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Lithium-Ion Battery Recycling Issues

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May 21, 2009

Project ID: pmp_05_gaines

U.S. Department of Energy

UChicago Argonne LLC

A U.S. Department of Energy laboratory managed by UChicago Argonne, LLC

Overview

Timeline

- Start: spring 2008
- Completion: fall 2011
- 15% complete

Budget

- Total project funding
  - 100% DOE funding
- FY09 funding $300K
- FY08 funding $50K

Barriers

- Scarcity could increase costs for battery materials
  - Recycling is an excellent way to increase effective material supply and keep costs down
  - Current processes recover cobalt, use of which will decline

Partners

- New project
- Project lead: Argonne

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

Milestones: Lithium-Ion Battery Recycling Issues

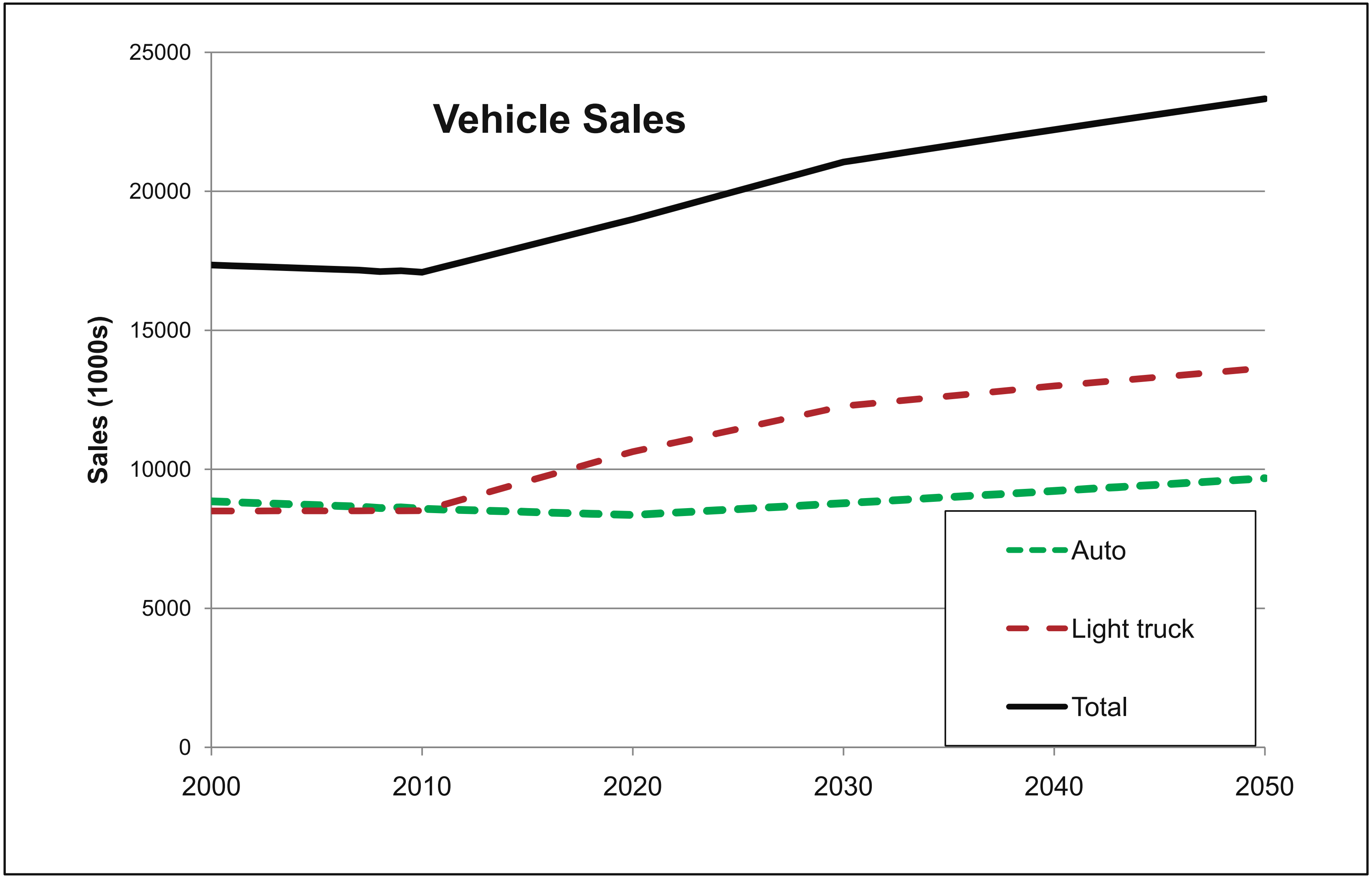
- FY2008
  - Present project plan to DOE *completed*
  - Select promising battery chemistries *completed*
- FY2009
  - Design battery packs for each chemistry and vehicle type *completed*
  - Estimate materials use for optimistic EV demand scenario *completed*
  - Compare US and world lithium demand to reserves *completed*
  - Present lithium demand estimates at battery conference *completed*
  - Determine current production methods for lithium *completed*
  - Characterize current battery recycling processes 3Q
  - Determine current production methods for other materials 4Q
- FY2010
  - Estimate impacts of current recycling processes 1Q
  - Estimate energy use/emissions for current material processes 1Q
  - Estimate energy use/emissions for current battery processes 2Q
  - Report on production and recycling of Li-ion batteries 3Q
  - Evaluate alternative strategies for additional material recovery 4Q
- FY2011
  - Begin development of improved recycling processes 1Q

Approach:
We answer these questions to address material supply issues

- How many vehicles will be sold in the US and world-wide?
  - How many of them might have electric drive?
- What kind of batteries might be used?
  - How much lithium would each battery use?
- How much lithium would be needed each year?
  - How much difference can recycling make?
- How does the demand compare to the available resources?
- Are there possible constraints on other key material supplies?

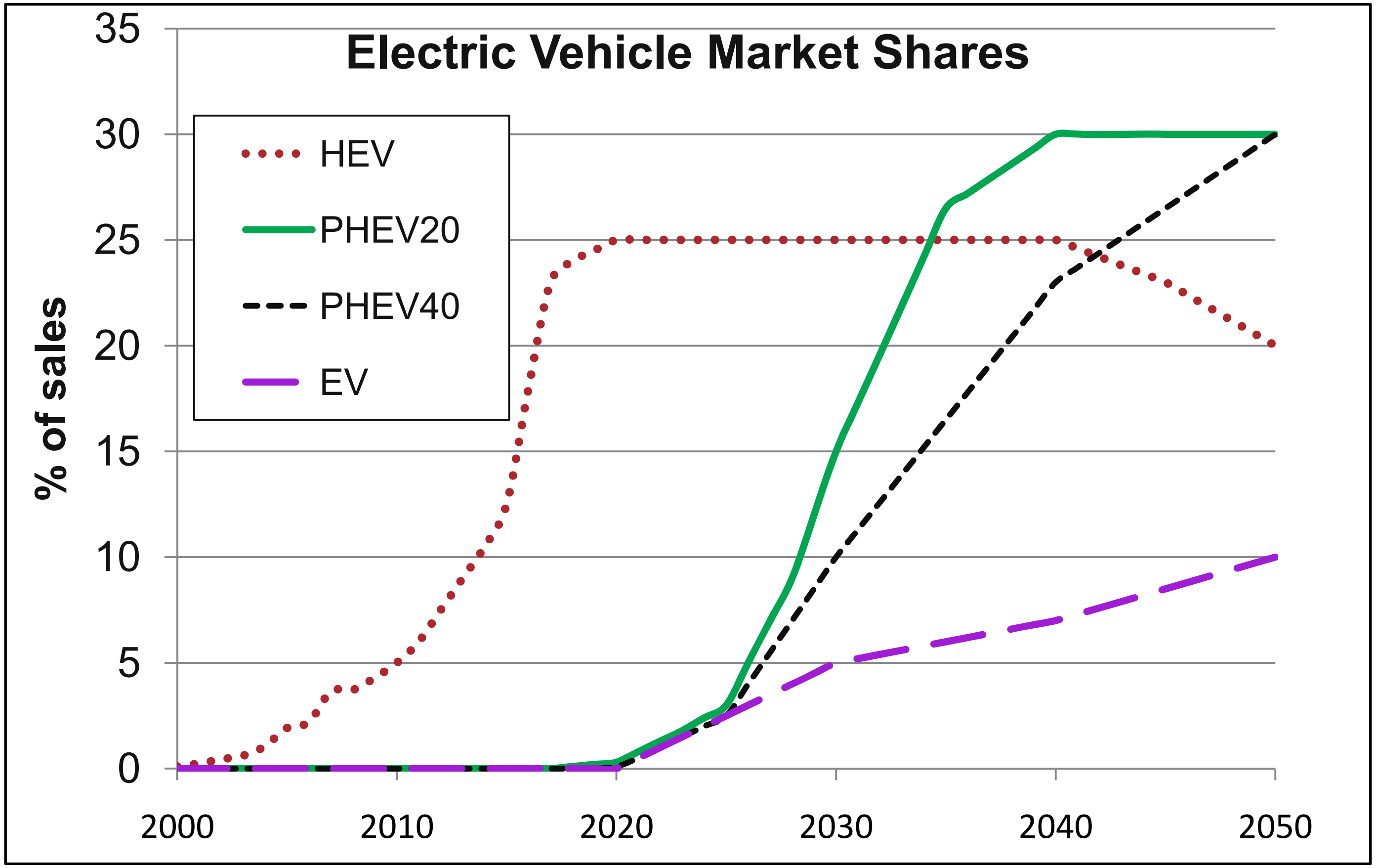
Technical Accomplishments

How many light-duty vehicles will be sold in the U.S.?



How many of them might have electric drive?

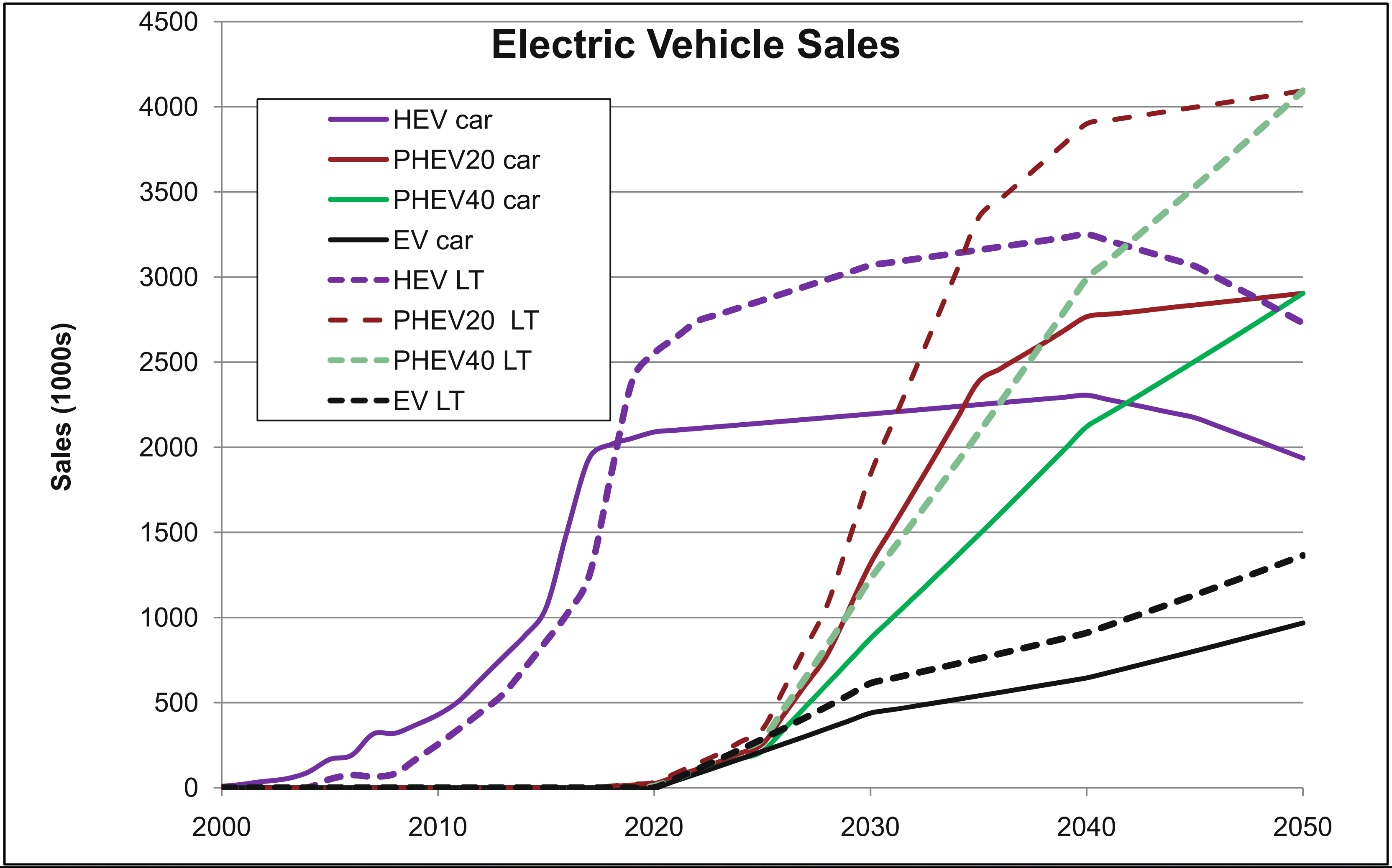
We chose an optimistic market penetration scenario



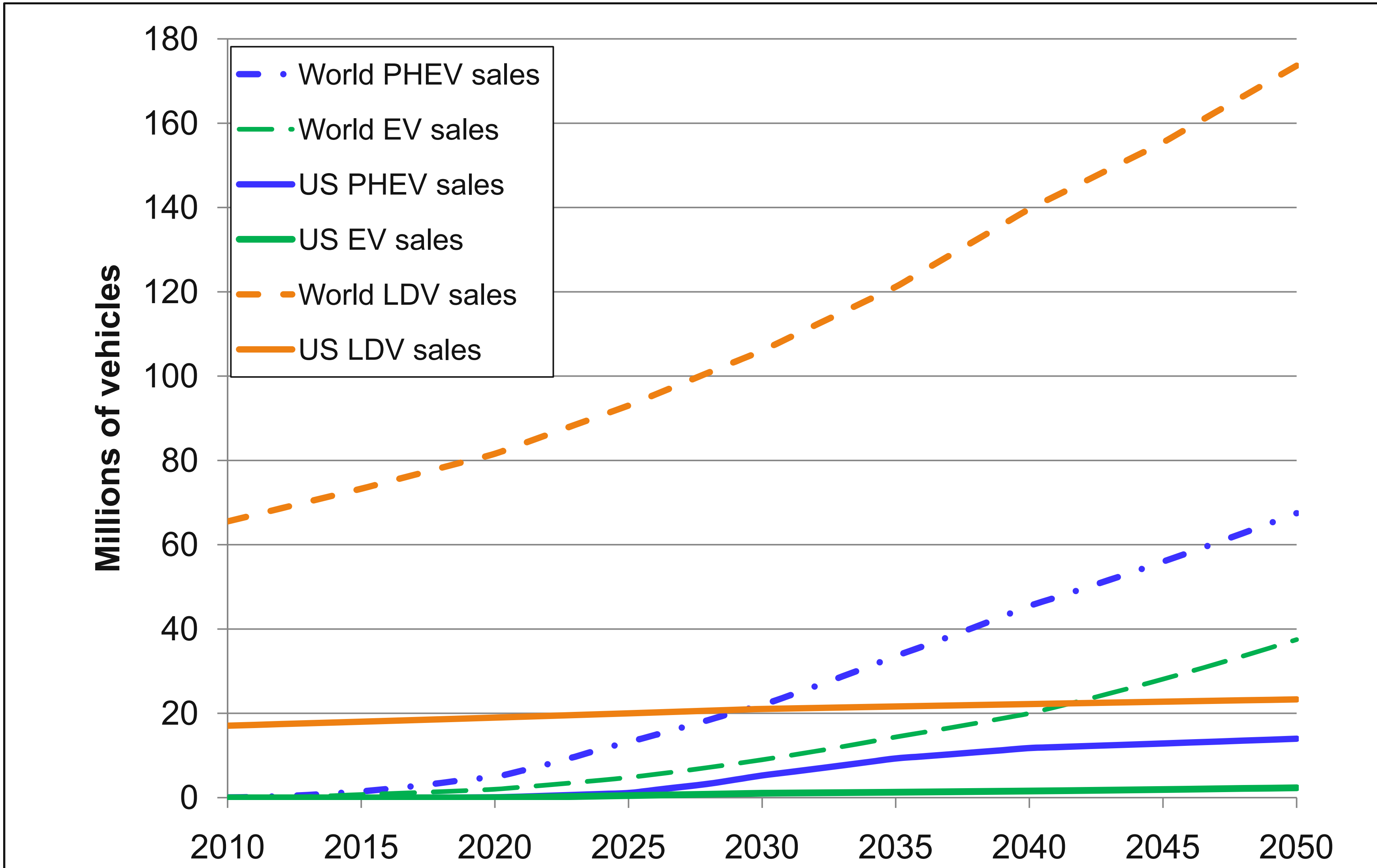
Source: Multipath Study Phase 1, Maximum Electric Scenario, http://www1.eere.energy.gov/ba/pba/pdfs/multipath_ppt.pdf

We used sales and penetration to calculate U.S. sales by type

- Total annual sales in 2050 are 21 million
- Cumulative total is 465 million



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

Four batteries were designed for each of 4 automobile ranges

Battery Type	NCA-G				LFP-G				LMO-G				LMO-TiO			
Vehicle Range(mi) at 300 Wh/mile	4	20	40	100	4	20	40	100	4	20	40	100	4	20	40	100
Materials Composition (g/cell)																
Cathode (+) active material	77	314	635	635	74	302	609	609	63	255	514	514	125	502	1,003	1,003
Anode (-) active material	51	209	423	423	51	208	419	419	42	170	342	342	83	334	669	669
Electrolyte	50	149	287	287	64	194	376	376	41	124	242	242	69	239	477	477
Total cell mass (g)	424	1088	2043	2043	471	1162	2170	2170	347	888	1671	1671	483	1534	3062	3062
Cells per battery pack	60	60	60	150	60	60	60	150	60	60	60	150	60	60	60	150
Battery mass (kg)	31	76	140	350	35	82	150	376	26	63	115	289	36	106	209	523

Source: P. Nelson, ANL

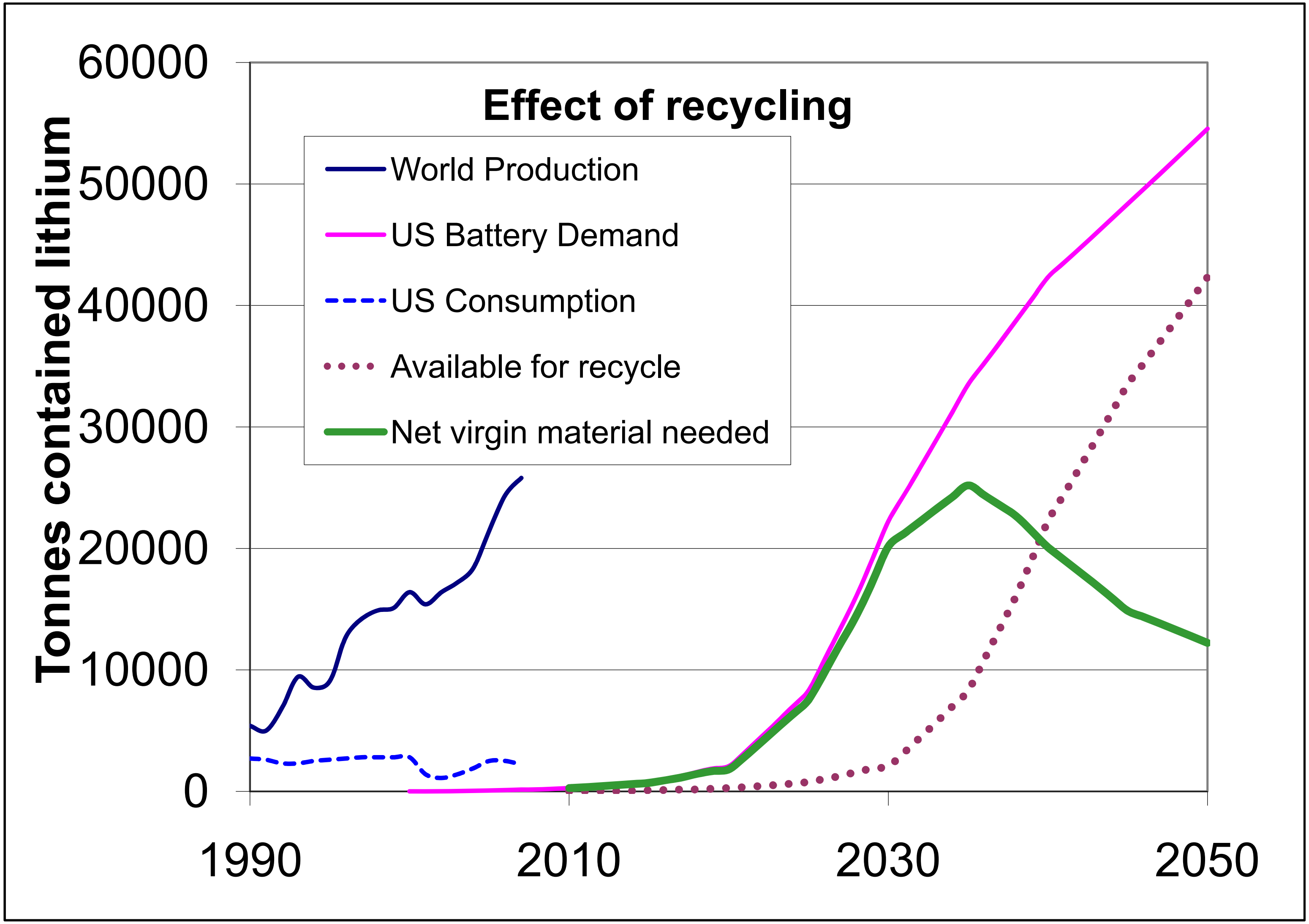
How much lithium would each battery use?

- 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



Total demand for lithium depends on battery chemistry used

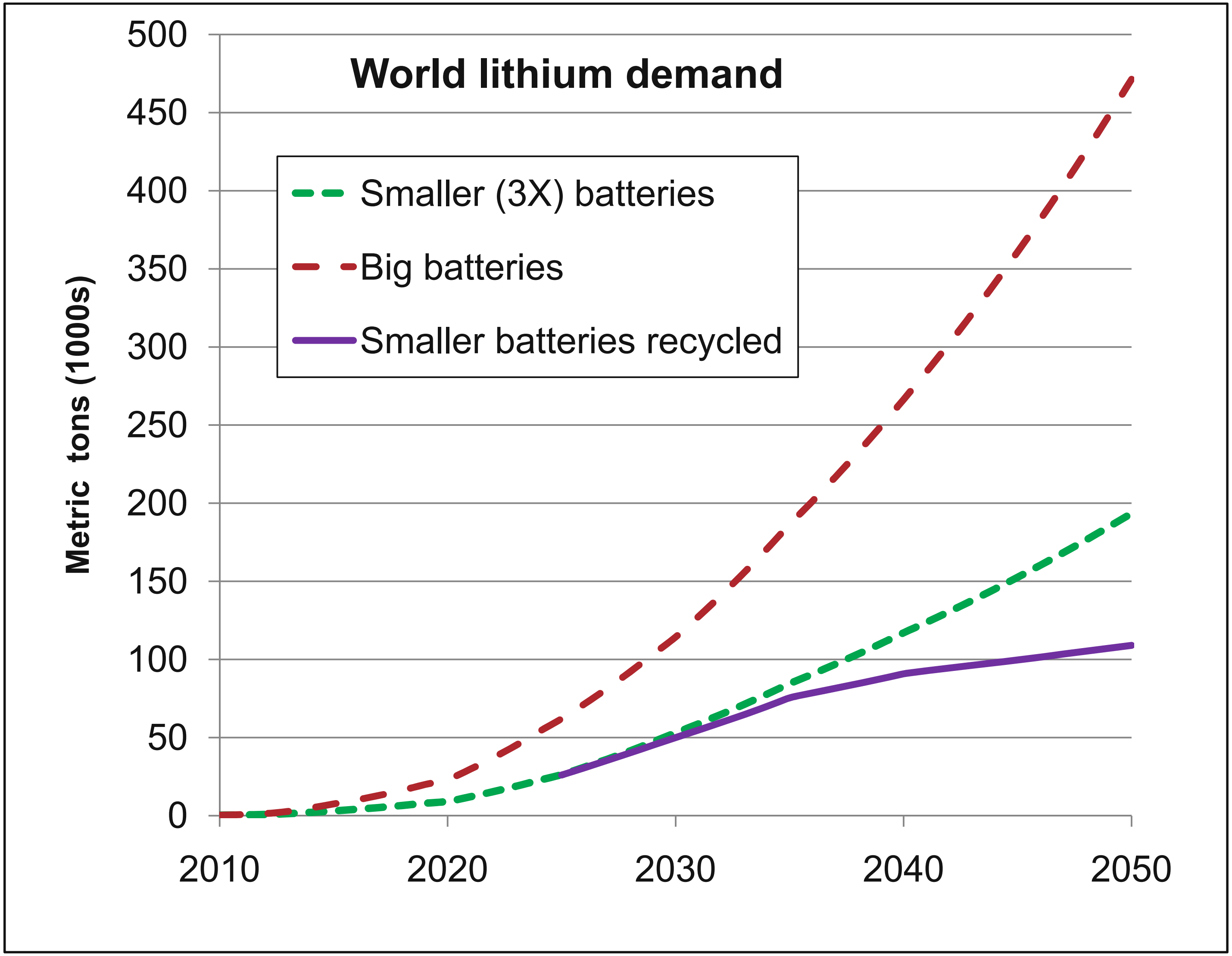
- For NCA-G chemistry, the highest U.S. vehicle battery demand is 54,000 tonnes in 2050
  - About double current world production
  - US demand reaches current world production level of 25,000 tonnes about 2030
  - Never exceeds current production level if material is all recycled
- There is a range of lithium demands for different chemistries
  - Minimum is LMO-G 25,000 tonnes in 2050
  - Maximum is LMO-TiO 93,000 tonnes in 2050

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

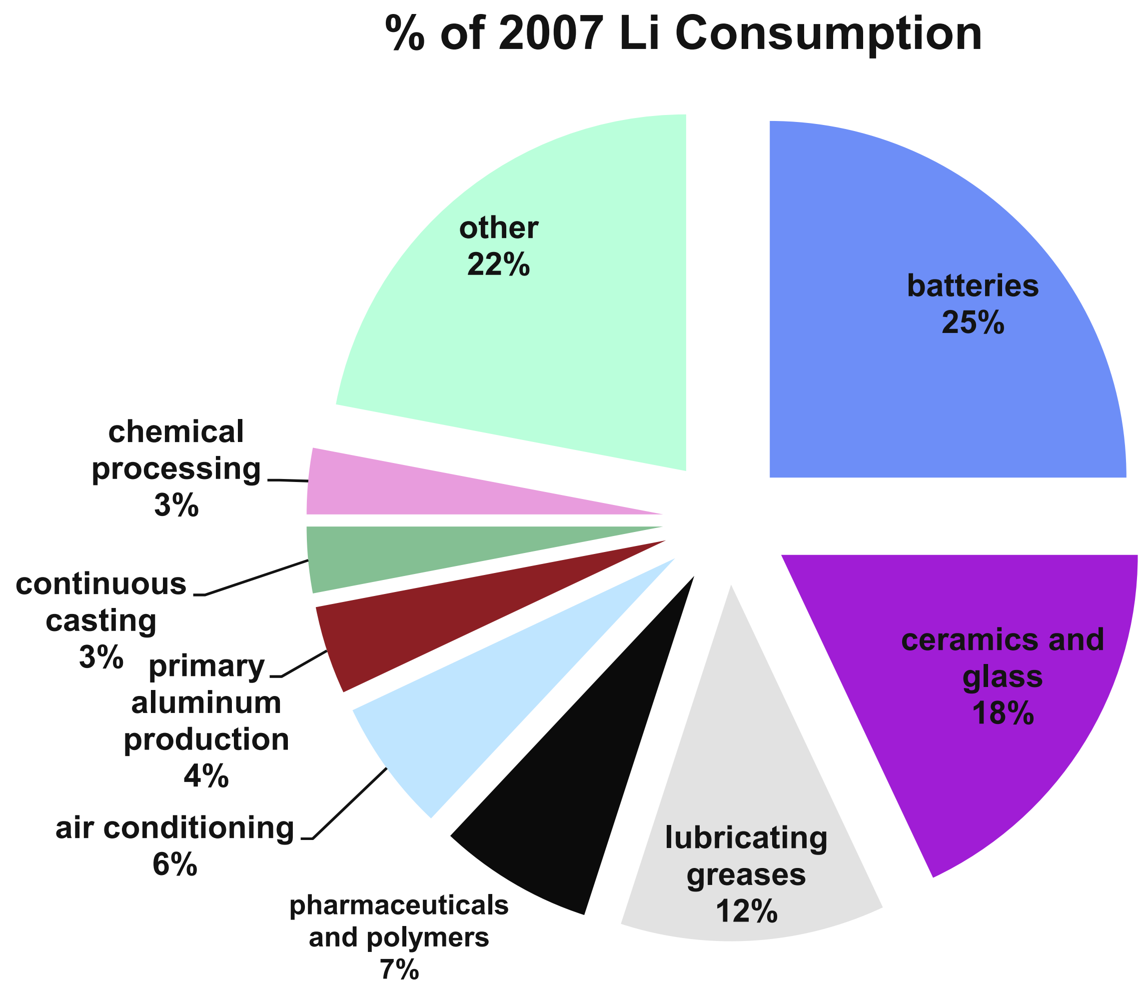
- Need for new supplies can be substantially reduced by recycling
  - Rapid early demand growth implies rapid early recovered material echo
  - Recovered material often ignored when projecting supply

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



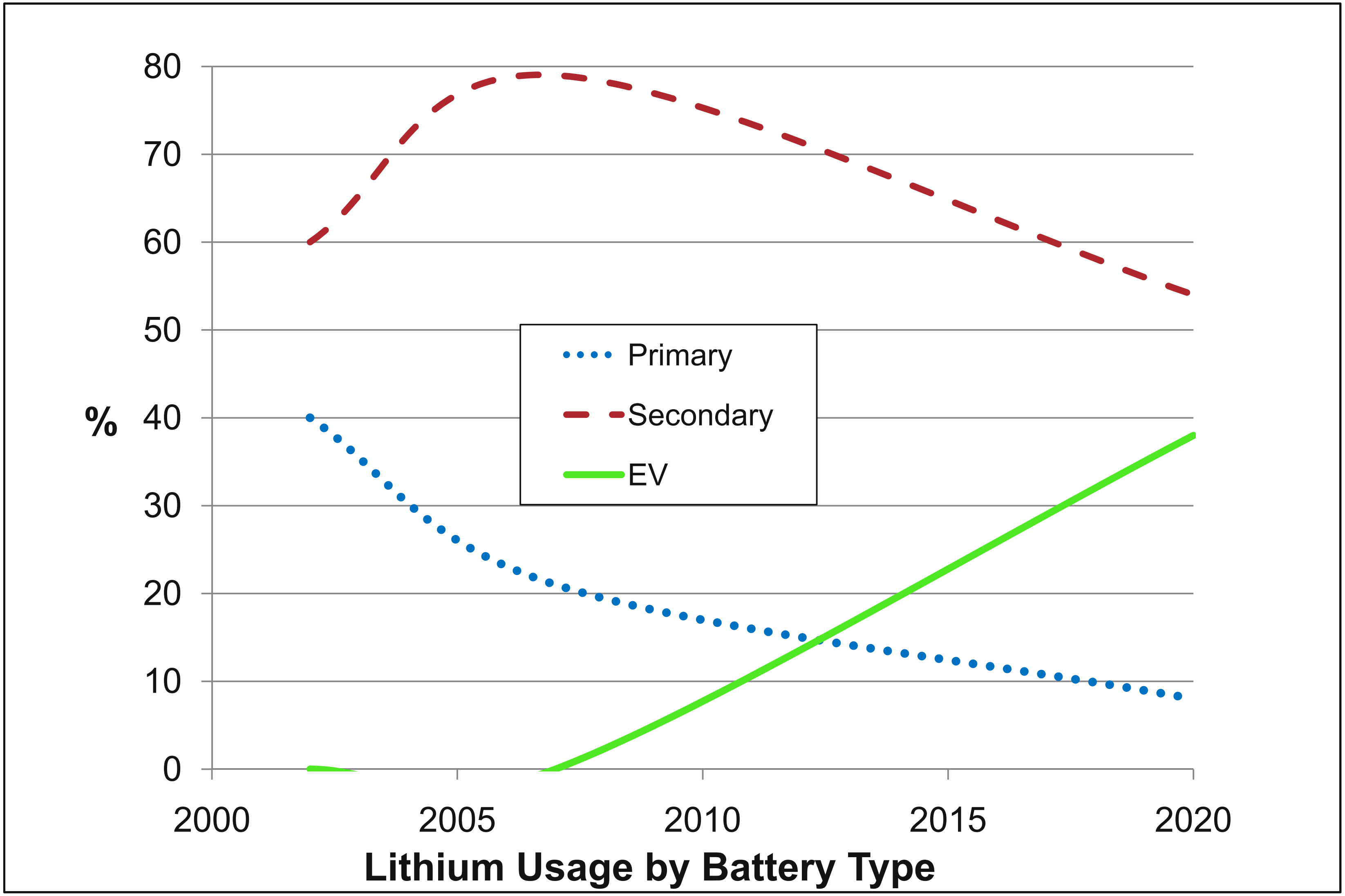
IEA assumed 12-18 kWh batteries

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

Electric vehicle batteries are projected to dominate long-term lithium demand



Source: E.R. Anderson, TRU Group

Vehicle batteries will dominate Li demand
We compared cumulative U.S. demand to reserves

- Total to 2050 for NCA-G chemistry is about 950,000 tonnes
  - Would be about double that for LMO-TiO
  - U.S. would still need to import Li
- Total material required to 2050 is halved by recycling
- World reserve base is the subject of debate (USGS is conservative)

World Mine Production, Reserves, and Reserve Base (metric tons contained lithium):

	Mine production		Reserves	Reserve base
	2006	**2007**		
United States	W	W	38,000	410,000
Argentina[e]	2,900	3,000	NA	NA
Australia[e]	5,500	5,500	160,000	260,000
Bolivia	—	—	—	5,400,000
Chile	8,200	9,400	3,000,000	3,000,000
China	2,820	3,000	540,000	1,100,000
Russia	2,200	2,200	NA	NA
World total (rounded)	23,500	25,000	4,100,000	11,000,000

W = proprietary information

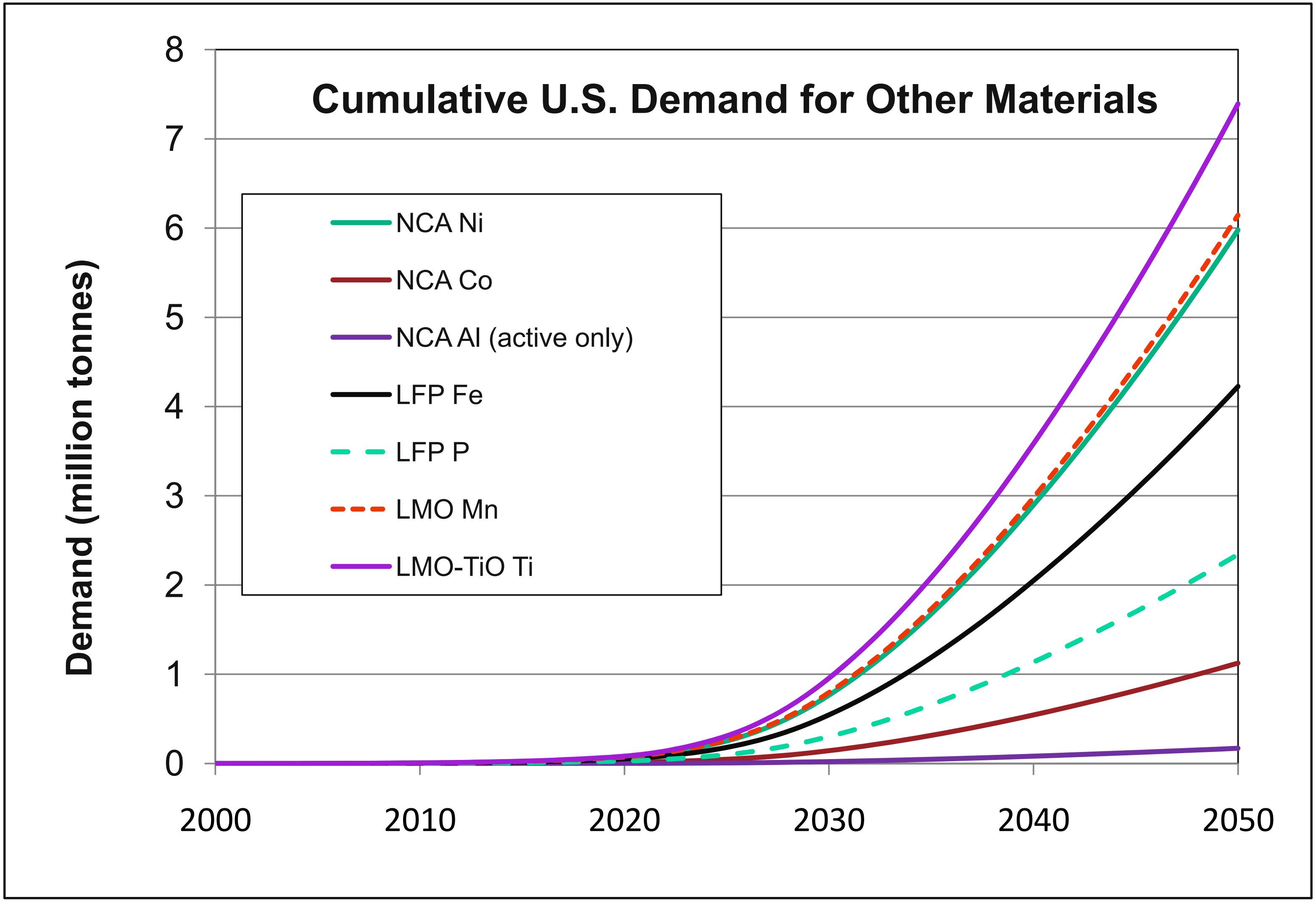
NA= not available

Source:http://minerals.usgs.gov/minerals/pubs/commodity/lithium/mcs-2008-lithi.pdf

Known Li reserves could meet world demand to 2050

	Cumulative demand to 2050 (Contained lithium, 1000 Metric tons)
Large batteries, no recycling	6474
Smaller batteries, no recycling	2791
Smaller batteries, recycling	1981
USGS Reserves	4100
USGS Reserve Base	11000

Are there possible constraints on the supply of other key materials?



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

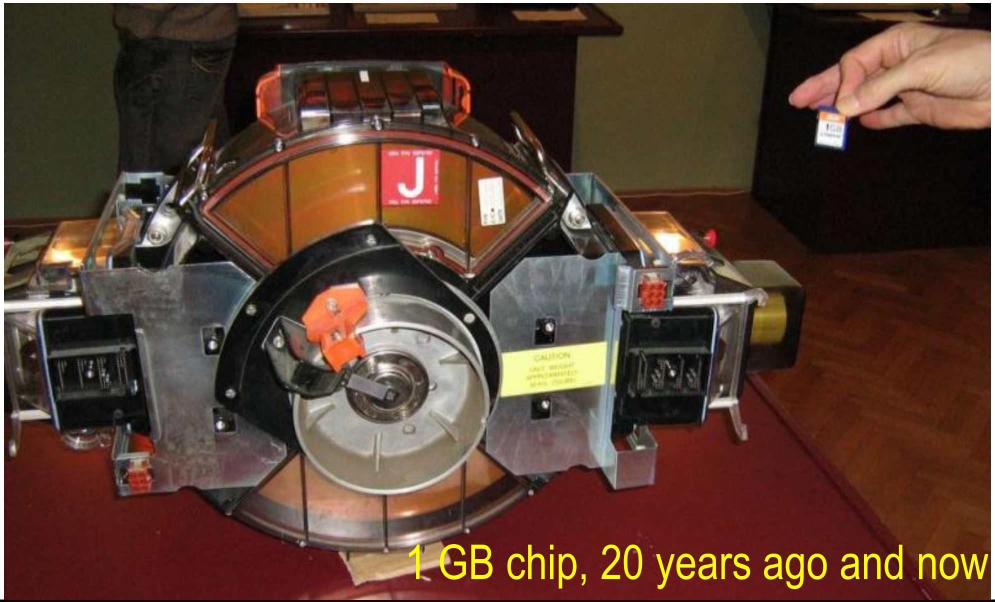
Material	Availability (million tons)	Cumulative demand	Percent demanded	Basis
Co	13	1.1	9	World reserve base
Ni	150	6	4	World reserve base
Al	42.7	0.2	0.5	US capacity
Iron/steel	1320	4	0.3	US production
P	50,000	2.3	~0	US phosphate rock production
Mn	5200	6.1	0.12	World reserve base
Ti	5000	7.4	0.15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

Future work:
We need to make sure these batteries can be recycled

- FY09: Complete estimate of material available for recycling vs. time
  - Include possibility of reuse of battery for lower-performance duty
  - Include all materials, all chemistries
- FY09-10: Examine current recycling processes
  - Characterize current production processes for comparison and insight
  - Will build on past analysis work: http://www.transportation.anl.gov/pdfs/TA/149.pdf
  - Need to understand energy and environmental impacts
- FY10: Consider future recycling processes to maximize recovery with minimum impacts
- FY11: Begin process development

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


1 GB chip, 20 years ago and now