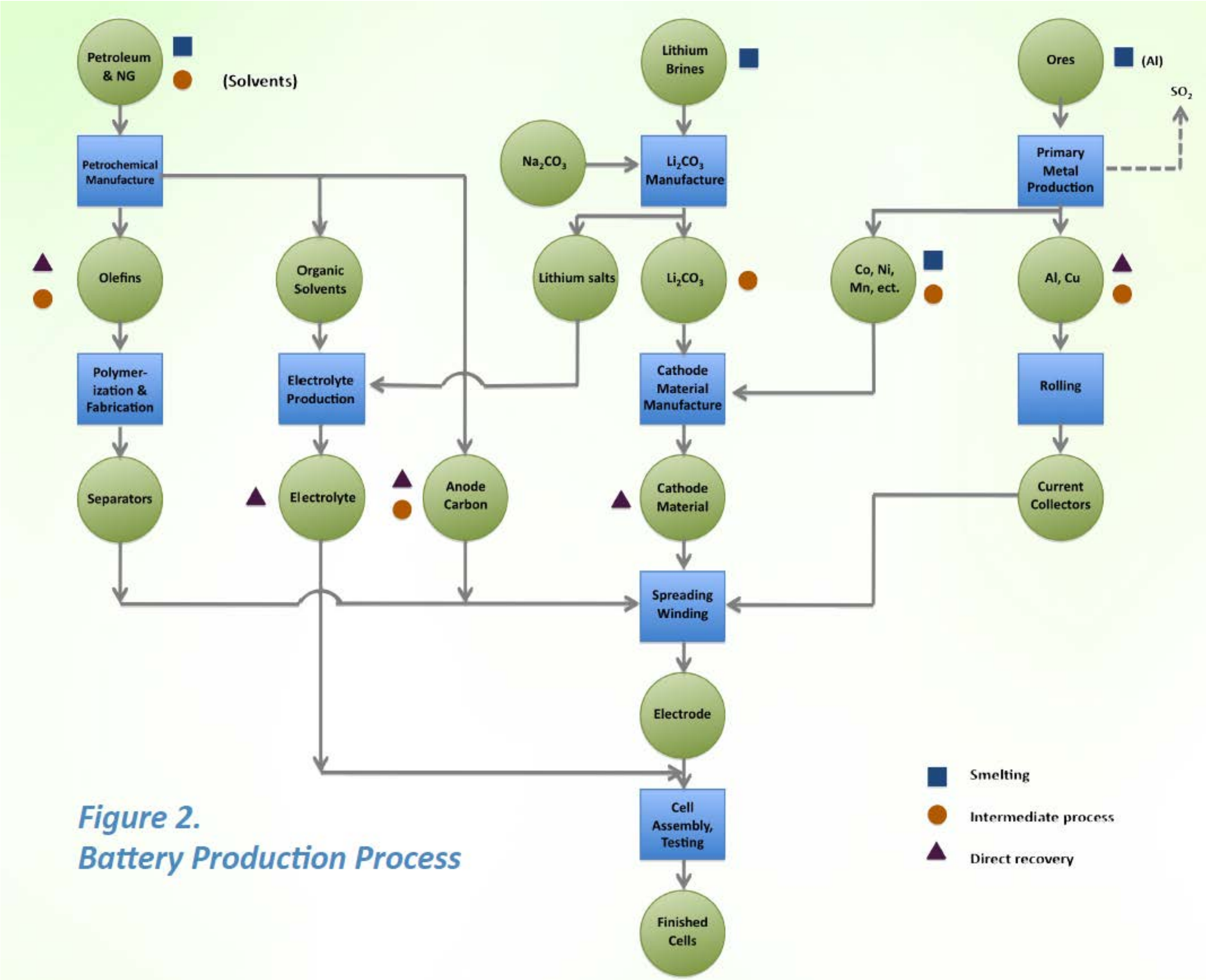
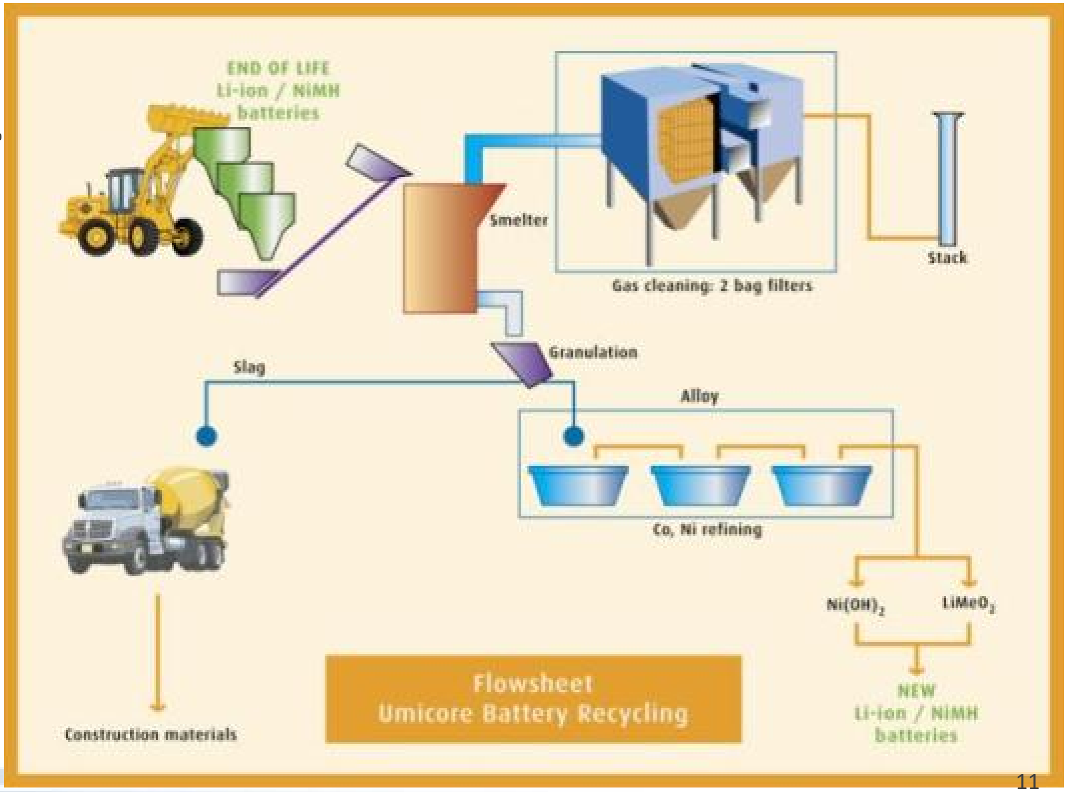


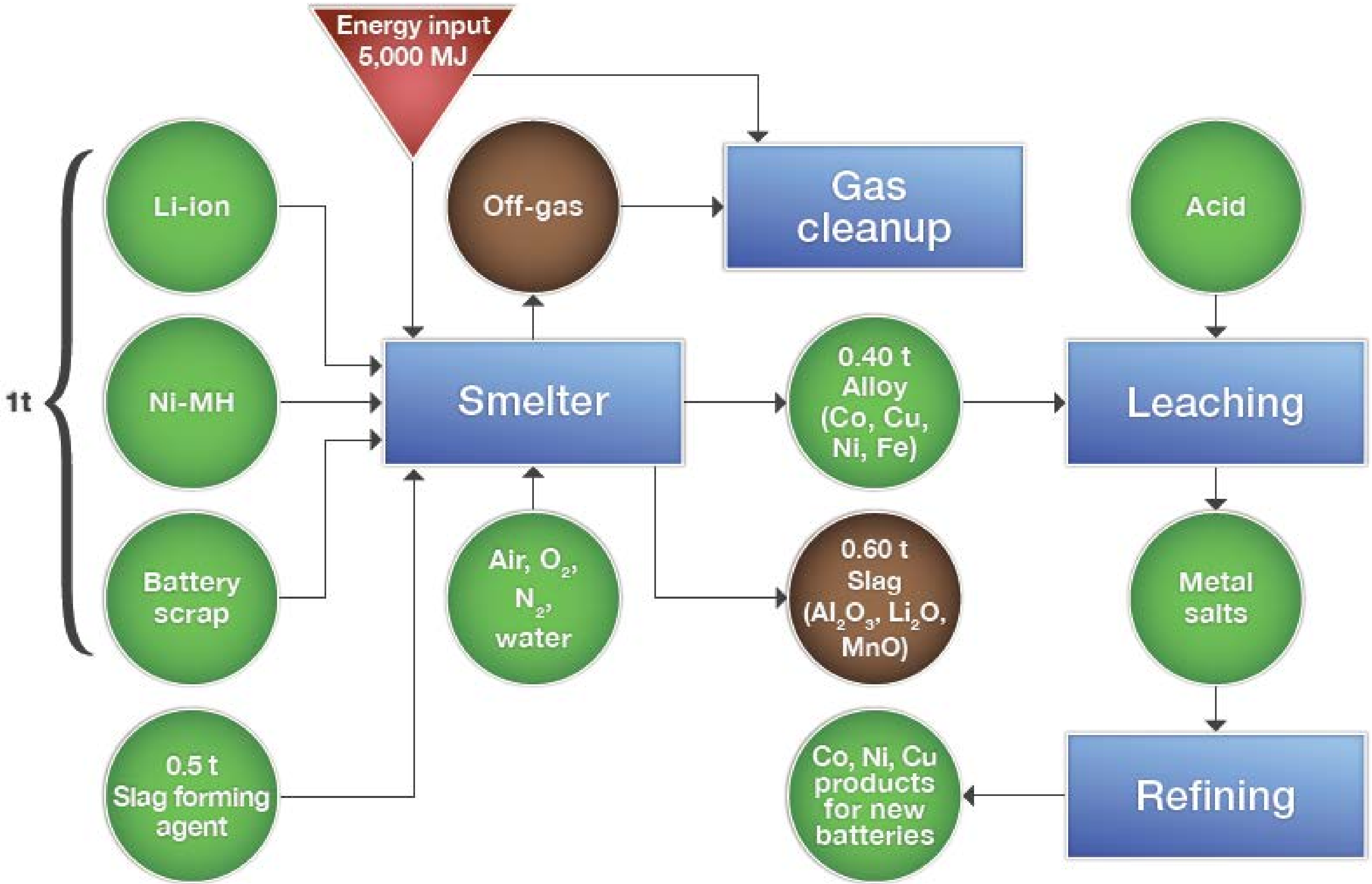

*Figure 2.*
*Battery Production Process*

# Smelting processes avoid metal ore processing

- **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
  - 70% of cobalt production energy saved; sulfur emissions avoided
  - Fabrication still needed
  - Less Co → less value
- **Volatiles burned at high-T**
- **Li, Al go to slag**
  - Could be recovered



# Commercial smelting process recovers metals



# In Finland, batteries are collected and sent to a small plant



# They are sorted and chopped up

# The product is leached at a large plant, along with tailings from a copper mine in Congo to recover cobalt

# Several cobalt products are produced

Raw Material Leaching

↓

Copper SX → Copper Cathode

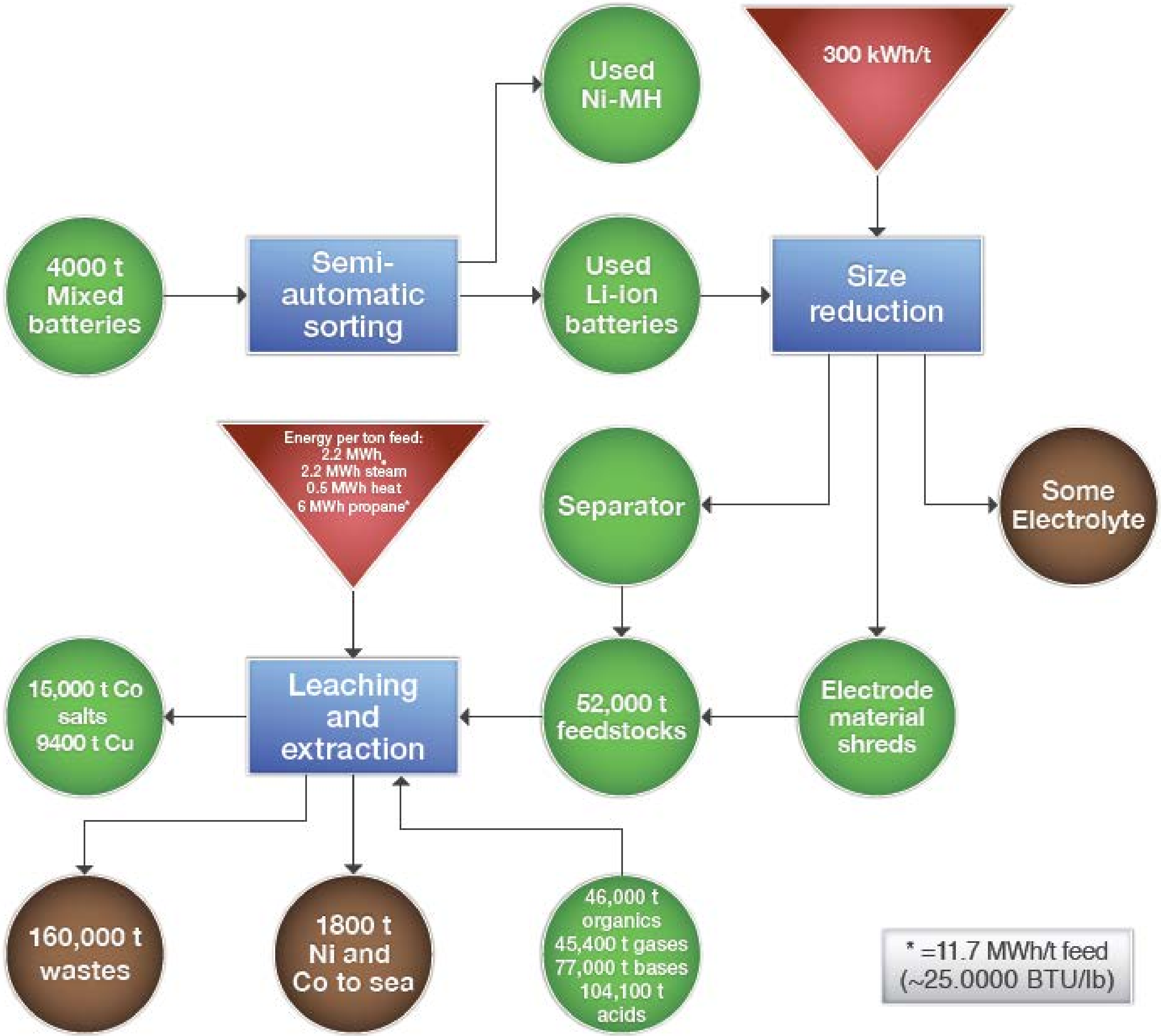
↓

Solution Purification

↓

Cobalt SX

# Battery materials are small part of cobalt plant input



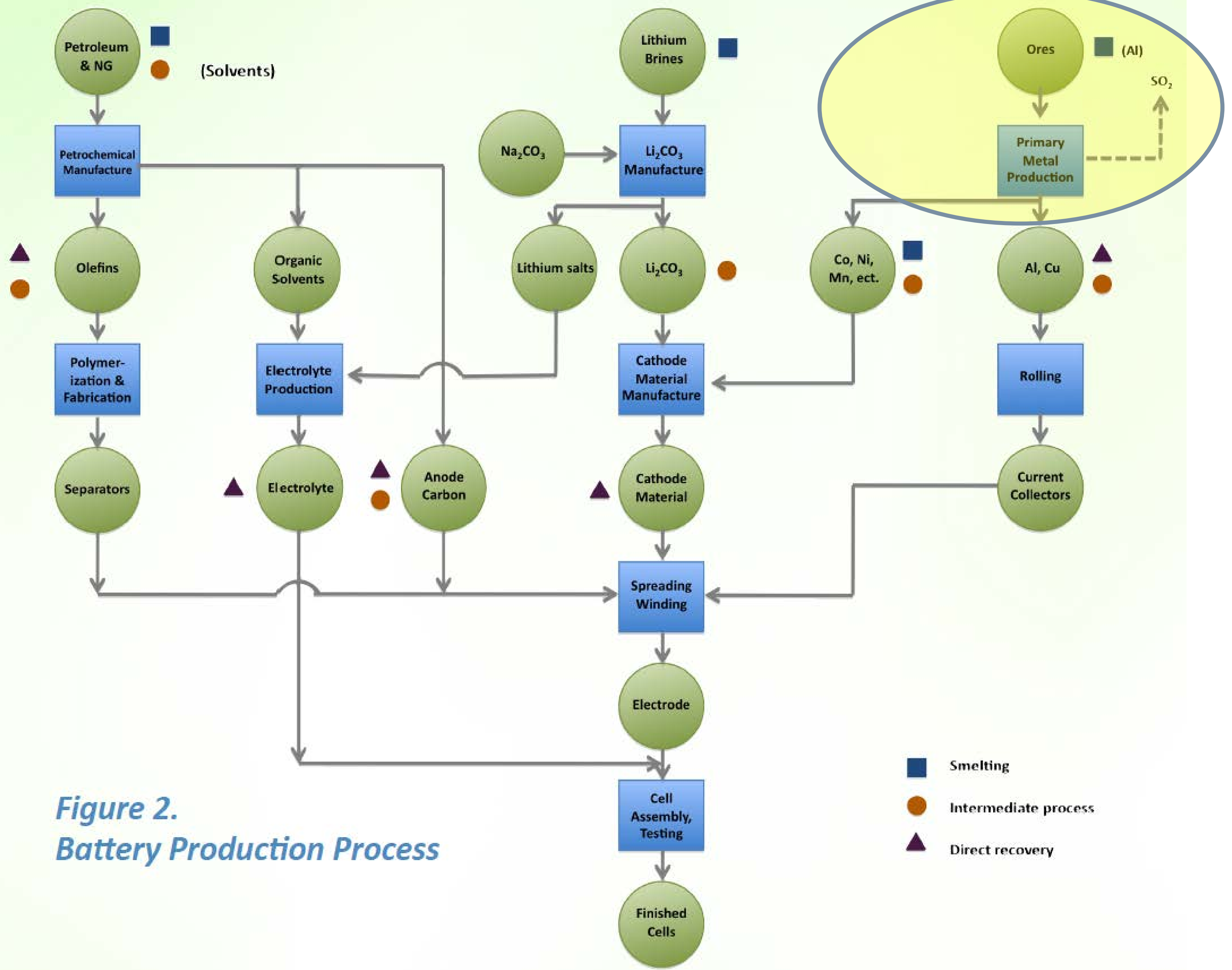
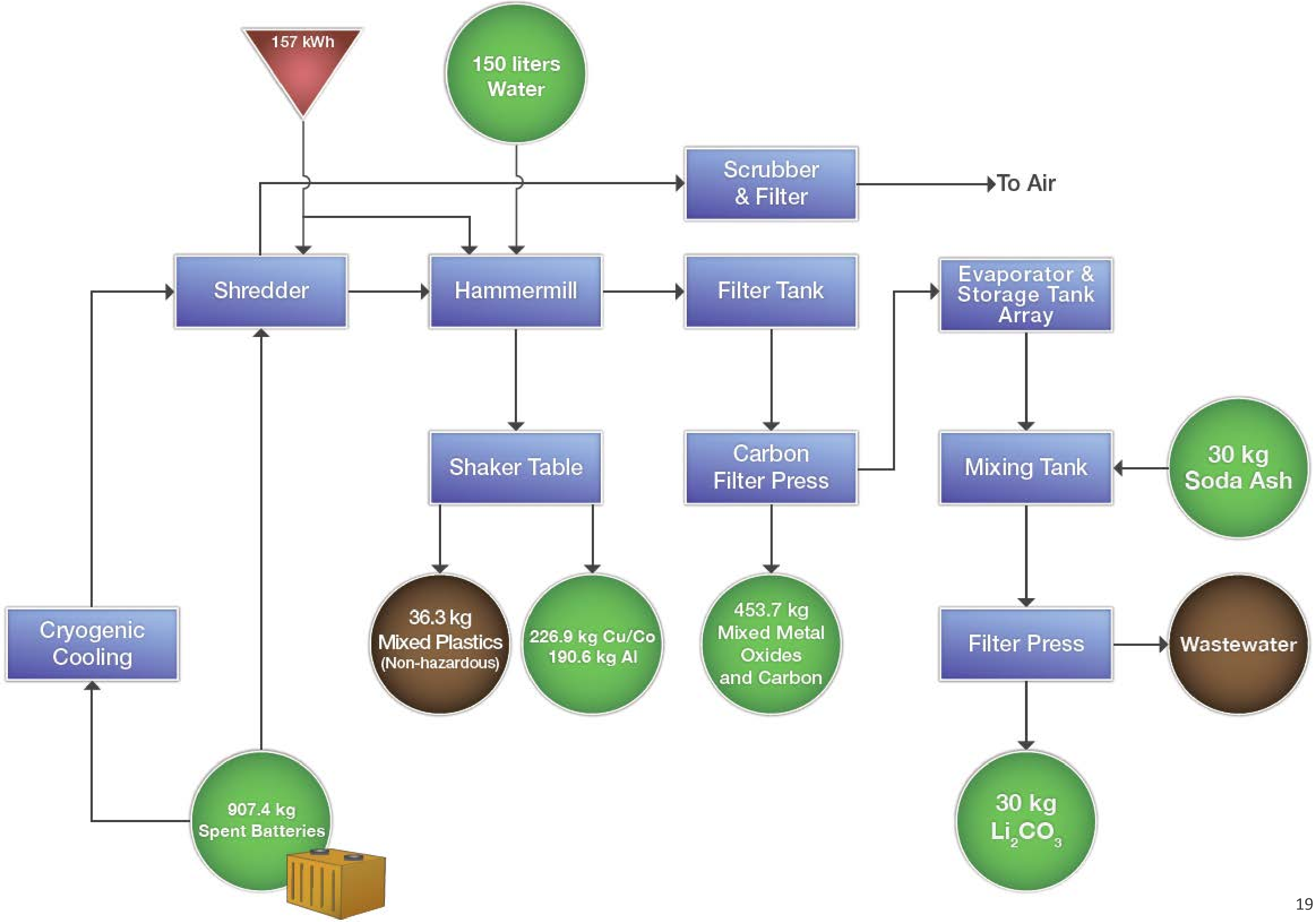
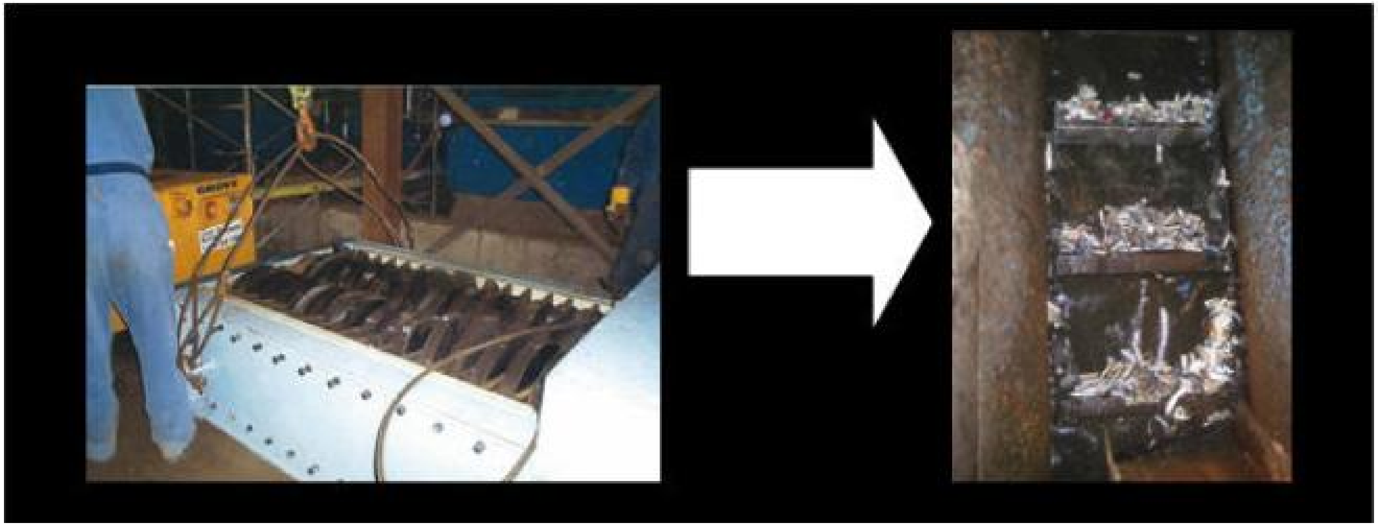



*Figure 2.*
*Battery Production Process*

# Toxco Ohio plant will use improved process to recover lithium as well as metals



# Products are suitable for further processing



Copper cobalt and filter cake products

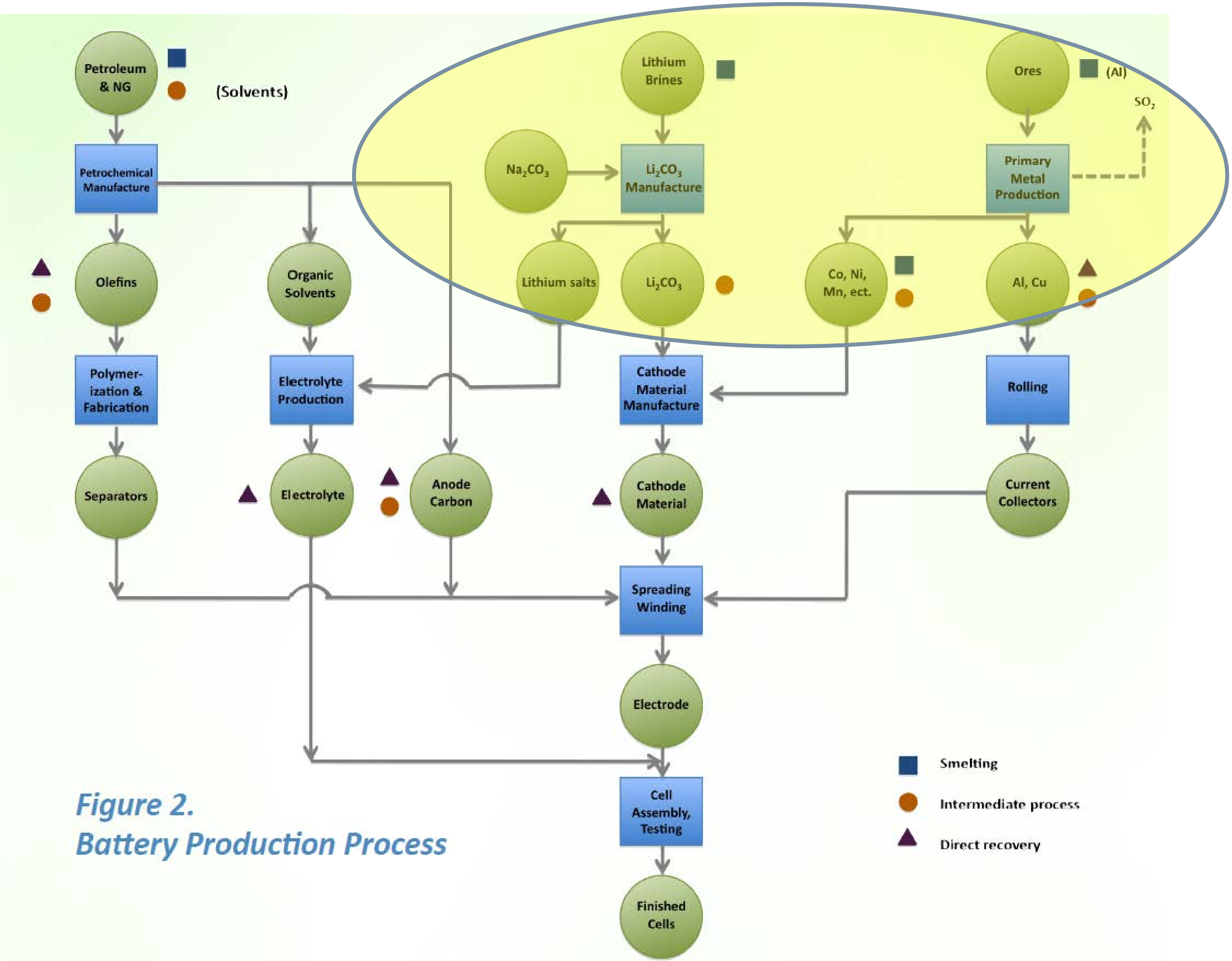
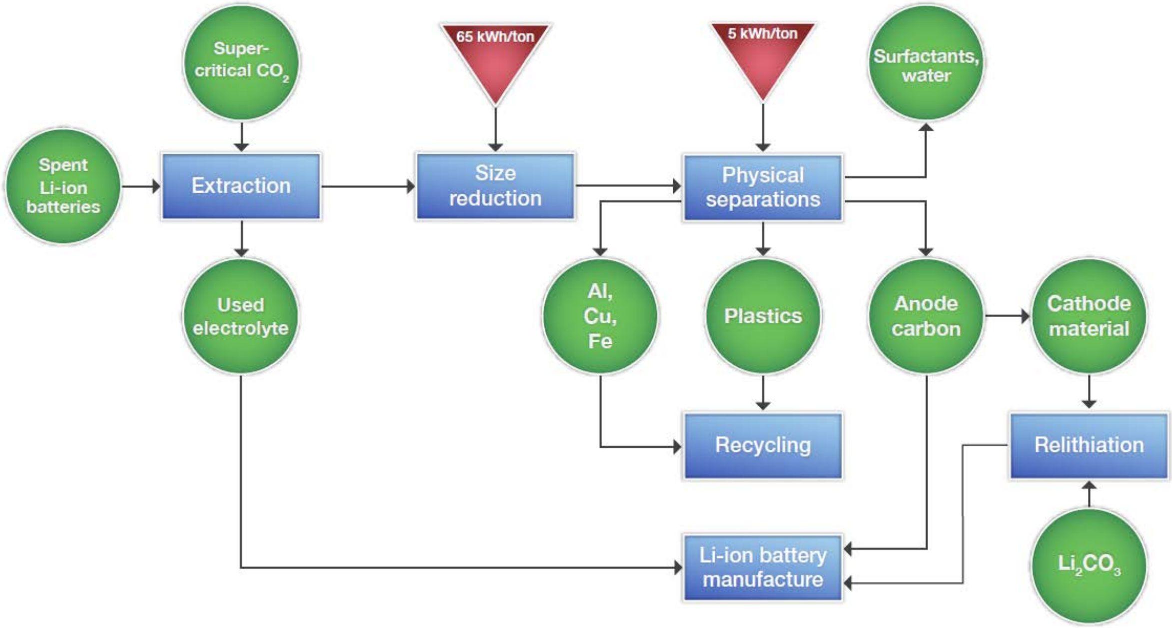



*Figure 2.*
*Battery Production Process*

# Recovery of battery-grade materials avoids impacts of production from raw materials

- **Requires as uniform feed as possible**
- **Components are separated to retain valuable material structure**
  - Costs lower than virgin materials
  - Purify/reactivate components if necessary for new batteries
  - Separator is unlikely to be usable, as form cannot be retained
- **Low-temperature process, low energy requirement**
- **Does not require large volume**



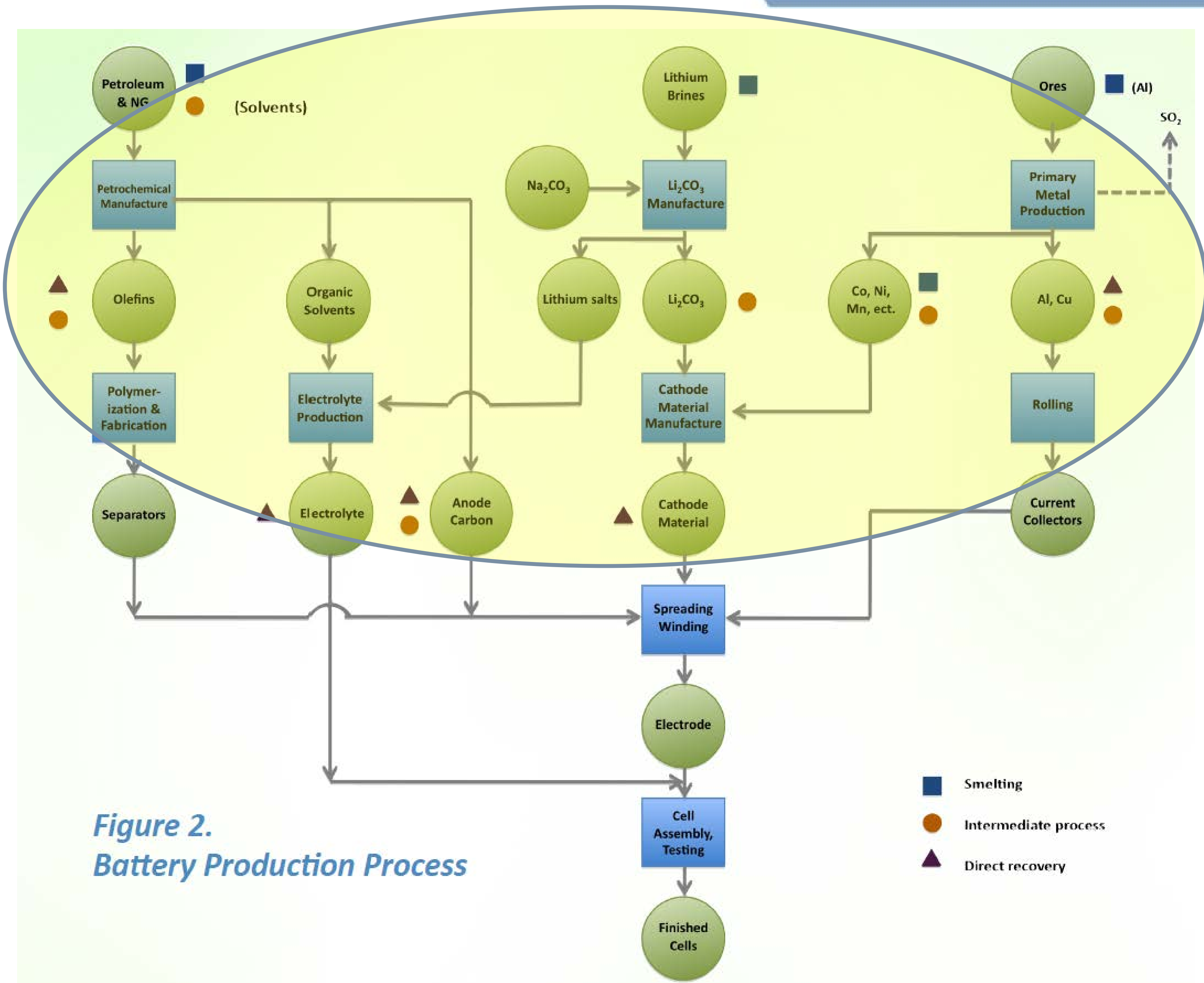



*Figure 2.*
*Battery Production Process*

# 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 at ~$100/gram
  - Recycling process would be cheaper


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

# Battery materials are responsible for only 2% of energy but 20% of life-cycle SOx!

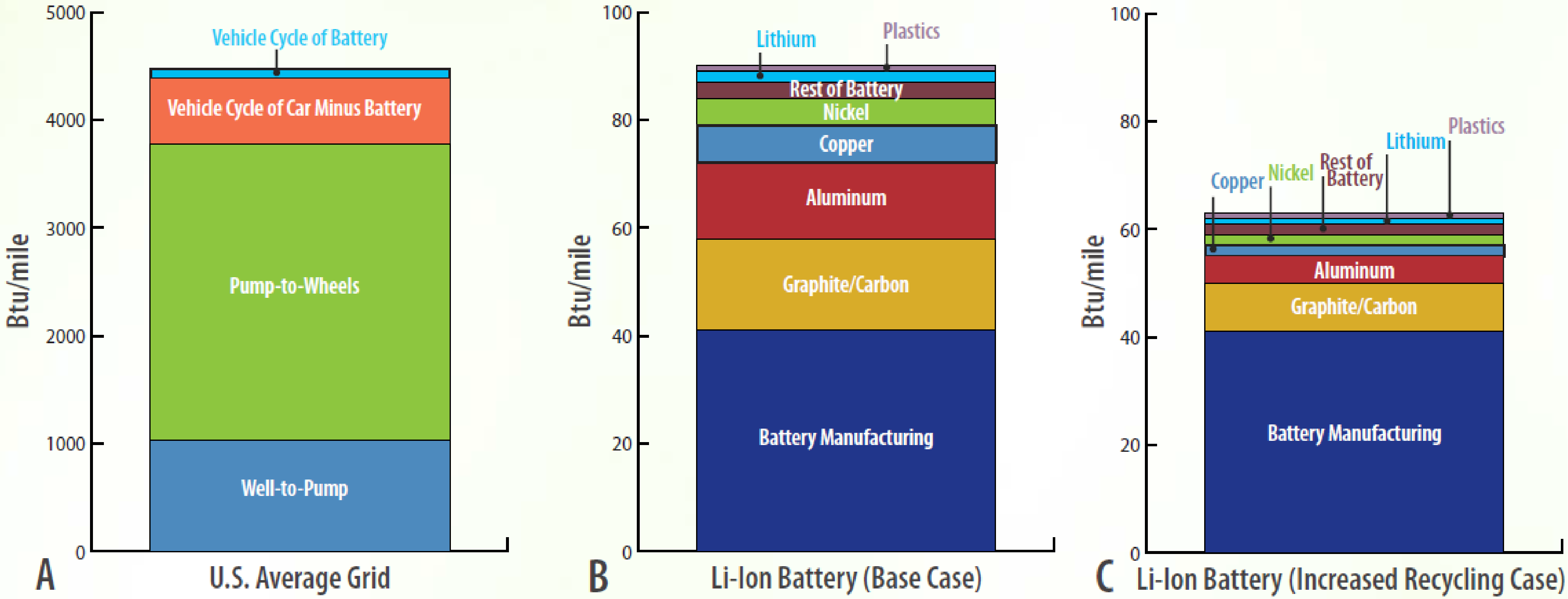
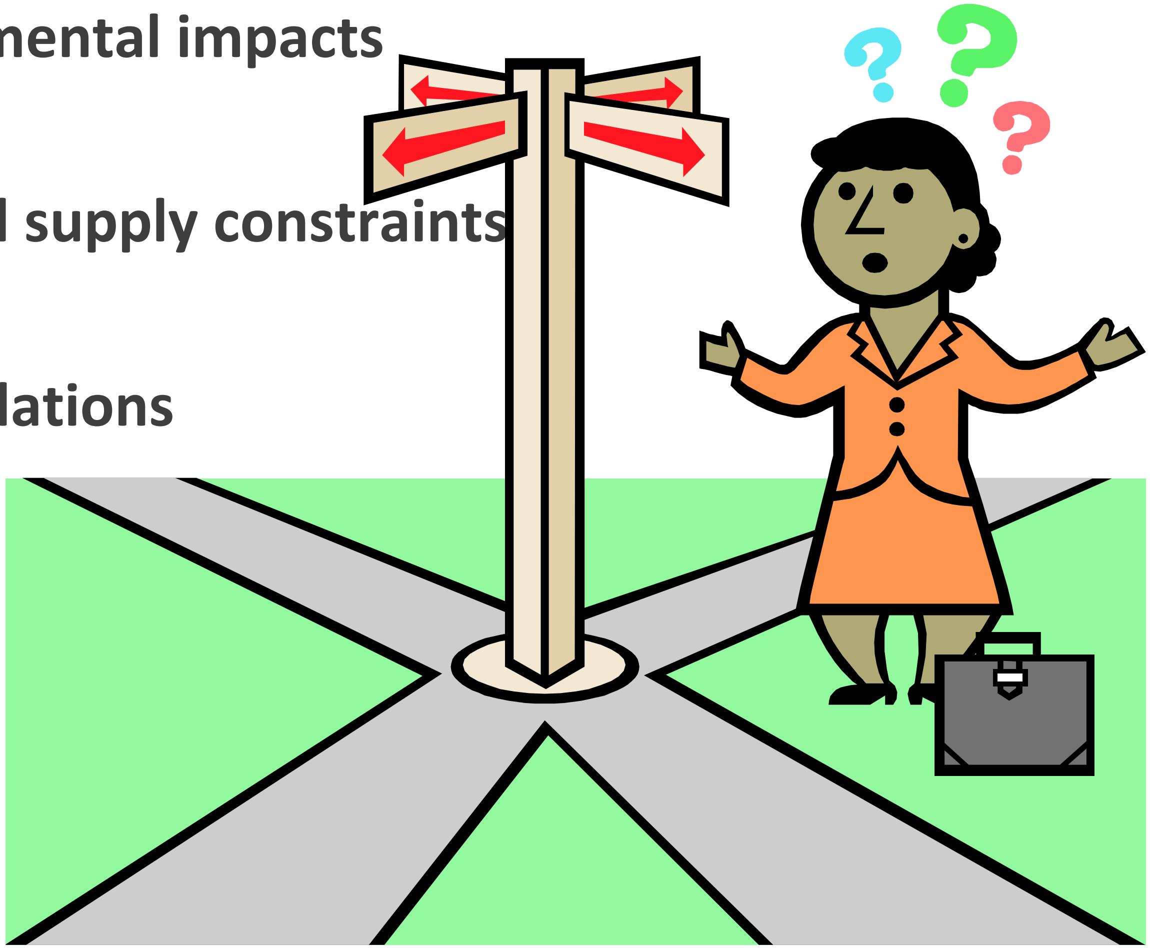



*Figure 3. Life-Cycle Energy Analysis of PHEV20*

***Battery impacts rise with all-electric range.***

# Recycling processes will be compared using several interconnected criteria

- Reduction of environmental impacts
- Energy savings
- Alleviation of material supply constraints
- Economics
- Compliance with regulations
- Feed requirements
- Utility of products
- Scale



# Several strategies could facilitate recycling

- Standard configuration enables design of recycling equipment
- Chemistry standardization reduces need for battery sorting
- Cell labeling enables sorting
- Design for disassembly enables material separation

# Stay tuned for more results. Thank you!

- Co-authors: P. Nelson, J. Sullivan, A. Burnham, and I. Belharouak
- Work sponsored by DOE Office of Vehicle Technologies
- Contact me: lgaines@anl.gov