U.S. Department of Energy
Energy Efficiency and Renewable Energy

Hybrid and Vehicle Systems

International Collaboration

With a Case Study in

Assessment of World's Supply of Lithium

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This presentation does not contain any proprietary, confidential, or otherwise restricted information.

This will be a joint presentation with Dr. Linda Gaines of Argonne National Laboratory.

Overview

- International collaboration includes membership in the **International Energy Agency's (IEA) Implementing Agreement on Hybrid and Electric Vehicles (IA-HEV)**
  - The IA-HEV was organized in 1994.
  - A new 5-year phase will begin in 2010.
- IA-HEV works to facilitate exchange of information and to address specific issues and questions.

International Energy Agency

- The IEA (International Energy Agency) is a Paris based organisation of 26 Governments interested in energy issues
- The IEA has 40 different technical groups that address specific topics.
  - These are called Implementing Agreements (IA)
  - Each IA has its own membership and organizational structure.
  - Most IAs conduct their technical activities through working groups called Annexes.

IEA INTERNATIONAL ENERGY AGENCY
HYBRID & ELECTRIC VEHICLE IMPLEMENTING AGREEMENT

Agreement Addresses All Aspects of HEVs, PHEVs and EVs

Member Countries:

- Austria
- Belgium
- Canada
- Denmark
- Finland
- France
- Italy
- Netherlands
- Sweden
- Switzerland
- Turkey
- United Kingdom
- United States

Internet site is www.transportation.anl.gov/ia_hev

Annexes of IA-HEV

The IA-HEV Annexes 1994-2008 (Active ones in **Bold)**:

- **Information Exchange (Annex I)**
- Environment Issues of EVs and components (Annex II)
- Infrastructure of electric vehicles (Annex III)
- Batteries and super capacitors (Annex V)
- Hybrid Vehicles (Annex VII)
- Deployment Strategies (Annex VIII)
- Clean City Vehicles (Annex IX)
- **Electrochemical Systems (Annex X)**
- **Electric cycles (Annex XI)**
- **Heavy-Duty Hybrid Vehicles (Annex XII)**
- **Fuel Cells for vehicles (Annex XIII)**
- **Market Deployment – Lessons learned (Annex XIV)**
- **Plug-in Hybrid Vehicles (Annex XV)**

- The U.S. is a member of most active annexes.

Example of Annex Activities

- **Annex X, Electrochemistry,** in conjunction with **Annex XV, Plug-In Hybrid Vehicles** organized and hosted a meeting on the **World's Supply of Lithium.**
- The meeting was held in Charlotte, North Carolina, USA in early December 2008.

Why This Topic?

- There has been much discussion in the news and on the internet as to whether there is enough lithium in the world to allow for the production of a significant number of vehicles using lithium-ion batteries.
- This assertion has provoked concern in a variety of organizations.
- The Annex meeting was to collect data on the issue.

Attendees

- Attendees included the following:
  - Governments and national laboratories:
  - Universities
  - Lithium suppliers from North and South America
  - Battery manufacturers
  - Vehicle manufacturers
  - Battery Recycling Industry
- Over 25 attended.

Topics Discussed

- Current supply of lithium
- Potential sources of lithium, not now being exploited
- Current uses of lithium
- Impact of HEVs, PHEVs and EVs on lithium market
- Impact of recycling on lithium supply

Brief Conclusions

- The world's current production capacity for lithium exceeds current demand.
- Current production capacity can be increased significantly.
  - Increasing capacity at a given site can require several years.
- Lithium reserves exist around the world
  - Europe
  - North America
  - South America
  - Asia

Brief Conclusions (cont.)

- The technology for exploiting most of the world's reserves exists.
  - Some reserves may require technologies that are marginally more expensive than the brine-based technologies used today.
- As lithium-ion batteries are used in more vehicles, recycling of lithium metal and lithium compounds could become a significant part of the supply stream.
  - About 85% of the lead in lead/acid batteries is recycled.

Brief Conclusions (cont.)

- The world's supply of lithium is sufficient to allow for the use of lithium-ion batteries in all appropriate HEVs, PHEVs, and EVs likely to be produced in the next several decades.
  - Some HEVs will not use lithium-ion batteries.
    - Micro (Stop/Start) hybrids will probably use lead/acid batteries.

- Dr. Gaines has studied this issue in more detail.
- She presented some of her work at the December meeting.

Lithium-Ion Battery Supply Issues

(Extract from a Poster Presentation Scheduled for May 21, 2009)

Linda Gaines

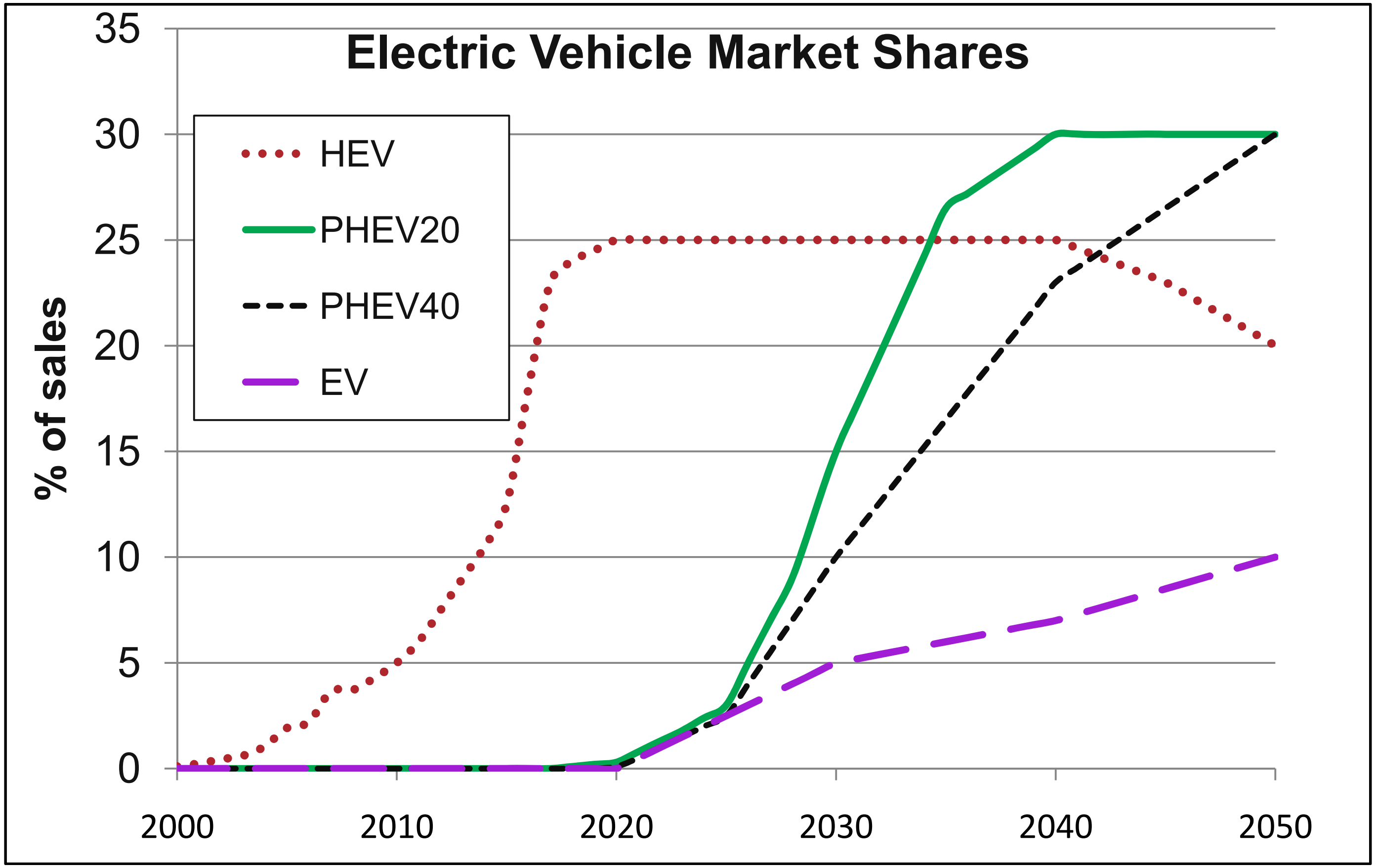
Argonne National Laboratory

Objectives of this Study

- Estimate material demands for Li-ion batteries
  - Identify any potential scarcities
- Calculate theoretical potential for material recovery
- Evaluate real potential for recovery using current recycling processes
- Determine potential for recovery via process development
- Develop improved process(es) to maximize material recovery

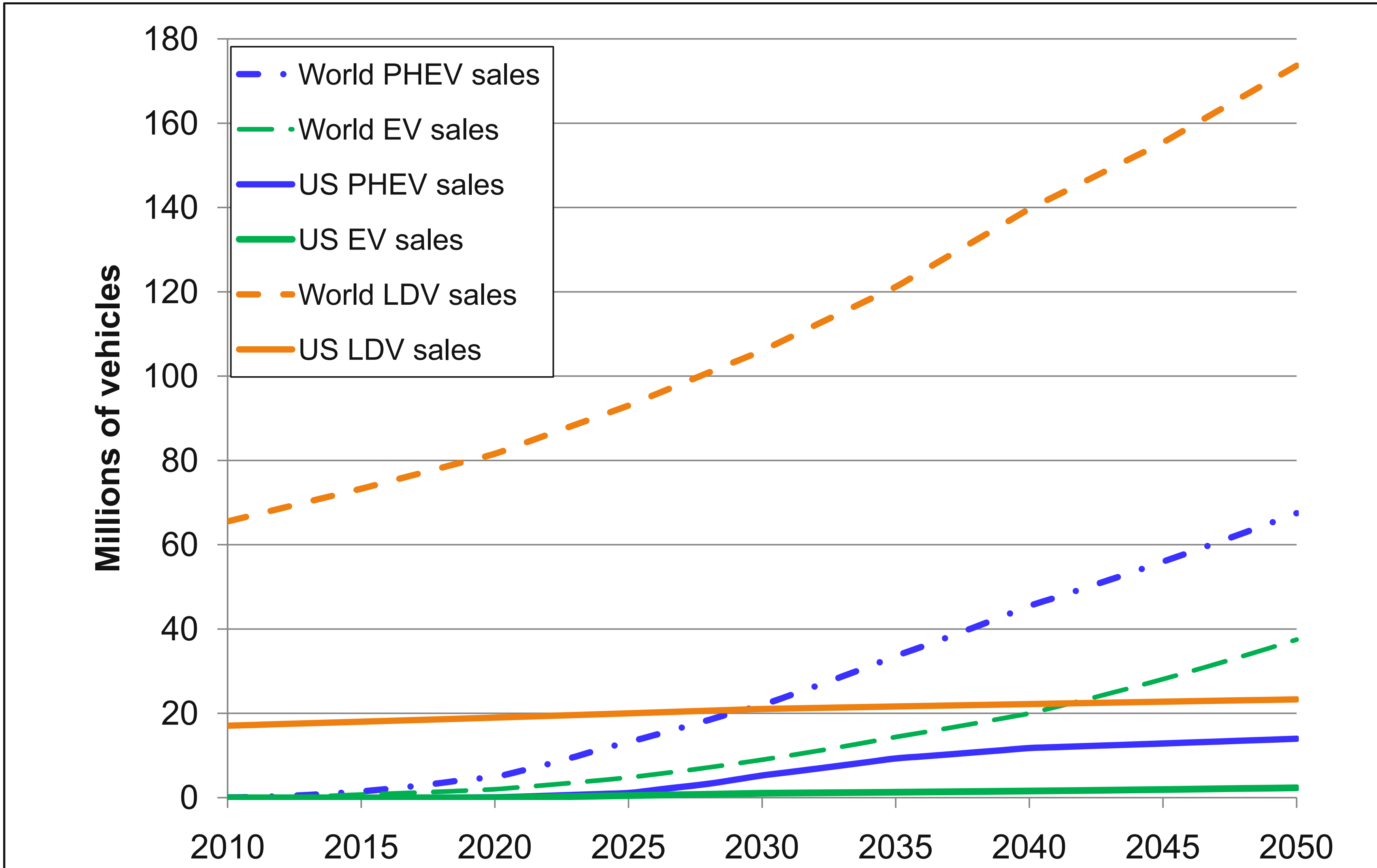
How many vehicles might have electric drive?

We chose an optimistic market penetration scenario



Source: Multipath Study Phase 1, Maximum Electric Scenario, http://www1.eere.energy.gov/ba/pba/pdfs/multipath_ppt.pdf

World light-duty vehicle sales will grow faster than U.S. LDV sales and could have higher percent EVs



Source for world data: IEA scenario draft

What kind of batteries might be used?

System → Electrodes ↓	NCA Graphite	LFP (phosphate) Graphite	MS (spinel) Graphite	MS TiO
Positive (cathode)	$LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$	$LiFePO_4$	$LiMn_2O_4$	$LiMn_2O_4$
Negative (anode)	Graphite	Graphite	Graphite	$Li_4Ti_5O_{12}$

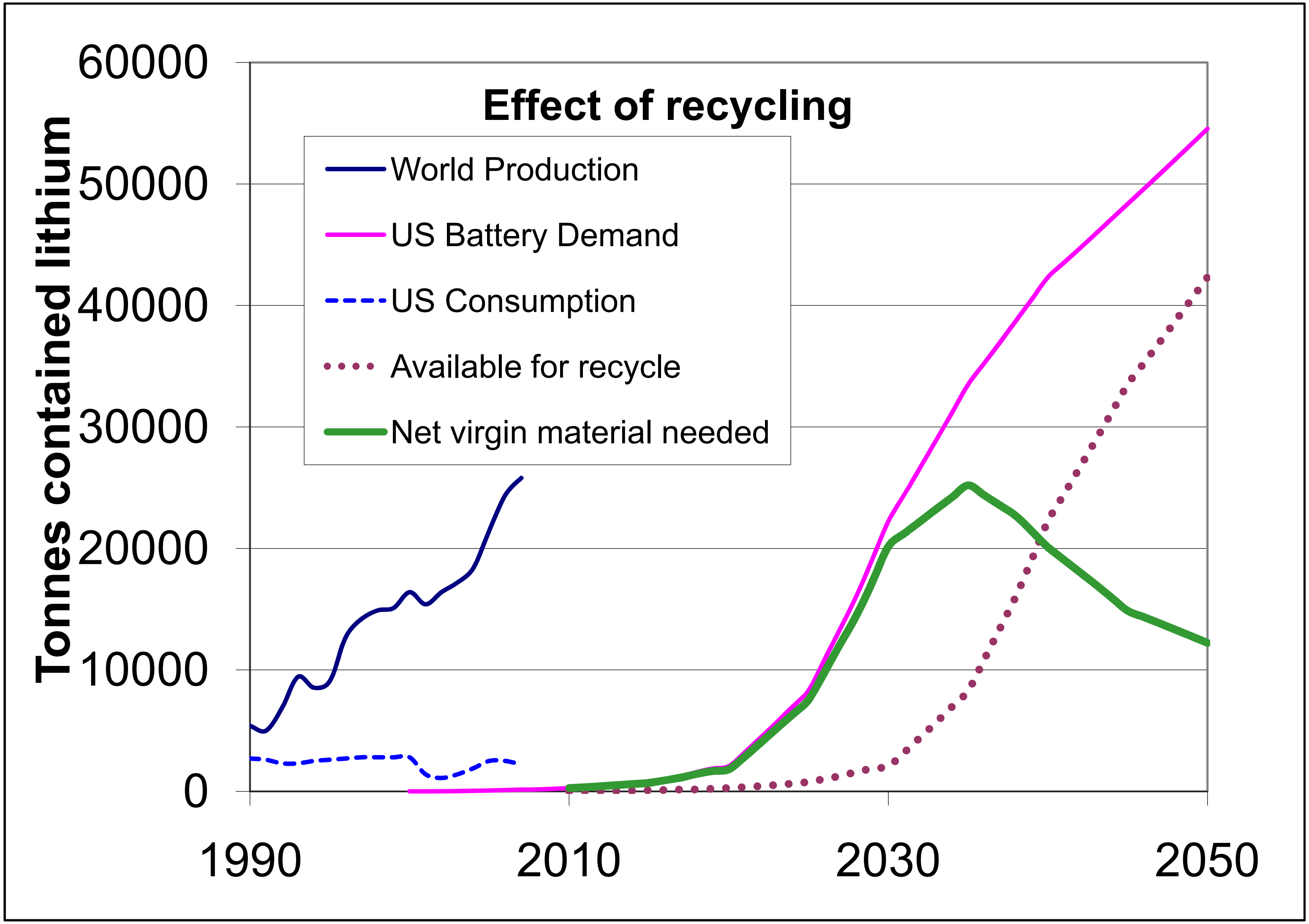
- We considered four battery chemistries
- All contain lithium in cathode
- One uses lithium in anode as well
- Electrolyte contains lithium salt ($LiPF_6$) in solution

How much lithium would each battery use?

- Total is sum of Li from cathode, electrolyte, and anode (for titanate)
- Mass estimates were scaled up for light trucks

Battery Type	NCA-G				LFP-G				LMO-G				LMO-TiO			
Auto range (mi) at 300 Wh/mile	4	20	40	100	4	20	40	100	4	20	40	100	4	20	40	100
Li in cathode (kg)	0.34	1.4	2.8	6.9	0.20	0.80	1.6	4.0	0.15	0.59	1.18	3.0	0.29	1.2	2.3	5.8
Li in electrolyte (kg)	0.04	0.10	0.20	0.55	0.045	0.14	0.26	0.66	0.03	0.09	0.17	0.43	0.05	0.17	0.34	0.85
Li in anode (kg)	0	0	0	0	0	0	0	0	0	0	0	0	0.30	1.21	2.4	6.1
Total Li in battery pack (kg)	0.37	1.5	3.0	7.4	0.24	0.93	1.9	4.7	0.17	0.67	1.4	3.4	0.64	2.5	5.1	12.7

How much lithium would be needed each year?
Recycling can drastically reduce lithium demand

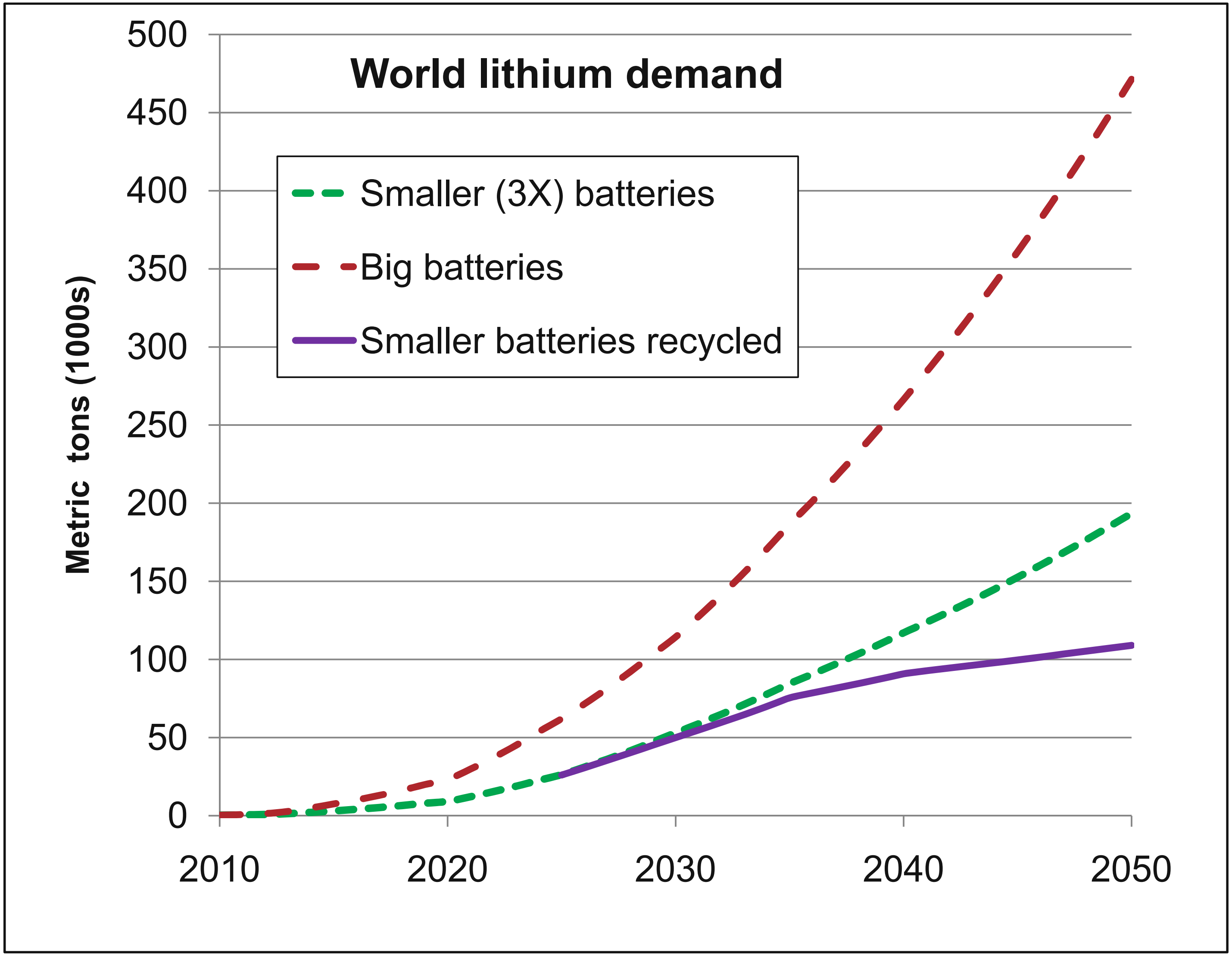


World demand is highly uncertain

- Lithium demand per vehicle depends on battery size
  - What size car? Or is it a bicycle?
  - What range? Is extra range built in?
  - EV or PHEV?
  - Incentives can favor models with lowest impacts

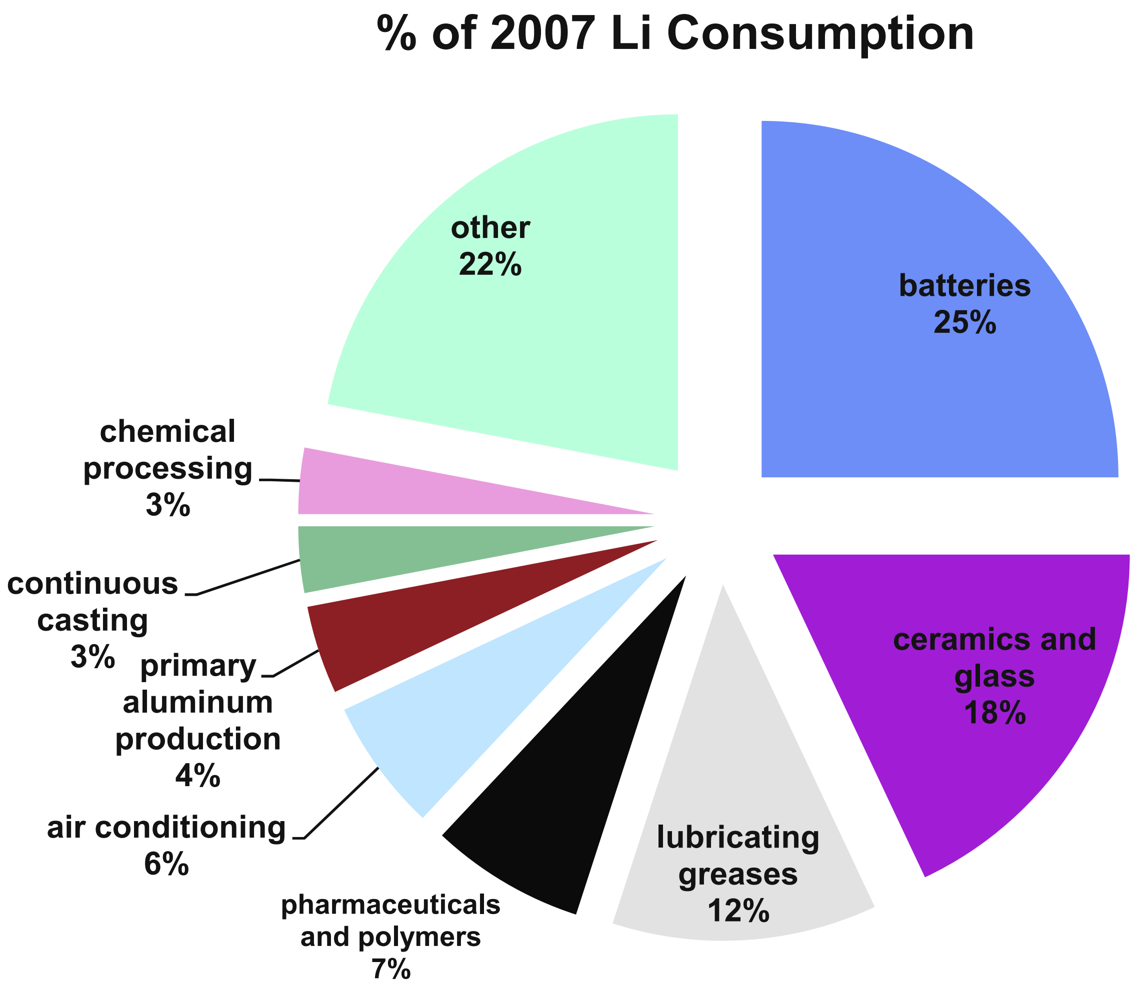
- Need for new supplies can be substantially reduced by recycling
  - Rapid early demand growth implies rapid early recovered material echo
  - Recovered material often ignored when projecting supply

Recycling with smaller batteries reduces world demand in 2050 from 20X current demand to 4X



IEA assumed 12-18 kWh batteries

How does the demand compare to the resource available?
Batteries make up 25% of lithium use and growing fastest



Source: SQM, cited in 2007 USGS Minerals Yearbook

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
USGS Reserves	4,100
USGS Reserve Base	11,000
Other Reserve Estimates Presented at IA-HEV meeting in 2008.	30,000+

Summary:
Lithium-ion batteries can provide a bridge to the future

- Lithium demand can be met, even with rapid growth of electric drive
  - Scenarios extended to 2050
  - Better batteries, additional exploration could extend supply
  - New technologies are likely in the next 40 years
- Cobalt supply and price will reduce importance of NCA-G chemistry
- Recycling must be an important element of material supply
  - Economics
  - Regulations
- Material recovered must be maximized