Lithium-ion Batteries and Nanotechnology for Electric Vehicles: A Life-Cycle Assessment

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Presentation Overview

- Background and Purpose of LCA Study
- Objectives
- Methodology and Data Collection
- Key Results
- Opportunities for Improvement

Project Background

- Previous Design for the Environment Program LCA experience:
  - computer displays
  - lead-free solders
  - wire & cable insulation and jacketing
- Office of Research and Development LCA expertise
  - National Risk Management Research Laboratory: project co-lead and co-funder
- OPPT interest in nanomaterials and responsible development of nano applications
- DOE interest in advanced batteries and electric vehicles

Study Goal and Objectives

- Goals:
  - Conduct an LCA of Li-ion batteries for electric vehicles
  - Assess single-wall carbon nanotube (SWCNT) anode technology for use in next-generation Li-ion batteries
- Objectives:
  - Identify **product improvements** that reduce impacts to human health and the environment
  - Assess potential impacts associated with **nanomaterials**
  - Promote life-cycle thinking for **emerging products**
  - Develop a **benchmark** for future life-cycle assessments
  - Encourage movement toward **energy independence** and **reduced greenhouse gas generation**

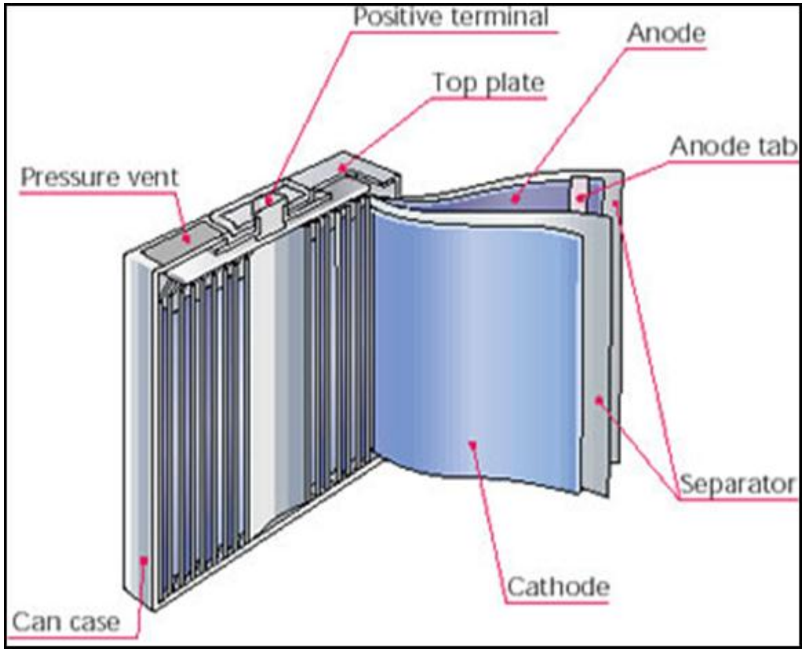
Multi-Stakeholder Partnership

- Battery Manufacturers
  - Electrovaya
  - EnerDel
- Battery Recyclers
  - Kinsbursky Brothers/Toxco
  - Umicore Group
  - RSR Technologies
- Battery Suppliers
  - Novolyte Technologies
- Office of Research and Development, National Risk Management Research Lab
- Office of Air and Radiation, Office of Transportation and Air Quality
- Dept. of Energy, Argonne National Laboratory
- Academia
  - Arizona State University; Rochester Inst. of Technology
- Non-governmental organizations
  - NAATBatt; NextEnergy
- Other
  - Rechargeable Battery Association

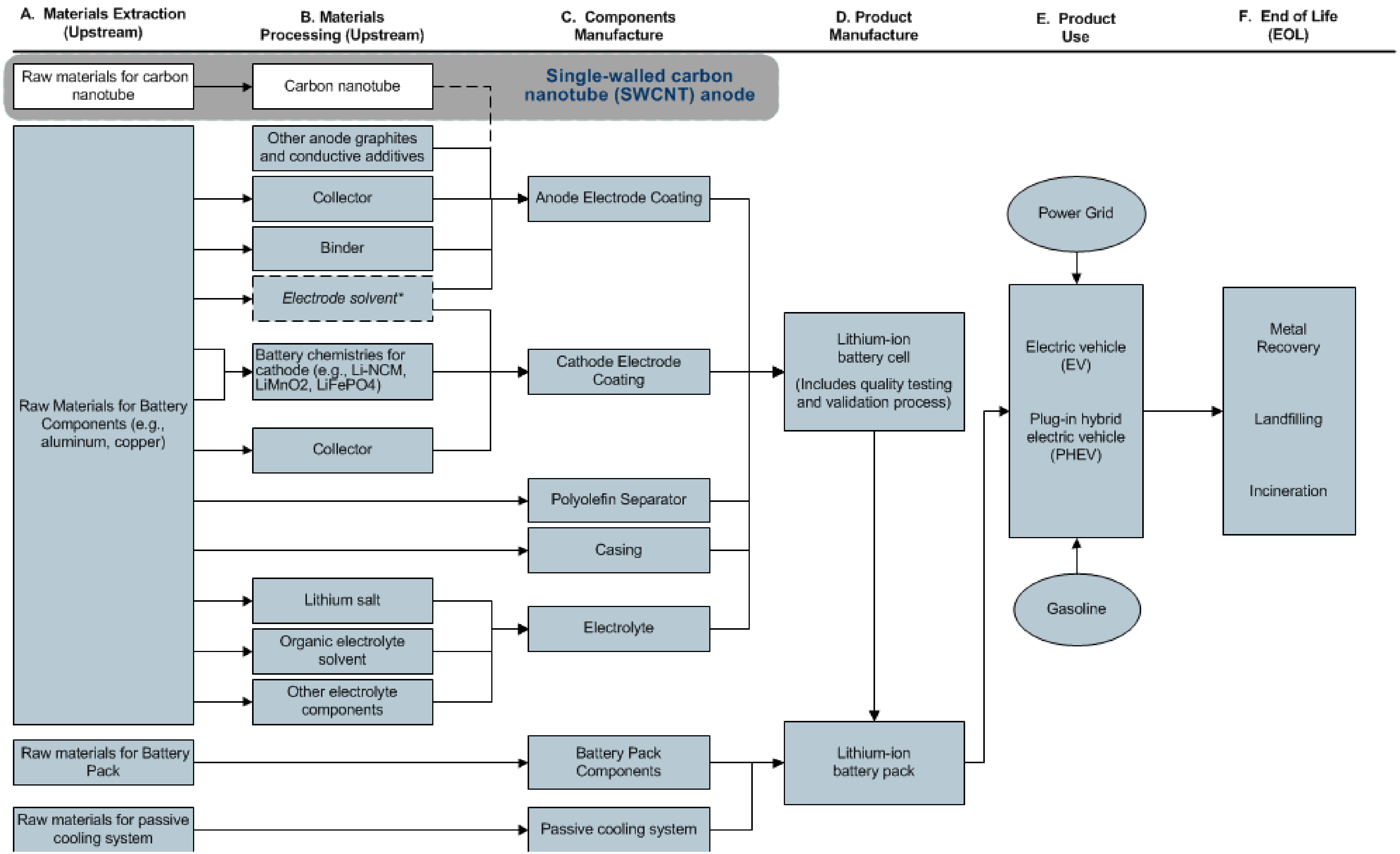
Product System

Li-ion Battery Chemistry	EV	PHEV
Li-manganese oxide-type chemistry ($LiMnO2$)	✓	✓
Li-nickel-cobalt-manganese-oxide ($LiNi0.4Co0.2Mn0.4O2$ or Li-NCM)	✓	
Li-iron phosphate ($LiFePO4$)	✓	✓

Illustration of Prismatic Li-ion Battery Cell (NEC/TOKIN, 2009)



Generic Process Flow Diagram for Li-ion Battery for Vehicles

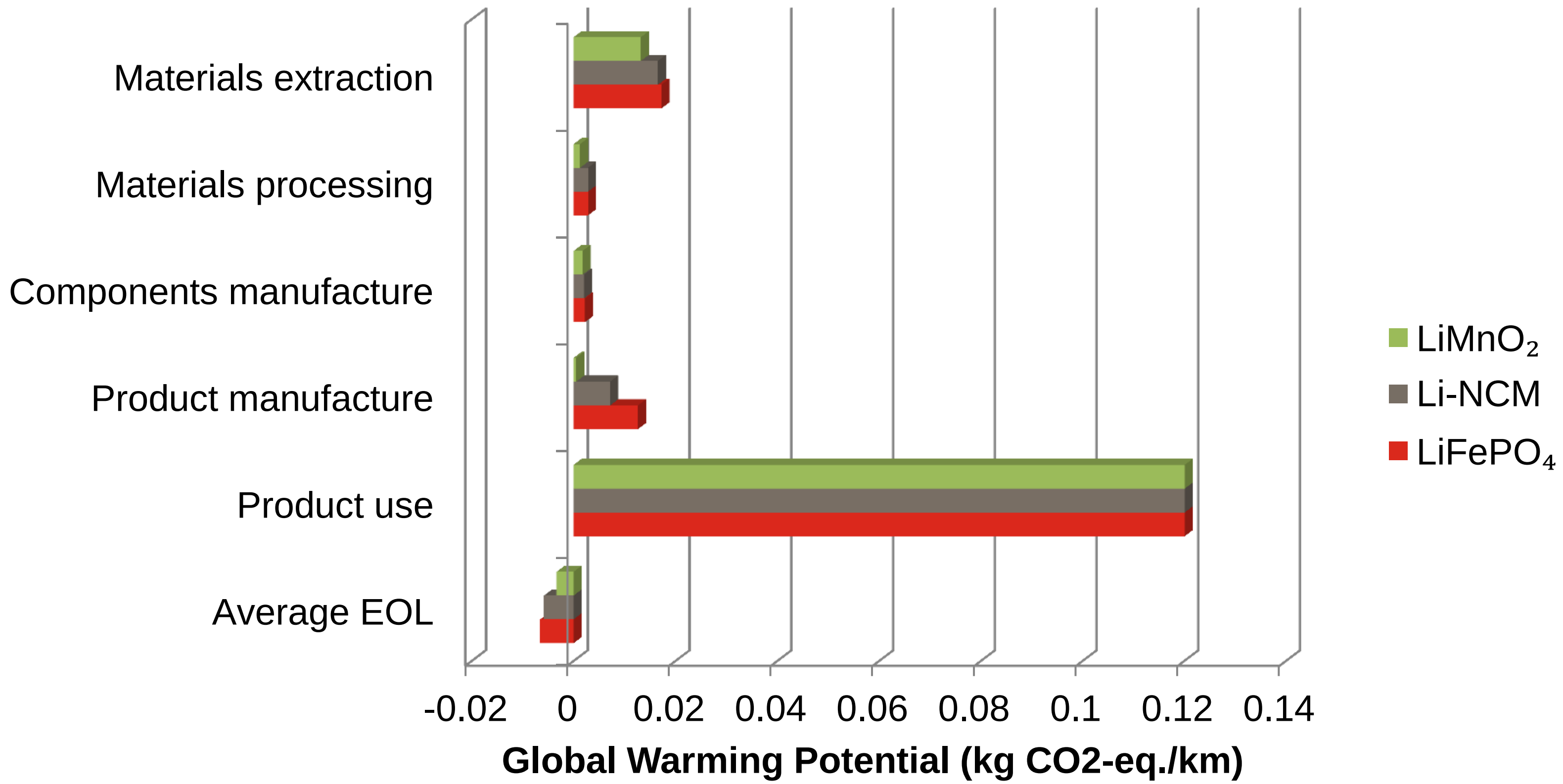


Life-Cycle Impact Assessment

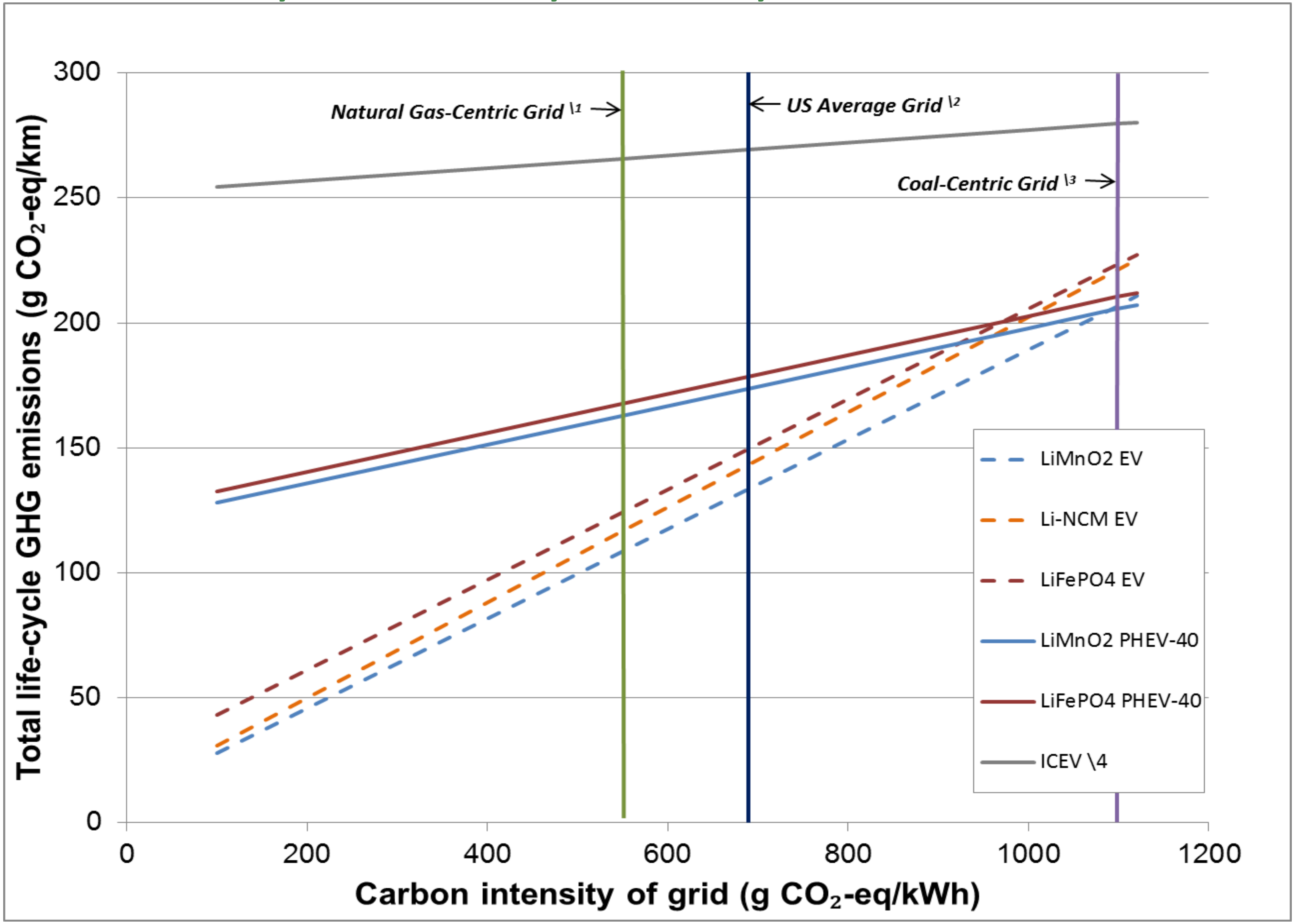
- Material Use and Primary Energy Consumption
- Impact Categories
  - Abiotic resource depletion
  - Global warming potential
  - Acidification potential
  - Eutrophication potential
  - Ozone depletion potential
  - Photochemical oxidation potential
  - Ecological toxicity potential
  - Human toxicity potential
  - Occupation cancer hazard
  - Occupational non-cancer hazard
- Sensitivity Analysis
  - Battery life span (from 10 years to 5 years)
  - Recovery rate of materials in recycling processes
  - Six different charging/grid scenarios

Global Warming Potential

EV Global Warming Potential by Stage and Battery Chemistry



GHG Emissions by Carbon Intensity of Electricity Grid



\1 Based on ISO-NE grid unconstrained charging grid from the Elgowainy et al., 2010 study.

\2 U.S. Average Grid based on EIA, 2010c.

\3 IL smart charging grid from the Elgowainy et al., 2010 study, which relies primarily on coal (over 99 percent).

\4 Internal Combustion Engine Vehicle (ICEV) emissions based on Samaras and Meisterling, 2008.

Key Results

- The use stage is an important driver of battery impacts. Most impacts, including global warming potential (GWP), are greater with more coal-dependent grids
- Cathode active material affects human health and toxicity results (e.g., Co and Ni vs. Mn and Fe)
- Cathode materials all require large quantities of energy to manufacture; Li-NCM requires 1.4 to 1.5 times as much as the other two chemistries
- Cell and battery casing and housing materials (steel or aluminum) are significant contributors to upstream and manufacturing stage impacts

Key Results

- Both EVs and PHEV-40s present significant benefits in GWP, compared to internal combustion engine vehicles, regardless of the grid's carbon intensity, based on battery use
- Recovery of materials (including Li) in the end-of-life (EOL) stage significantly reduces overall life-cycle impacts
- SWCNT anodes made by laser vaporization consume electricity orders of magnitude greater than battery-grade graphite anodes
- Both battery partners are researching the use of nano-based anodes within battery cells

Opportunities for Improvement

- **Reduce cobalt and nickel material use** (or exposure in the upstream, manufacturing, and EOL stages), to reduce overall potential toxicity impacts
- **Consider using a solvent-less or water based process** in battery manufacturing
- **Reduce the percentage of metals by mass** for the passive cooling system, BMS, pack housing and casing
- **Reassess manufacturing process and upstream materials selection** to reduce primary energy use for cathode
- **Incorporate recovered material** (especially metals) in the production of the battery to rely less on virgin materials upstream
- **Increase the life-span** of the battery to at least 10 years
- Look for ways to **produce SWCNT more efficiently**, to be able to realize energy efficiency gains in the use stage

Ideas for Future Research

- Broaden scope to conduct **full vehicle LCA study**
- Assess **changes to the grid** as a result of large increase in demand from PHEVs and EVs (e.g., use of more renewables, energy storage systems, new power plants)
- Assess **electricity and fuel use from battery manufacturers**, to address highly variable manufacturing methods, including those that use water and those that operate without solvent
- Assess **differences between battery chemistries and sizes** for different vehicles, including how these differences may impact the lifespan
- Assess whether the **use of certain lightweight materials** that generate high impacts upstream are mitigated during the use stage (e.g., aluminum)
- Assess **recycling technologies** as stream of Li-ion batteries for vehicles increases and the technologies evolve
- Additional **research on SWCNTs and other nanomaterials**, especially through component suppliers

CONTACT INFORMATION:

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Website Link: http://epa.gov/dfe/pubs/projects/lbnp/index.htm

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