Battery Materials Availability and Recycling

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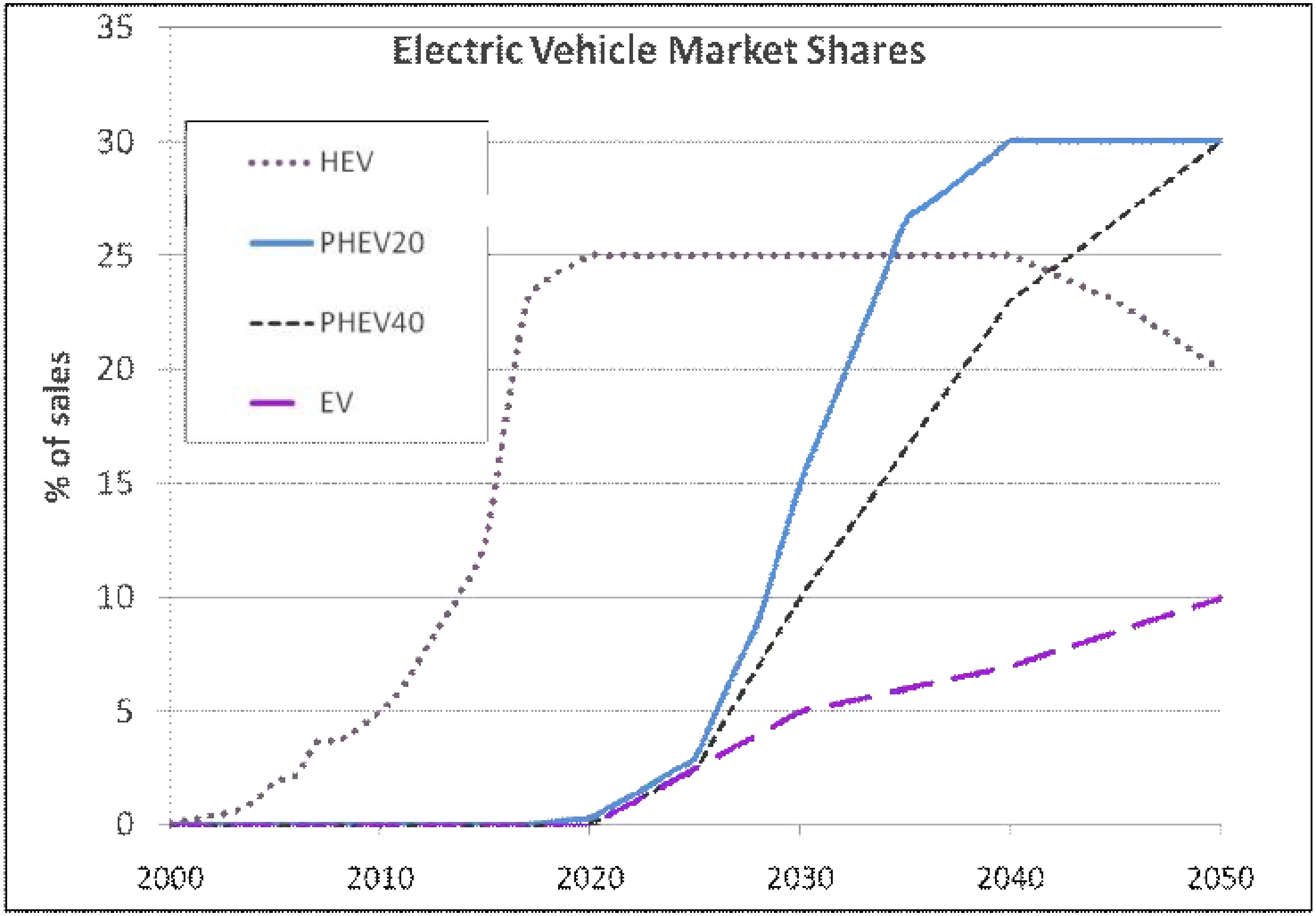
We don’t want to trade one crisis for another!

- Insure against material shortages
- Check for unforeseen environmental impacts

We answer these questions to address material supply issues

- How many electric-drive vehicles will be sold in the US and world-wide?
- What kind of batteries might they use?
  - 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?

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

Then we looked at battery composition

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	$Li_4Ti_5O_{12}$

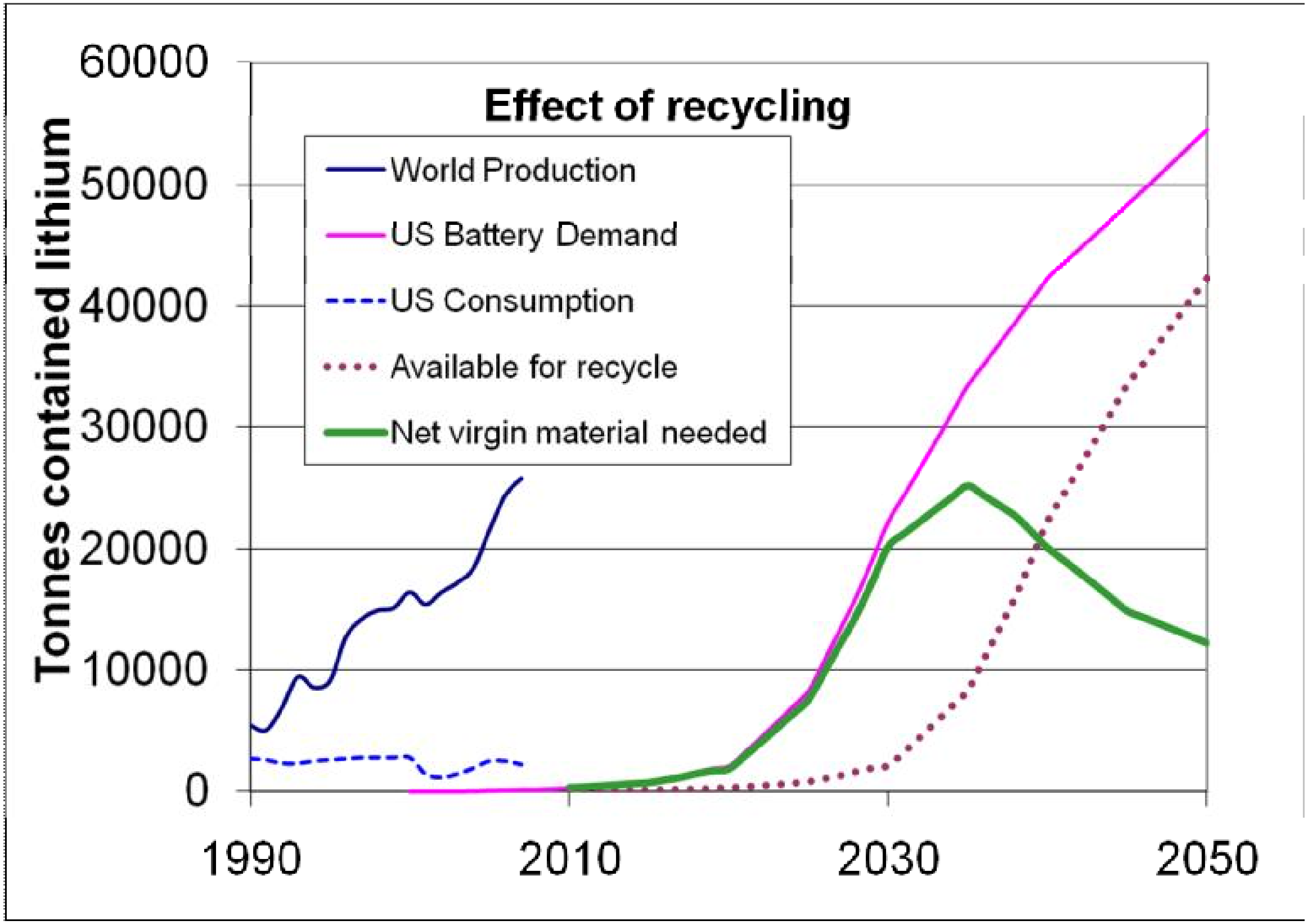
- We considered four battery chemistries
- All contain lithium in cathode
- One uses lithium in anode as well
- Electrolyte contains lithium salt ($LiPF_6$) in solution

We calculated lithium required per battery pack

- Total is sum of Li from cathode, electrolyte, and anode (for titanate)

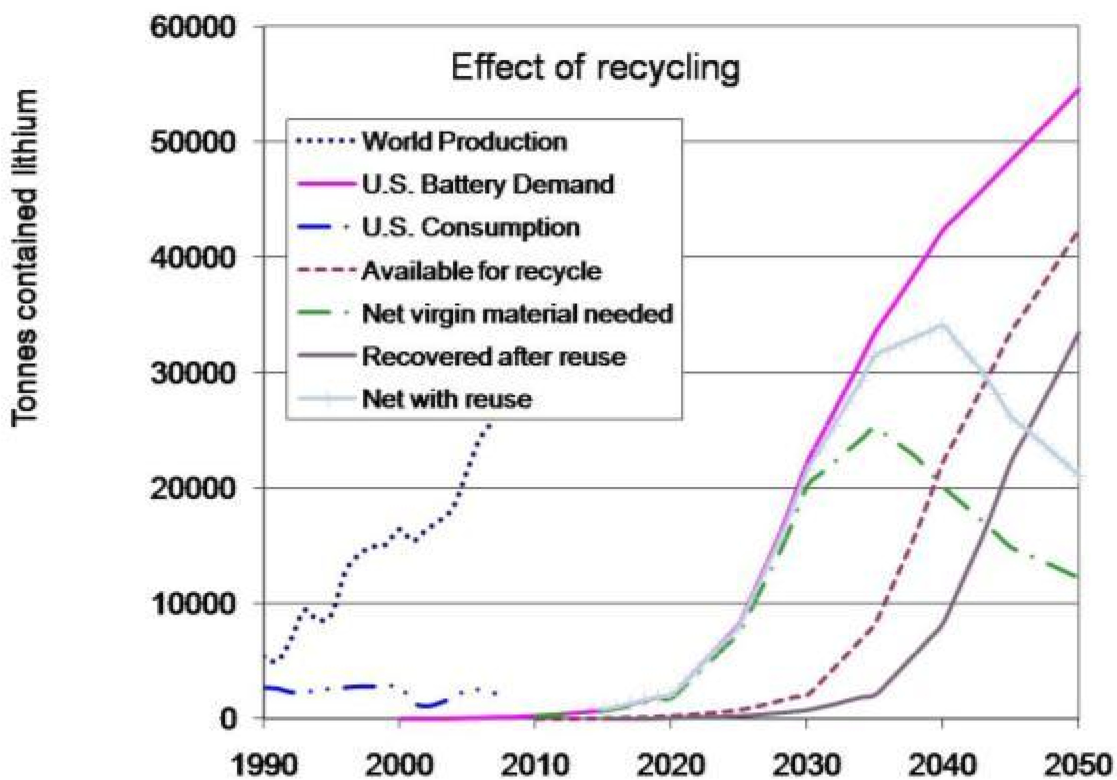
Battery Type	NCA-G				LFP-G				LMO-G				LMO-TiO			
Vehicle range (mi) at 300 Wh/mile	4	20	40	100	4	20	40	100	4	20	40	100	4	20	40	100
Li in cathode (kg)	0.34	1.4	2.8	6.9	0.20	0.80	1.6	4.0	0.15	0.59	1.18	3.0	0.29	1.2	2.3	5.8
Li in electrolyte (kg)	0.04	0.10	0.20	0.55	0.045	0.14	0.26	0.66	0.03	0.09	0.17	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

Recycling can drastically reduce virgin lithium demand



A word about battery reuse

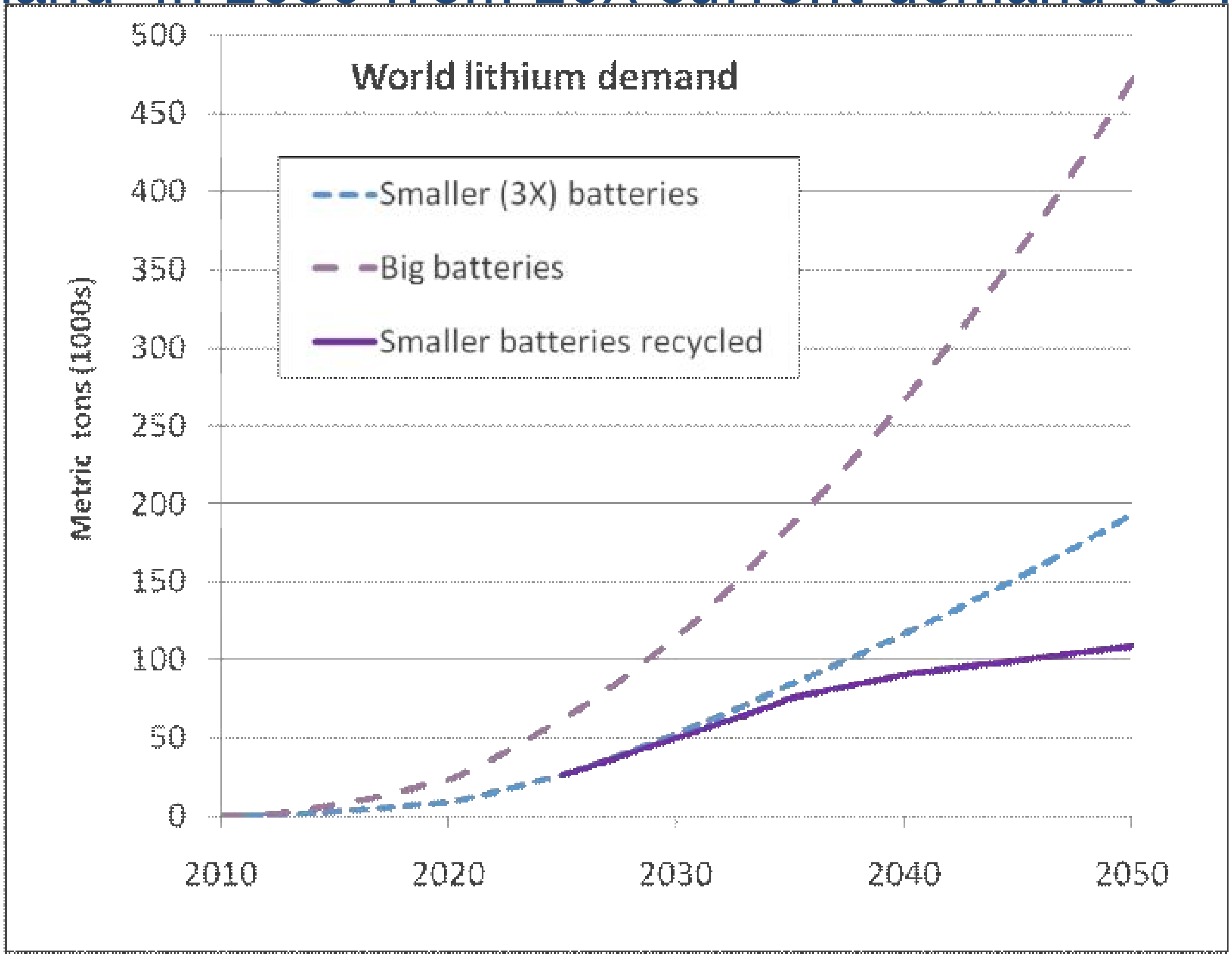
- Reuse takes battery directly back to lower-performance use
- Nissan will reuse batteries to store energy from PV panels or to store back-up power
- Reuse delays return of material for recycling and increases peak demand for virgin material
  - Assumes virgin material would not be used for backup batteries



World demand is highly uncertain

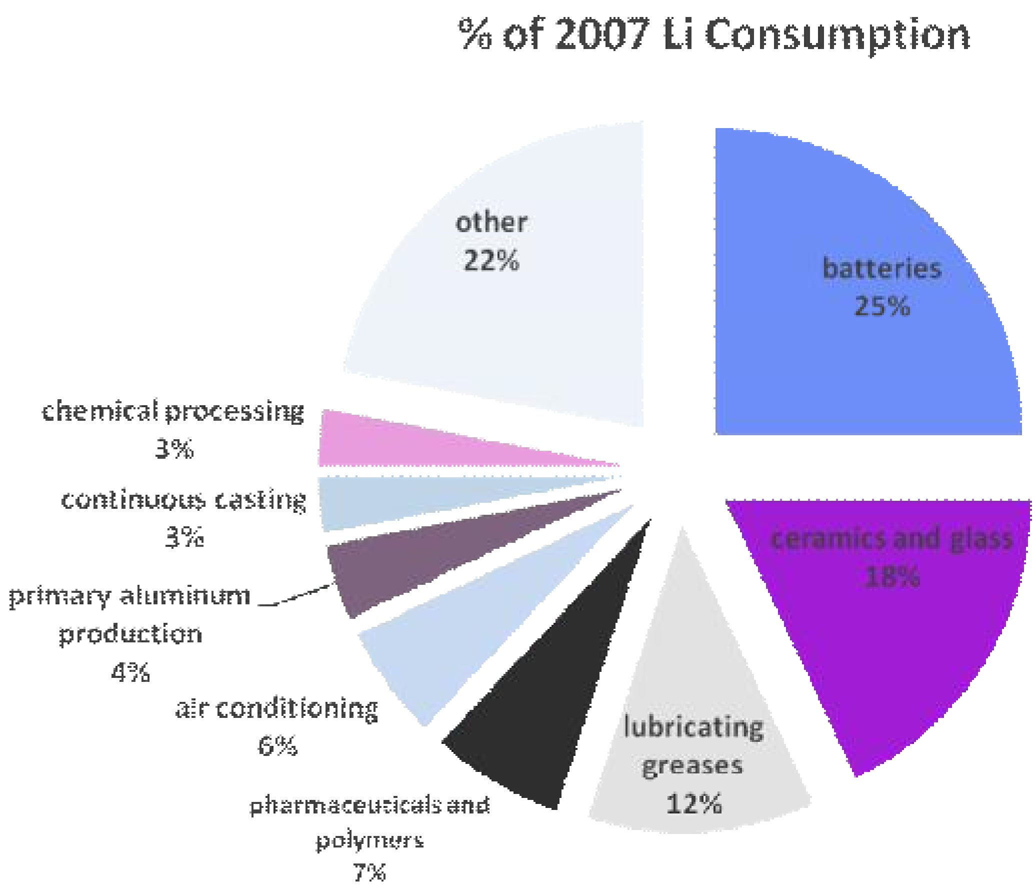
- Lithium demand per vehicle depends on battery size
  - What size car? Or is it a bicycle?
  - What range? Is extra range built in?
  - EV or PHEV?
  - Incentives can favor models with lowest impacts
- Need for new supplies can be substantially reduced by recycling
  - Rapid early demand growth implies rapid early recovered material echo
  - Recovered material often ignored in alarmist presentations

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



IEA assumed 12-18 kWh batteries

Batteries make up 25% of Li use, growing fastest, and EV batteries will dominate battery market



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
	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

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

Lithium-ion batteries can provide a bridge to the future

- Lithium demand can be met, even with rapid growth of EVs
  - Scenarios extended to 2050
  - Better batteries, additional exploration could extend supply
  - New technologies are likely in the next 40 years
- Co 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

Warnings of disaster are often premature

1885: The US Geological Survey announces there is "little or no chance" of oil being discovered in California, and a few years later they say the same about Kansas and Texas.

1939: The US Department of the Interior says American oil supplies will last only another 13 years.

1949: The Secretary of the Interior says the end of US oil supplies is in sight.

1974: Having learned nothing from its earlier erroneous claims, the US Geological Survey advises that the US has only a 10-year supply of natural gas.

1969: Environmentalist Nigel Calder warns, "The threat of a new ice age must now stand alongside nuclear war as a likely source of wholesale death and misery for mankind". CC Wallen of the World Meteorological Organization says, "The cooling since 1940 has been large enough and consistent enough that it will not soon be reversed".

1970: Senator Gaylord Nelson warns that by 1995 "somewhere between 75 and 85% of all the species of living animals will be extinct".

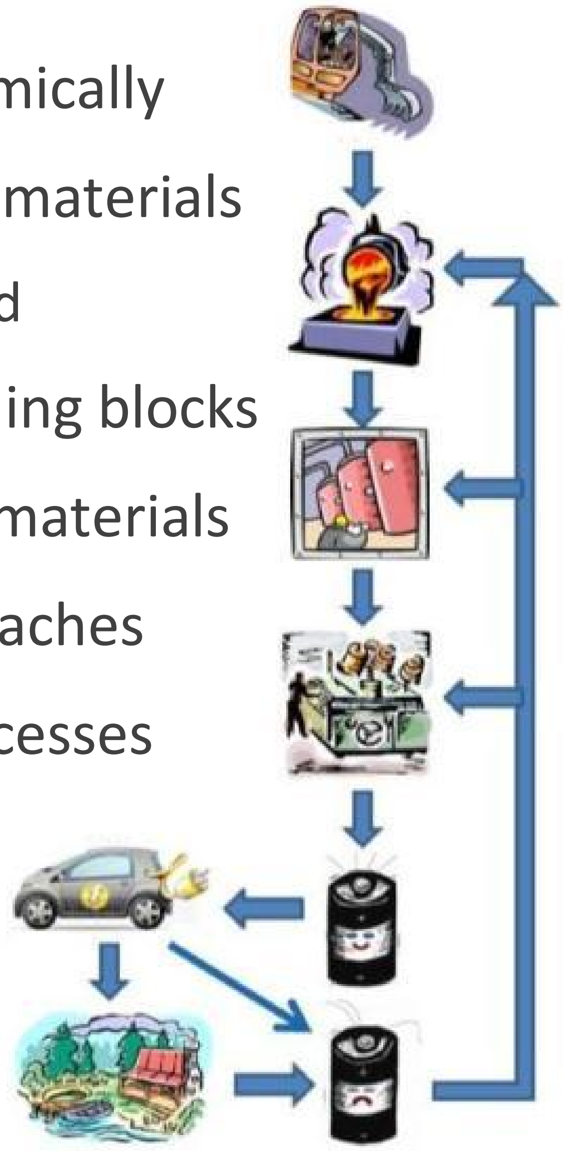
1972: A report for the Club of Rome warns the world will run out of gold by 1981, mercury and silver by 1985, tin by 1987 and petroleum, copper, lead and natural gas by 1992.

Sir John Houghton (Scientific Assessment for IPCC, Chairman and Co-Chairman 1988-2002.) said, "Unless we announce disasters no one will listen"

Source: Dr Phillip Bratby, Testimony to the UK Parliament. http://snipurl.com/6xytl.

Recycling can recover materials at different production stages

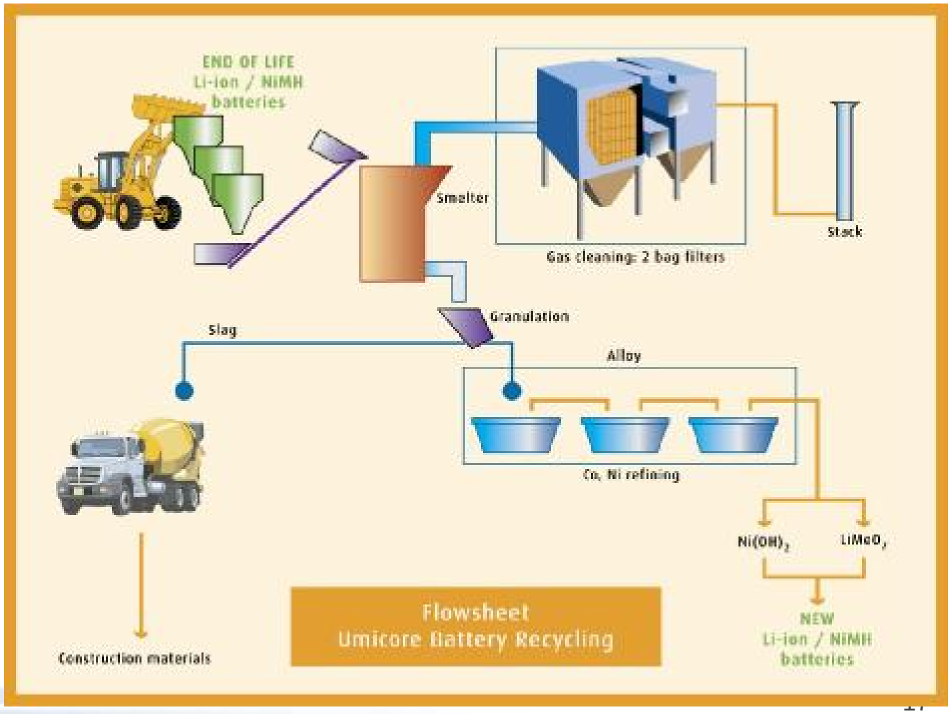
- It is difficult to recover all materials economically
- A possible goal is to recover battery-grade materials
  - Impacts are lower if more steps are avoided
- The other extreme is to recover basic building blocks
- Business drives recovery of most valuable materials
- There are pros and cons of different approaches
- Lifecycle analysis identifies “greenest” processes



Smelting processes are operating now

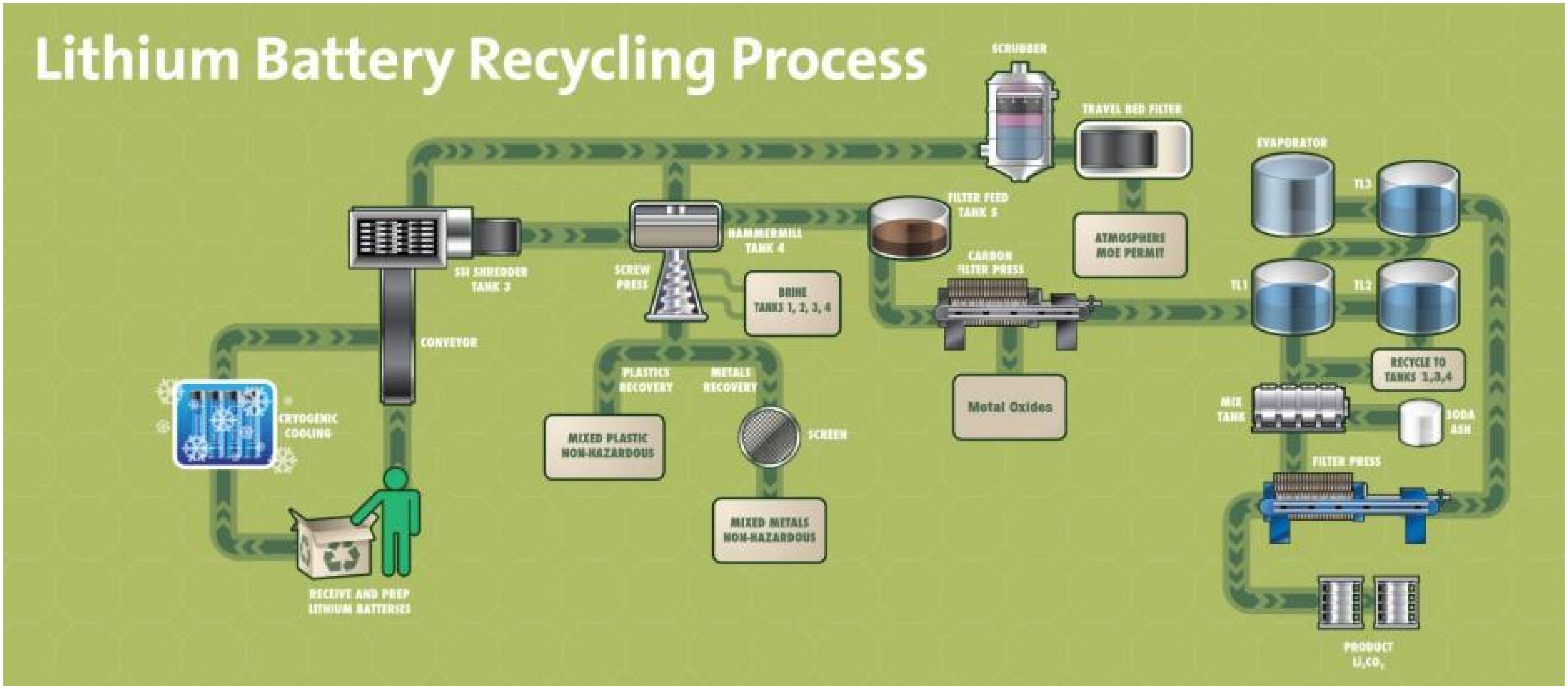
Umicore, Xstrata

- These can take just about any input, high volume
  - Different chemistries (including Li-ion, Ni-MH, etc.), mixed feed
- High-temperature required
  - Organics, including electrolyte and anode, used for energy/reductant
- Reduce materials to elemental (or salt) forms
- Valuable metals (Co and Ni) recovered and sent to refining
  - Suitable for any use
- Volatiles burned at high-temperature to avoid toxic emissions
- Other materials go to slag
  - Used in concrete
  - Could recover via hydrometallurgy



Toxco Ohio plant will used improved process to recover lithium

Toxco/ Kinsbursky



Future recycling could reuse materials in batteries

- Require as uniform feed as possible
  - Impurities in feed jeopardize product quality
- Components are separated
  - A variety of physical and chemical processes are possible
  - 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
- C-nanotubes are 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
- Contact me: lgaines@anl.gov